Pacific Earthquake Engineering Research Center

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(Lead Institution)

California Institute of Technology

Stanford University

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9th Year Progress Report and Renewal Proposal

Volume 1

Jack P. Moehle
Director
University of California, Berkeley

Gregory G. Deierlein
Deputy Director for Research
Stanford University

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1 SYSTEMS VISION AND BROADER IMPACTS OF THE PEER CENTER

1.1 Systems Vision

PEER Mission

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

The PEER mission is to develop and disseminate procedures and supporting tools and data for performance-based earthquake engineering (PBEE). 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 (e.g., 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 the societal impacts and regulatory choices relating to minimum performance standards for public and private facilities. PEER seeks to make technical contributions to the 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 the costs of reducing risks and the benefits resulting from seismic improvements.

The clients for 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 recent advances in the use of performance-based earthquake engineering, existing technologies and methods for PBEE fall short in several ways. Although response to strong ground motions in most cases is expected to be nonlinear, earthquake hazard today is represented by 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 and limited earthquake experience rather than systematic performance considerations. Furthermore, engineering design and assessment generally focus on engineering parameters and stop short of identifying performance measures or quantifying socio-economic parameters such as direct financial losses, 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 must make decisions about performance of facilities, networks or campuses, or the built environment 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 (Fig. 1.1). The first step is definition of the seismic hazard, which we have represented by the term *intensity measure*. The second step is determination of *engineering demand parameters* (e.g., deformations, velocities, accelerations) given the seismic input. This leads naturally to definition of *damage measures* such as permanent deformation, toppling of equipment, or cracking or spalling of material in structural components and architectural finishes. Finally, these damage measures lead to quantification of decision variables that relate to casualties, cost, and downtime.

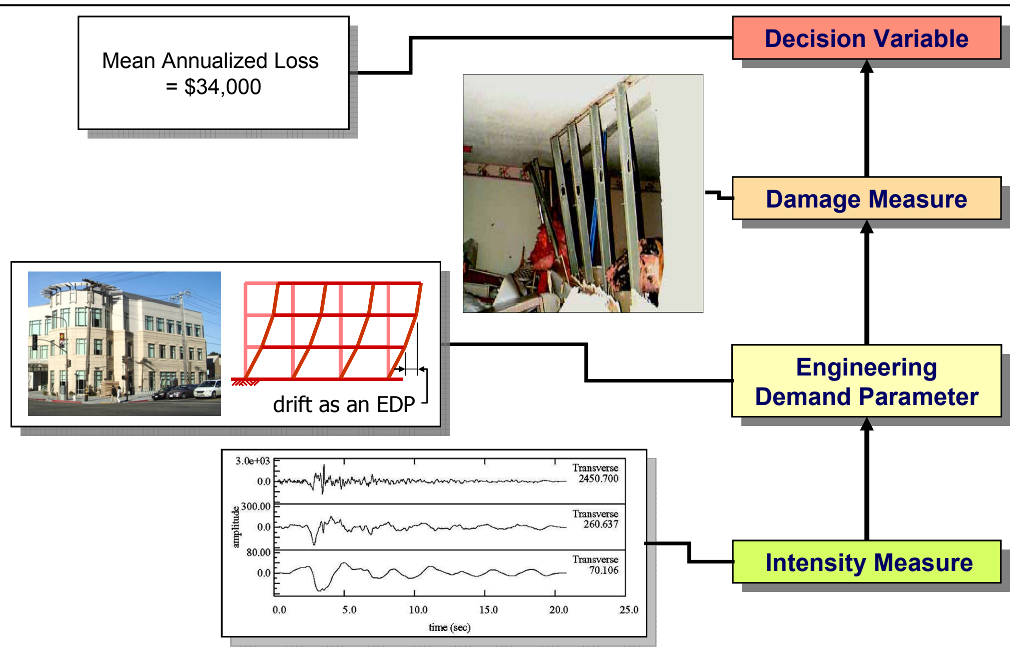

Figure 1.1 – Performance-based earthquake engineering framework. PEER is conducting research on the overall framework (right) and individual elements (left). In this example, building repair costs including structural, nonstructural, and contents losses are presented as a mean annual loss.

An essential element of performance-based earthquake engineering is the integration of issues across disciplinary boundaries, as illustrated qualitatively in Figure 1.2. The central column of the figure suggests various steps that might be involved in a performance assessment of a system for a single earthquake. The left side of the figure shows discrete variables that PEER has defined as part of its framework for performance-based earthquake engineering (Fig. 1.1). The right side of the figure identifies the traditional disciplinary contributions to the problem. Clearly, the solution of the earthquake problem is a multidisciplinary endeavor.

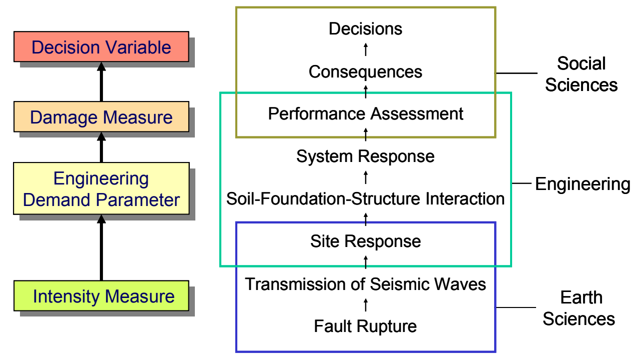

Figure 1.2 – Multidisciplinary integration in performance-based earthquake engineering. Steps in performance-based earthquake engineering shown center, PEER's framework variables shown left and traditional disciplines shown right.

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 and assessment methods to performance-based methods. 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 presents the PEER activities and products to a broad audience including students, researchers, industry, and the general public.

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, FEMA 354). PEER is working closely with other organizations, including the Applied Technology Council and the Federal Emergency Management Agency on the ATC 58 project, *Development of Next-Generation Performance-Based Seismic Design Procedures for New and Existing Buildings*. Additionally, PEER produces models and data that are useful, useable, and used in industry. The process is aided by the involvement of practicing earthquake professionals in our program, who help guide and incorporate our research advances as they occur. As a result, the PEER program is an important contributor to national, state, and local efforts to reduce earthquake hazards that threaten the interests of the government, industry, and the general public.

1.2 Value Added and Broader Impacts

1.2.1 Summary

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 been an 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 multidisciplinary effort involving earth scientists, engineers, social scientists, and experts from other related disciplines. It also requires the development of a framework that can link the various 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 incremental improvement in current methods but instead makes the quantum step in information and technology 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 and industry participants 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. This is producing unique accomplishments in new areas with outcomes that impact the overall research direction.

A major recent accomplishment has been the evolution in thinking about quantification of damage and the decision variables. This evolution is primarily a result of multidisciplinary work on the PEER methodology testbeds. The testbeds were introduced in Year 5 as a means of testing the PEER methodology on real structures and networks, identifying methodology, tool, and data gaps, and improving participation of PEER's industry partners. The testbeds significantly improved integration of the different aspects (and disciplines) of the performance-based earthquake engineering problem, and helped focus attention on modeling, simulation, and data gaps that required additional development in Years 8 through 10. They also provided a model for benchmarking studies that are a major focus of these years.

Collaborations with other earthquake centers in the U.S. and worldwide have grown. In the U.S., noteworthy collaborations are between PEER and the Southern California Earthquake Center, Mid-America Earthquake Center, Multidisciplinary Center for Earthquake Engineering Research, and agencies such as Caltrans and FEMA that are funding efforts on performance-based earthquake engineering. Internationally PEER is collaborating substantively with the National Center for Research in Earthquake Engineering (Taiwan), the E-Defense project on RC building collapse (Japan), and the Asia-Pacific Network for Centers in Earthquake Research (ANCER). Joint strategic planning with these groups leads to joint funding of projects that provides important leverage and synergy.

1.2.2 Nuggets of Significant Achievement and Impact

PEER has made several specific accomplishments in the broad categories of *People*, *Ideas*, and *Tools*, including:

PEOPLE:

Undergraduate Shake Table Competition

In just three years, PEER's Student Leadership Council initiated the first annual Undergraduate Shake Table Competition, then expanded it to involve MCEER and the MAE Center, and in 2006 moved the competition to become a centerpiece of the 8th US National Conference on Earthquake Engineering, where it was hugely successful in attracting an audience of earthquake professionals and financial sponsors. In the "shake-off," a team of practitioners judges factors including performance, technical merit, economics, and oral presentation. This competition not only gives students the opportunity to apply what they've learned in the classroom, but also introduces them to research and education in earthquake engineering.

Figure 1.3 – Earthquake professionals anticipate the imminent collapse of a structure during the 2006 Undergraduate Shake Table Competition.

Concrete Coalition

The Pacific Earthquake Engineering Research Center partnered with the Earthquake Engineering Research Institute (EERI) to sponsor a major collaborative effort to address the high earthquake risk posed by older concrete buildings in the western U.S. The objective is to encourage mitigation of older existing hazardous concrete construction by helping distinguish truly dangerous, collapse-prone buildings within the large inventory of these buildings, retrofit the truly bad buildings, and avoid future casualties. The newly proposed Concrete Coalition is uniting structural engineers, materials organizations, building officials, public policy interests, building owners, and managers in a long-term effort to meet the multidisciplinary challenge.

Figure 1.4 – The Concrete Coalition is bringing together engineers, building officials, public policy interests, and building owners/managers to encourage active mitigation programs.

Student Leadership Council Takes the Lead

Figure 1.5 – Student Leadership Council representative teaches K–12 students about earthquake engineering and what structural engineers do to make buildings safe.

Undergraduate and graduate student representatives on the **Student Leadership Council (SLC)** provide an active and valuable voice for all PEER students. Over the past six years, PEER's SLC has been an influential contributor to the PEER Education Committee and PEER Administration concerning the needs of undergraduate and graduate students. In addition to planning an annual Student Day held concurrently with the PEER Annual Meeting, and the complete coordination of the annual PEER Seismic Design Competition, now in its third year, the SLC is very active in outreach. Through events such as "Minds in Motion" held at California State University, Chico, and the "Introduce a Girl to Engineering Day" held at Caltech, K–12 students learn first hand about earthquake engineering and future career opportunities in science and engineering. By exposing K–12 students to the university environment, they can begin to realize it is an achievable goal for them.

IDEAS:

Building Collapse Safety Assessment

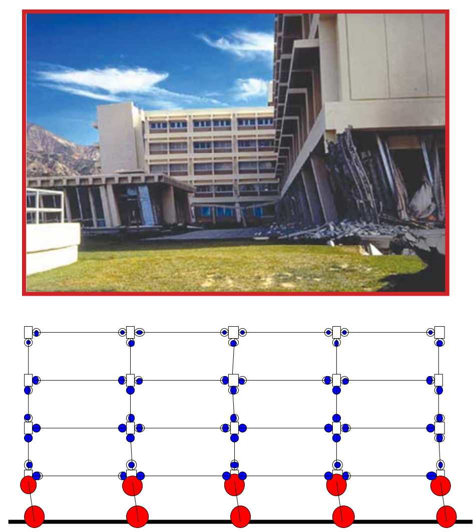

Figure 1.6 – Actual building collapses in earthquakes can be simulated using PEER's framework and simulation tools.

Building safety during strong earthquakes is a fundamental goal of building codes, but just how safe are modern buildings? and how have seismic safety measures of the past decades improved safety? PEER researchers have applied PEER's performance-based earthquake engineering framework and simulation tools to answer these questions. The studies show that advances in reinforced concrete building standards since the mid-1970s have reduced collapse risk in modern buildings to one twentieth of the risk in the older construction. Quantitative assessments of this sort can help inform policy decisions about the benefits of retrofitting older existing buildings. The same tools used in these studies can be used by earthquake engineers to design more cost-effective retrofit solutions. PEER is working with industry and government partners to extend this methodology so that all building systems can be judged on the fair basis of their true merits, thereby achieving improved building uniformity and accelerating the introduction of new technologies for earthquake safety.

Bracing Berkeley

As the centennial of the 1906 San Francisco earthquake approached, Professors Mary Comerio and Stephen Tobriner had the idea to use the UC Berkeley seismic safety program as a focal point for teaching and public policy promotion. A series of special seminars, focused on the UC Berkeley seismic retrofit program, promoted active participation of students, whose project reports were compiled into *Bracing Berkeley, a Guide to Seismic Safety on the UC Berkeley Campus*. Containing a short history on the Berkeley mitigation program, a discussion of performance-based earthquake engineering and disaster recovery, and brief reports on individual buildings, *Bracing Berkeley* has been hugely popular among academics, engineers, and facility managers who each find a unique application in their own professional spheres.

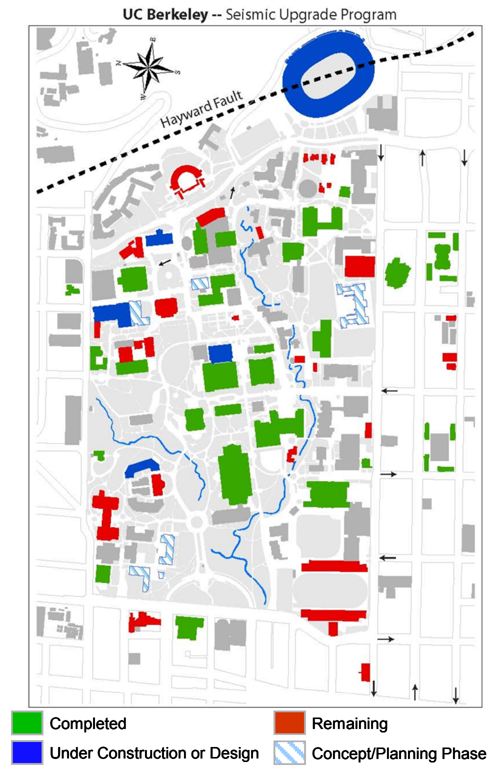

Figure 1.7 – Map of seismic retrofitting progress at Berkeley

Improving Seismic Hazard Analysis

The process of seismic hazard analysis has improved steadily over the past decades, from simple estimates of peak ground acceleration over broad geographic regions to very precise statements of the probability that ground shaking at a specific site will exceed a defined intensity over a defined period of time. Despite all the advances, the intensity of ground shaking still is expressed in terms of maximum response of a linear oscillator, even though building and bridge response is expected to be nonlinear. As PEER's performance-based approach takes root, it is sprouting a range of new ideas about how to express seismic hazard. In one example, PEER graduate student Jennie Watson-Lamprey used the PEER Strong Ground Motion Database to generate seismic hazard relations considering nonlinear response as part of a class project. The results of the study demonstrate that the traditional approach using linear response is unconservative for ground shaking associated with long return periods.

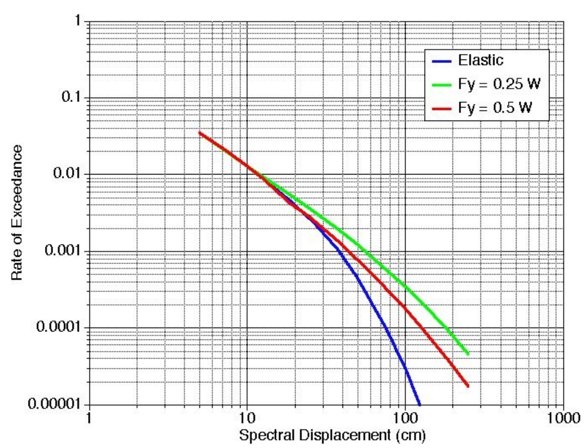

Figure 1.8 – Advanced probabilistic seismic hazard analysis shows that the conventional approach (blue curve) is unconservative relative to results obtained considering nonlinear response (red and green curves).

TOOLS:

Seismic Assessment Guidelines

Researchers at the Pacific Earthquake Engineering Research Center synthesized results of a multiyear research program to propose new engineering models for seismic assessment of older hazardous concrete buildings. The findings were presented to practicing professionals in daylong seminars in Los Angeles, San Francisco, and Seattle. The principal findings were forwarded to the responsible ASCE committee in time to incorporate needed changes in the upcoming Standard for Seismic Rehabilitation. The improved engineering models will help pinpoint needed retrofits and avoid unnecessary retrofit, thereby promoting effective mitigation programs.

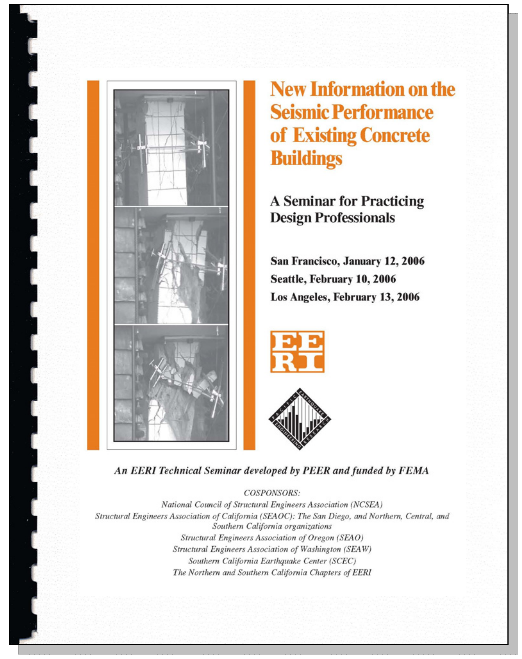

Figure 1.9 – PEER's data and engineering models are being implemented in more efficient retrofitting applications.

OpenFresco

OpenFresco is a powerful tool to support and extend the use of hybrid simulation in earthquake engineering research. Developed by graduate student Andreas Schellenberg and Professor Stephen Mahin, OpenFresco builds on the versatile open source, object-oriented architecture of OpenSees, enabling hybrid simulations where portions of a structure are modeled numerically using OpenSees and other parts are modeled physically in the laboratory. The software can be easily adapted to consider new laboratories, new test setups, and new types of specimens. It supports advanced capabilities such as geographically distributed computers and laboratories, multiple-support excitation, soil-structure interaction, and hydrodynamic loads. OpenFresco is being considered for adoption by several laboratories, organizations, and manufacturers worldwide.

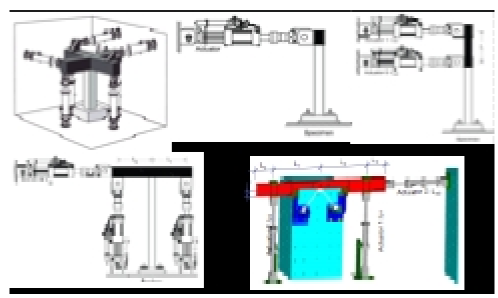

Figure 1.10 – OpenFresco seamlessly links computer and laboratory simulations in a

Seismic Performance Assessment Tool

Performance-based earthquake engineering aims to predict performance of a facility as a function of the seismic actions to which it is subjected. To facilitate the calculations, PEER developed the Seismic Performance Assessment Tool, which combines seismic response data with building construction and occupancy data to compute expected losses. The new tool enables engineers to convert complex

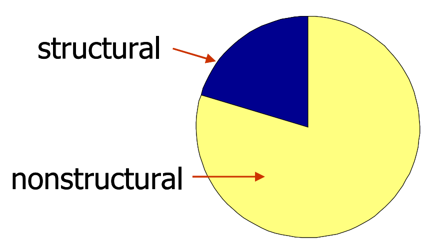

Figure 1.11 – The Seismic Performance Assessment Tool can compute expected losses, and can break them down by component type for design purposes.

multidimensional engineering data into decision variables such as anticipated repair cost) understandable by lay decision makers. The software has been adopted as the main computational engine by the FEMA-funded project *Development of Next-Generation Performance-Based Seismic Design Procedures for New and Existing Buildings*.

2 STRATEGIC RESEARCH PLAN

This section describes PEER's strategic research plan, including research outreach and detailed thrust-level plans. Additional details on individual projects are in Volume II.

2.1 PEER Strategic Research Plan

The PEER mission is to develop, validate, and disseminate performance-based earthquake engineering (PBEE) technologies for buildings and infrastructure to meet the diverse economic and safety needs of owners and society. Although some methodologies already exist (e.g., FEMA 356 for performance-based building evaluation and HAZUS for regional loss estimation), these procedures are largely unverified and lack necessary capabilities. PEER aims to enhance existing thinking on PBEE and to respond to needs and requirements of various stakeholders by providing products and outcomes that are of broad impact and utility.

The PEER research program for developing performance-based earthquake engineering is guided by a strategic research plan and organized around four thrust areas. The strategic plan has evolved over the life of the Center, including a significant restructuring of the thrust areas in Year 7 (see Section 2.2). The strategic plan is illustrated by a series of graphics that display the integration of various disciplines, projects, and products that ensures balance among research aimed at producing fundamental knowledge, enabling technologies, and systems-level methodology development and implementation. An overview of the systems-level research plan is described in this section, followed by details on specific milestones, research organization, and thrust-area plans in subsequent sections.

Figure 2.1 illustrates the systems-level research plan. The plan is driven by the *Needs and Requirements of Clients, Stakeholders, and the Marketplace*; involves research within *Technology Integration*, *Enabling Technologies*, and *Knowledge Base Planes*; and produces *Products and Outcomes* that respond to the *Needs and Requirements*. The following subsections describe each of the main elements of Figure 2.1.

2.1.1 Needs and Requirements of Clients, Stakeholders, and the Marketplace

As discussed in Chapter 1, three levels of decision making are served by enhanced technologies for PBEE. These define the *Needs and Requirements* (Fig. 2.1) for PEER research:

- One level of decision making is that of designers, owners, or investors in individual facilities (e.g., a building, a bridge) who face decisions about the seismic integrity and the management of risk posed by that facility. PEER seeks to develop a rigorous PBEE methodology that will inform decisions about seismic design, retrofit, and financial management for individual facilities.
- A second level of decision making 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 decision making concerns not only individual structures but priorities among the elements of that portfolio (as well as the behavior of the network in the case of lifelines). PEER seeks to show how to use the rigorous PBEE methodology to inform decisions about setting priorities for seismic improvements within such systems by making clear trade-offs among improved performance of the system elements.

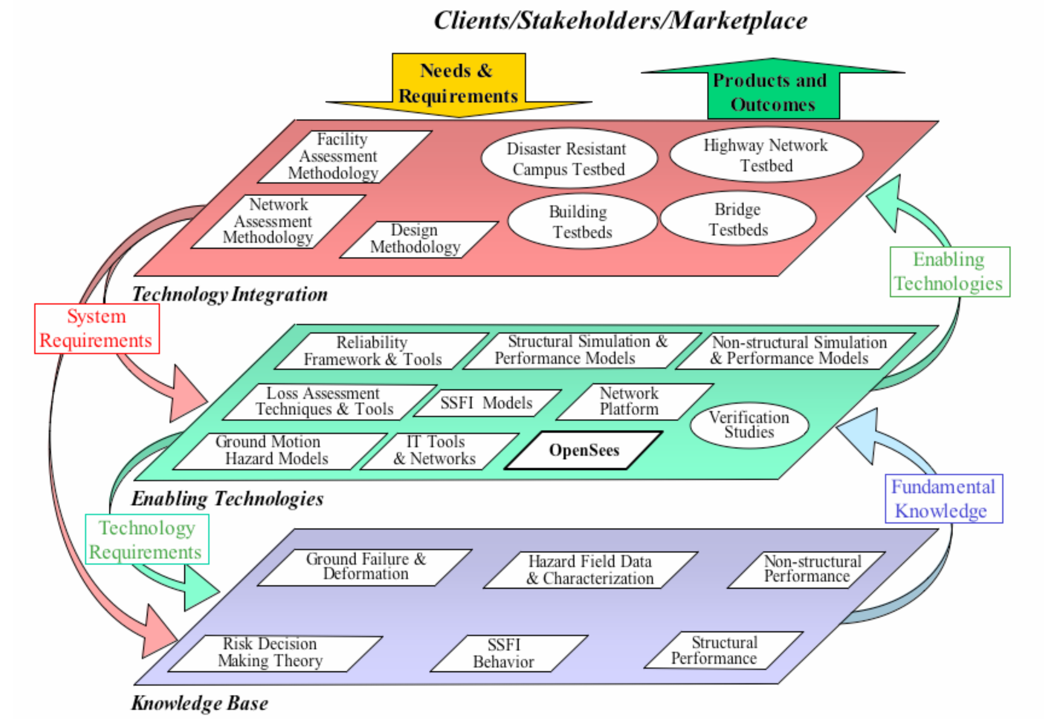

Figure 2.1 – Systems-level strategic plan

- A third level of decision making is 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.

PEER's research is creating a unified methodology for characterizing performance in ways that support these various decision types. The underlying approach is to evaluate performance in terms of probabilities of exceeding a specified loss during a specified exposure period, or for a scenario event. This differs from current seismic design and assessment methods, which are based on satisfying limit states of structural components for imposed localized demands associated with specific hazard levels.

A conceptual illustration of this approach is shown in Figure 2.2. The upper portion of the curve illustrates the load-displacement envelope for a facility such as a bridge or building. Two readily defined points on the curve correspond to the limit of elastic response (onset of damage) and collapse (onset of instability). One performance-based design procedure in widespread use for seismic rehabilitation of existing buildings, FEMA 273/356, defines three performance levels: Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP). Each of these performance levels is established based on the individual structural component that has the worst performance, i.e., as soon as one component reaches the LS state, the entire building is assumed to be at the LS state. The component-based limit states of FEMA 273/356 were based considerably on judgment and have been the subject of continuing debate. The individual performance levels are paired with hazard levels (e.g., probability that the ground motion will exceed a certain level in a fixed period of time) without any calibration to determine if the results are optimal.

PEER's vision is to advance the state of the art and the state of the practice of PBEE by numerically tying performance to the losses of interest. As identified in Figure 2.2, the loss metrics include direct dollar loss, casualties (life loss), and downtime (loss of function). Since these concepts are applicable to individual facility design and assessment, facility rating systems, portfolio analyses, and regional loss studies, they provide a unifying means of assessing performance for the range of needs and requirements of the clients, stakeholders, and marketplace for PBEE.

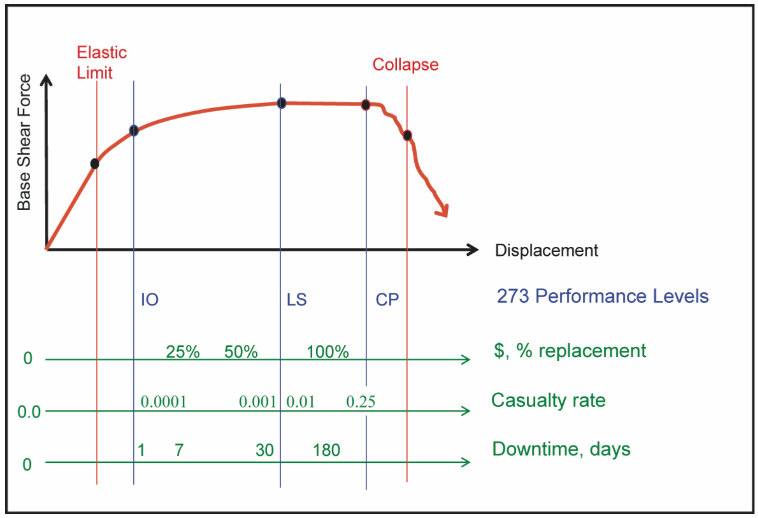

Figure 2.2 – Idealized relation between performance and load-deformation response (after Holmes, PEER 2001 Annual Meeting)

PEER's research focus toward developing an accepted "performance engine" or "means of verification" to evaluate the performance metrics will ultimately fulfill the promise of PBEE. In our view, PBEE must embrace the next generation of computational and modeling procedures; must explicitly represent randomness and uncertainty; and must model the seismic hazard, the site, the structure, the nonstructural elements and systems, and the socio-economic impacts. Furthermore, PBEE should take advantage of complete dynamic simulation where practicable, while providing guidance for simplified representations such as the inelastic load-displacement envelope (pushover curve) of Figure 2.2. This vision and methodology has recently been adopted by the ATC 58 project — a major FEMA-funded initiative to develop performance-based seismic design guidelines (Hamburger, R.O., "Development of Next-Generation Performance-Based Seismic Design Guidelines," *Performance-Based Seismic Design Concepts and Implementation PEER 2004/05,* pp. 89–100).

The conceptual elements and inter-relations of PEER's "performance engine" are shown in Figure 2.3. This chart, and its relationship to the systems-level strategic plan (Fig. 2.1), is described in detail in the following sections.

2.1.2 Technology Integration Plane

The Technology Integration Plane of Figure 2.1 represents the systems-level applications and studies in PBEE. For an individual facility, the system includes the seismic environment; the soil-foundation-structure–nonstructural-contents system; and the facility-impacted stakeholder segments. For a network of facilities as in a lifeline network, the system includes the seismic environment, the individual facilities and their linkages, and the impacted regional stakeholder segments.

The Technology Integration Plane contains the primary long-range objectives of the PEER research program — specifically, the development of assessment and design methodologies that integrate the seismic hazard and socio-economic components of earthquake engineering into a system that can be analyzed and on which rational decisions can be made. These methodologies are applicable to both individual facilities and inventories of interacting facilities. Testbeds are established to exercise the methodologies, to identify research and development needs, to develop simplified approaches, and to demonstrate the socio-economic impact of different performance objective formulations.

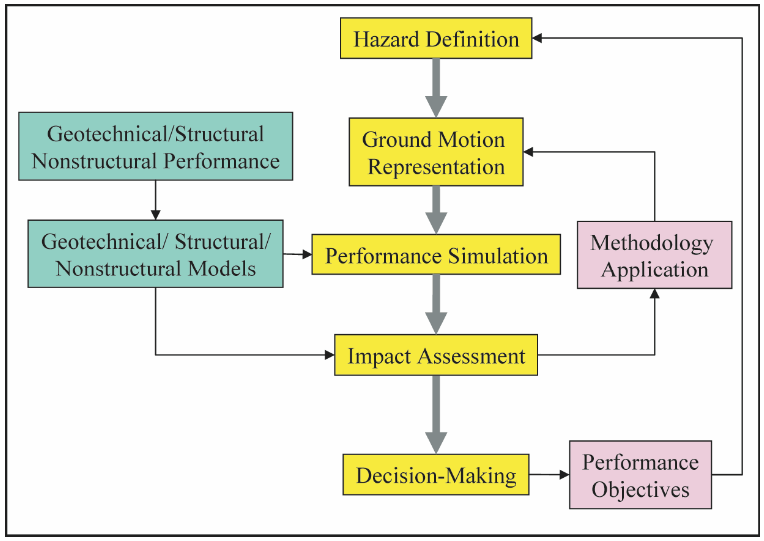

Figure 2.3 – Research elements in the performance-based earthquake engineering methodology

2.1.2.1 Methodology Description

The assessment methodologies under development need to span from seismic hazard to impact assessment. The fundamental process involved in the methodologies is depicted in Figure 2.3. The specific steps in the process are as follows (the global process is described for an individual facility, but is essentially the same for distributed networks):

- *Hazard Definition.* The seismic hazard environment is defined by identification of active faults affecting the site and a probabilistic statement of the occurrence of different magnitude and mechanism events as a function of time and space.
- *Ground Motion Representation.* This step is to identify and quantify (in a statistically acceptable way) assessment/design ground motions for the site considering the hazard, attenuation of critical ground motion parameters, and site characteristics (to the extent that the site and its effect on ground motions is considered external to the facility). For practical implementation, other ground motion representations such as response spectra may be used.
- *Geotechnical/Structural/Nonstructural Performance.* A fundamental understanding of the performance of components serves as a basis for performance simulation. Performance includes conventional representations such as strength and deformation capacity, but also includes damage parameters such as concrete spalling and its relation to required repair.
- *Geotechnical/Structural/Nonstructural Models.* Fundamental knowledge on performance is incorporated into analytical models (including randomness and uncertainty) that are defined for the facility and serve as a basis for performance simulations.
- *Performance Simulation.* A computer simulation of performance is conducted using the Geotechnical/Structural/Nonstructural Models and the Ground Motion Representation. The simulation produces detailed information on response parameters, such as interstory drift and inelastic strains, which are then related to component damage measures.
- *Impact Assessment.* Ideally the impact is in terms of the three performance measures adopted in this program, namely, direct dollar loss, functional loss, and casualty loss.

- *Decision Making.* Outcomes from the Impact Assessment lead to decision making by engineers, owners, lenders/insurers, government policy-makers and emergency planners.
- *Performance Objectives.* In an assessment or design of an individual facility, the Impact Assessment and Decision-Making process may be made in the context of established Performance Objectives that define what impacts are acceptable. When impacts are not acceptable, performance objectives may change, or the system may require redesign to match the objectives.
- *Methodology Application.* The methodology application refers to the iterative process of evaluation and re-evaluation of all the steps of the process associated with design of new facilities and retrofit of existing facilities.

2.1.2.2 Formalization of the Methodology

Two unifying features of the PEER program are the integration of the simulation/information technologies and the formalization of a comprehensive methodology for performance assessment. Given the inherent uncertainty and variability in seismic response, it follows that the assessment methodology is formalized with a probabilistic basis. Referring to Figure 2.4, PEER's probabilistic assessment framework is described in terms of four main analysis steps (hazard analysis, response analysis, damage analysis, and loss analysis), with the outcome of each step described in terms of a specific variable. Moving from left to right in Figure 2.4, the four steps directly follow from the methodology introduced in Figure 2.3. The outcome of each step is mathematically characterized by the four generalized variables: *Intensity Measure (IM), Engineering Demand Parameter (EDP), Damage Measure (DM)*, and *Decision Variable (DV).* These variables are expressed in a probabilistic sense as conditional probabilities of exceedance, i.e., $p[A|B]$. An underlying assumption of this approach is that the performance assessment components can be treated as a discrete Markov process, where the conditional probabilities between parameters are independent.

The first assessment step entails a hazard analysis, through which one evaluates one or more ground motion *Intensity Measures (IM)*. For standard earthquake intensity measures (such as peak ground acceleration or spectral acceleration), the *IM* is obtained through conventional probabilistic seismic hazard analyses. Typically, the *IM* is described as a mean annual frequency

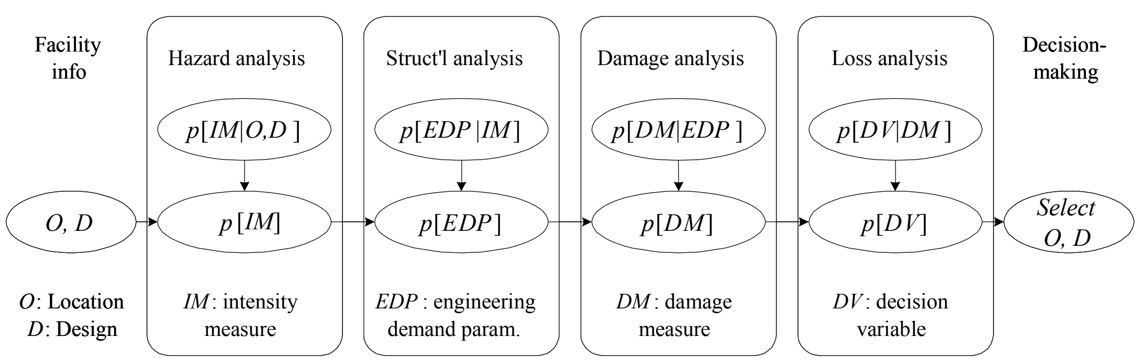

Figure 2.4 – Underlying probabilistic framework of PEER's performance-based earthquake engineering framework

of exceedance, *p*[*IM*], which is specific to the location (*O*) and design characteristics (*D*) of the facility. The design characteristics might be described by the fundamental period of vibration, by foundation type, by simulation models, etc. In addition to determining the *IM*, the hazard analysis involves characterization of appropriate ground motion input records for response-history analyses. PEER's research on hazard analysis involves close coordination with the earth science and engineering seismology communities both to improve the accuracy of determining conventional scalar *IM*s and to investigate alternative seismic intensity measures that best correlate with earthquake-induced damage. These alternative measures may include vector representations of multiple intensity measures, such as multiple representations of spectral acceleration, spectral shape, and duration.

Given the *IM* and input ground motions, the next step is to perform structural simulations to calculate the *Engineering Demand Parameters (EDP*), which characterize the response in terms of deformations, accelerations, induced forces, or other appropriate quantities. For buildings, the most common *EDP*s are interstory drift ratios, inelastic component deformations and strains, and floor acceleration spectra. Relationships between *EDP* and *IM* are typically obtained through inelastic simulations, which go to the essence of PEER's research on developing and implementing structural, geotechnical, SSFI (soil-structure-foundation-interaction), and nonstructural damage simulation models. PEER has developed various approaches, such as the incremented dynamic analysis technique, to systematize procedures for characterizing the conditional probability, *p(EDP|IM)*, which can then be integrated with the *p*[*IM*], to calculate mean annual frequencies of exceeding the *EDP*s.

The next step entails a damage analysis of the *EDP*s to *Damage Measures, DM*, which describe the physical damage and resulting consequences to a facility. The *DM*s include descriptions of damage to structural elements, nonstructural elements, and contents, in order to quantify the necessary repairs along with functional or life-safety implications of the damage (e.g., falling hazards, release of hazardous substances, etc.). PEER is developing conditional damage probability relationships, *p(DM|EDP)*, for a number of common and representative components, based on published test data, post-earthquake reconnaissance reports, and tests of a few select components. These conditional probability relationships, *p(DM|EDP)*, can then be integrated with the *EDP* probability, *p(EDP)*, to give the mean annual frequency of exceedance for the *DM*, i.e., *p(DM)*.

The final step is to calculate *Decision Variables*, *DV*, described in terms of mean annual frequencies of exceedance, *p*[*DV*]. Generally speaking, the *DV*s relate to one of the three decision metrics discussed above with regard to Figure 2.2, i.e., direct dollar losses, downtime (or restoration time), and casualties. In a similar manner as done for the other variables, the *DV*s are determined by integrating the conditional probabilities of *DV* given *DM*, *p(DV|DM)*, with the mean annual *DM* probability of exceedance, *p*(*DM*). PEER's research has served first, to establish the choice of appropriate *DV*s and ways of presenting these performance metrics to stakeholders, and second, to develop loss functions describing *p(DV|DM)* relationships.

The methodology framework just described and shown in Figure 2.4 is an effective integrating construct for both the PBEE methodology itself and the PEER research program. The framework provides researchers with a clear illustration of where their discipline-specific contribution fits into the broader scheme of PBEE. Moreover, the framework emphasizes the inherent uncertainties in all phases of the problem and provides a consistent format for sharing and integrating data and models developed by researchers in the various disciplines.

2.1.2.3 Proof-of-Concept Testbeds

During Years 5–7, PEER embarked on a series of proof-of-concept testbeds as identified within the ovals of the *Technology Integration Plane* of Figure 2.1. These testbeds had multiple objectives: to focus and integrate the multidisciplinary research, test research products and identify needed research, and provide a mechanism for PEER researchers and Business and Industry Partners to work jointly on research. The testbeds are real facilities or inventories of facilities containing seismic environments, geologic conditions, and construction types representative of those of interest in the PEER program. The following paragraphs describe the testbeds:

Van Nuys Building. This older concrete building (Fig. 2.5) has deficiencies typical of many buildings in the western U.S. Past earthquake performance records make it suitable for verifying analytical approaches. Testbed studies included a detailed performance assessment to evaluate the risk of collapse and casualties, a breakdown of economic losses associated with structural and nonstructural components, and a comparative assessment using FEMA 356.

Figure 2.5 – Van Nuys Building

UC Science Building. This relatively new building has nonstructural systems and valuable lab equipment and experiments (Fig. 2.6) that dominate performance decisions. It is a critical research facility on the UC Berkeley campus, with research involving hazardous and irreplaceable samples. Testbed studies include: performance of nonstructural systems; performance of research equipment including issues related to life-safety, egress, replacement, and post-earthquake functionality; and cost and benefits of nonstructural mitigation.

Figure 2.6 – Examples of equipment in UC Science Building

Humboldt Bay Bridge. Caltrans has found this older bridge to be vulnerable and to require retrofit (Fig. 2.7). The site is susceptible to strong ground shaking with potential soil liquefaction, approach fill settlement, and lateral spreading. This testbed provides an excellent example of where comprehensive simulations of the super- and sub-structure responses are necessary to accurately evaluate performance. Testbed studies include: impacts of permanent ground deformation, effectiveness of seismic retrofit options, and propagation of modeling uncertainties.

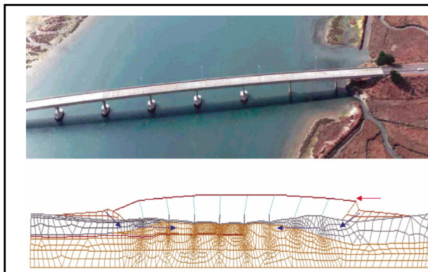

Figure 2.7 – Humboldt Bay Bridge

I-880 Interchange Bridge. This testbed is part of the I-880 highway viaduct constructed in the mid-1990s as part of the Caltrans Cypress Replacement Project in Oakland, California (Fig. 2.8). It provides a linkage between a bridge-specific study of performance and the highway network study. The viaduct consists of a box girder, supported on multi-column bents of modern ductile design, with cast-in-steel shell concrete pile foundations. Testbed studies include soil-pile-structure interaction, performance of conforming concrete details, P-delta effects, the response of multiple frames on different types of soils, and evaluation of bridge functionality and repair costs.

Figure 2.8 – I-880 bridge

Disaster-Resistant Campus. The UC Berkeley campus, located directly adjacent to the Hayward fault (Fig. 2.9), is designated a FEMA Disaster-Resistant Campus and has an extensive seismic retrofit program under way. Testbed studies include: documentation of potential losses; design criteria; quantifying the change in potential losses based on enumerated performance standards; and study of decision-making processes associated with a priority system for seismic upgrades. It provides a vehicle for assessing the interdependence of the UC Science Building performance with that of the campus network.

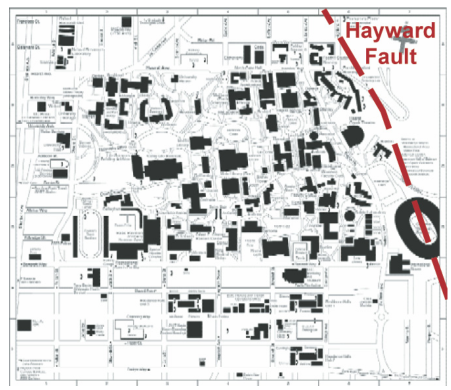

Figure 2.9 – UC Berkeley campus

San Francisco Bay Area Network. The Bay Area highway system (Fig. 2.10) plays an important role in the regional economy, is highly complex with limited redundancy, and is exposed to high and near-fault seismicity. The system includes over 2600 bridges, among which are several major bay crossings, and has been subject to extensive assessment and retrofit by Caltrans. Testbed studies include: potential direct and indirect economic losses following a major earthquake; interdependence of bridge performance on the network performance; and effect on system performance of various design objectives, including retrofitting objectives.

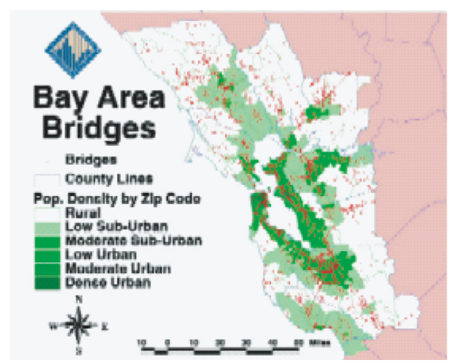

Figure 2.10 – Highway network

These testbeds were a major focus and served an important role to help integrate the PEER research in Years 5–7. They culminated with technical reports and summary presentations at PEER's Year 7 Annual Meeting. The success of the testbeds to integrate and focus the research motivated the restructuring of PEER's research management for Years 8–10 to include more emphasis on integrating the methodology and enabling technology products for building system performance, bridge system performance, and geographically distributed lifeline systems.

2.1.3 Enabling Technologies Plane

The systems studies of the *Technology Integration* (upper) plane of Figure 2.1 require *Enabling Technologies,* organized within the middle plane of Figure 2.1. Central to the enabling technologies are the *OpenSees* and *Network Platforms*. These software platforms integrate other enabling technologies including ground motion libraries and various analytical models; they are to be supported by various visualization and information technologies. The two computational platforms are tested using data from various laboratory tests as well as data recorded during past earthquakes. Detailed descriptions of these platforms follow:

- *OpenSees.* The Open System for Earthquake Engineering Simulation is an advanced performance simulation software framework for structural and geotechnical systems. The software is designed to facilitate development and implementations of models for structural behavior, soil and foundation behavior, and damage measures. Unlike traditional "codes," OpenSees is designed and implemented in a modular, object-oriented manner with a clearly defined application program interface (API). The modules for modeling, solution, equation solving, databases, and visualization are independent, which allows great flexibility in combining modules to solve classes of simulation problems. The modular design allows researchers from different disciplines, such as geotechnical and structural engineering, to combine their software implementations. In addition, parallel and distributed equation solvers developed by computer scientists and mathematicians are integrated into the framework for simulation of very large models.

  PEER researchers have begun to develop simulation methods for use in NSF's George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) program; and *OpenSees* has been adopted and made by NEESit (http://it.nees.org/software/index.php) as a standardized simulation platform for NEES. The open architecture of *OpenSees* provides support for combining computational simulation with advanced experimental methods, such as the pseudo-dynamic and hybrid testing methods. In addition, *OpenSees* supports parallel processing, which will become increasingly important for solving large problems on the NEESgrid.

  OpenSees plays an important role in education because students are more motivated to learn about computer science and advanced applications once exposed to the modern computing and software approaches incorporated in *OpenSees*. The software is "open source," meaning that all parts of the code are available for users to see, check, track changes, and contribute to. The *OpenSees* website (*opensees.berkeley.edu)* is being continuously maintained and enhanced to provide up-to-date downloads, source-code tracking, and communication. This is the first instance of an open-source, community software in earthquake engineering. Currently, more than 300 users have registered with the *OpenSees* software repository, including many who have attended hands-on workshops run by PEER.

  Validation of material and component models, in addition to overall system response, has been an integral aspect of the *OpenSees* development. The simulation and validation activities related to the *OpenSees* models include:

  - Component Simulations. The analytical models developed within the Enabling Technologies Plane (Fig. 2.1) were derived and validated with data from physical tests of structural and geotechnical components and materials.
  - System Simulations. Recorded earthquake response data for the Van Nuys testbed building and Humboldt Bay Bridge have provided an excellent opportunity to implement and refine OpenSees. Additional system simulations include shake table tests conducted by PEER and collaboration with other centers (e.g., collaboration with NCREE in Taiwan has included validation studies based on a pseudo-dynamic test of a full-scale three-story frame).
  - Performance Databases. System simulations generate a large amount of data that must be statistically processed for determining performance characteristics. The testbeds provide

an ideal opportunity to utilize the databases, and the connections between OpenSees and the databases, for performance evaluation.

- *Network Platform.* Through PEER's Highway Demonstration Project, a suite of analysis and GIS database tools has been assembled for simulating the seismic performance of the San Francisco Bay Area highway network. Beginning in Year 6, development of the Network Platform has been incorporated under the EERC Tri-Center Initiative on Geographically Distributed Lifeline Systems (described in the jointly authored Volume III to the annual report). As part of the Tri-Center collaboration, PEER has organized its bridge performance and highway risk assessment research to be compatible with a seismic risk assessment program, called "REDARS," whose core development is supported by MCEER-FHWA. PEER's current research focus is toward developing improved modular components of REDARS and using REDARS in studies of system performance. PEER's specific contributions include development of improved models for evaluating bridge performance, hazards due to ground shaking and ground deformation, characterization and propagation of uncertainties in the risk assessment methodology, and development of improved transportation network performance metrics for post-earthquake scenarios. A related longer-term goal of the Tri-Center initiative is to explore ways of extending the highway network models to evaluate electric utility systems.
- *Other Enabling Technologies.* Other enabling technologies, which appear in Figure 2.1 include:
  - *Hazard Models. The* hazard models represent the seismic hazard in terms of magnitude, mechanism, and recurrence; define attenuation of ground motion parameters to the site; and facilitate selection and scaling of representative ground motions, including an online ground-motion database.
  - *Geotechnical Simulation and Performance Models*. The simulation models model the mechanical behavior (e.g., load-deformation response) of various components/media, while the performance models relate performance to the various stages of mechanical behavior.
  - *Structural Simulation and Performance Models. These* are the structural parallels to the *Geotechnical Simulation and Performance Models.*
  - *Nonstructural Simulation and Performance Models.* These are the nonstructural parallels to the *Geotechnical Simulation and Performance Models.*
  - *SSFI Models.* Soil-structure-foundation interaction models are needed to supplement geotechnical and structural models.
  - *Reliability Framework and Tools.* These include procedures for selecting modeling parameters, frameworks for assessment methodologies (e.g., Equation 1), and implicit and explicit analytical procedures embedded within *OpenSees* and the Network Platform.
  - *Loss Assessment Techniques and Tools.* These provide linkages between physical performance measures such as damage and the economic or other social impacts, for use in both *OpenSees* and the Network Platform.
  - *IT Tools.* These include (a) the development and use of visualization tools to improve ways of expressing performance and (b) networks and databases to facilitate computation and sharing of information.

2.1.4 Knowledge Base Plane

The enabling technologies of the middle plane of Figure 2.1 are built upon fundamental studies in the lower *Knowledge Base* plane. Studies on this plane include seismic hazard characterization studies; geotechnical, structural, and nonstructural performance studies to define behavior models and performance parameters; and studies of risk analysis and decision making. The studies within this plane are primarily aimed at supporting model development or computer platform validation, and therefore are largely defined by the research needs of the middle and upper planes of Figure 2.1.

2.2 Overview of Thrust Area Research Organization, Outcomes, and Milestones

The Needs and Requirements described in Section 2.1.1 define in a broad sense the ultimate goals of the PEER research program; and descriptions of the *Integration, Enabling Technologies*, and *Knowledge Base* Planes in Sections 2.1.2–2.1.4 highlight significant research focus areas and products. This section and subsequent sections of this chapter provide further details of the research program organization and specific milestones as related to the needs for implementing PBEE. Section 2.2.1 begins with a brief overview of the research organization, followed with a description of thrust area research coordination and milestones (Section 2.2.2) and a list of Years 9 and 10 research projects (Sections 2.2.3 and 2.3 to 2.6).

2.2.1 Research Organization

PEER carries out research within two administratively distinct but coordinated programs. The *Core Research Program* is that portion of the program supported by the core NSF funds and matching funds. This program has the objective of developing the overall methodology for PBEE in addition to key enabling technologies (e.g., *OpenSees* simulation models) and decision-making criteria. The Core Research Program is complemented by the *Program of Applied Earthquake Engineering Research for Lifeline Systems,* commonly referred to as the "Lifelines Program. The Lifelines Program is designed to satisfy the unique needs of the industry and government sectors providing the funds for the programs. The Lifelines Program was established

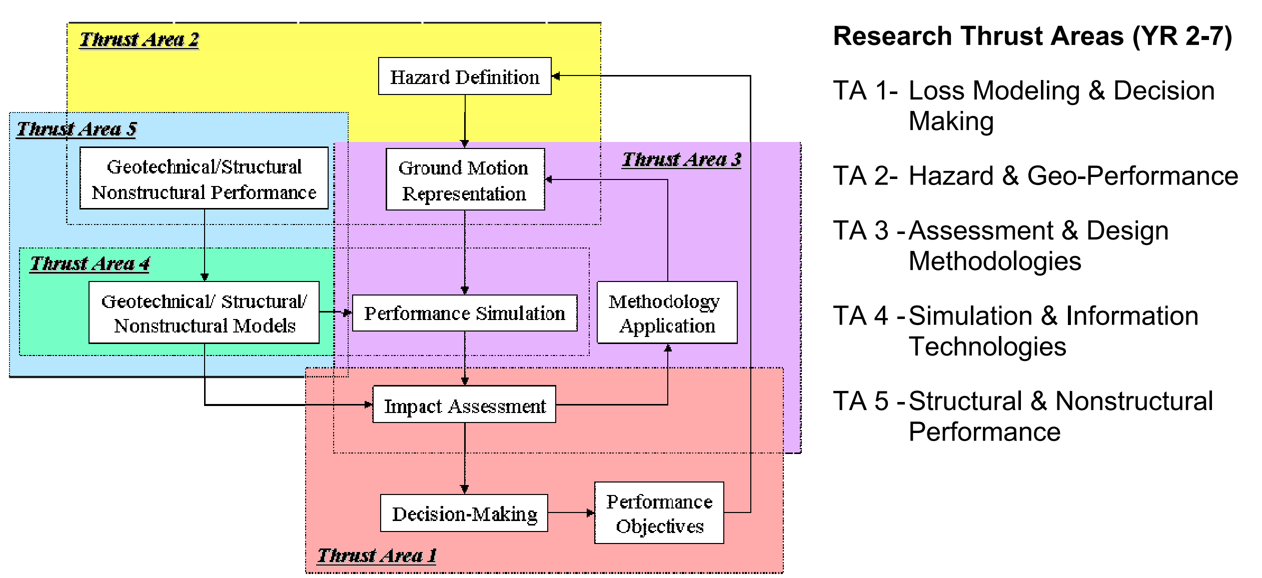

Figure 2.11 – Research thrust areas (Years 2–7)

early in the life of PEER under a contract with specific administrative requirements. Research conducted through the two programs is coordinated through center-wide strategic planning.

During Years 2–7, PEER's research program was organized through five thrust areas defined around the PBEE methodology components, as illustrated by the flowchart of Figure 2.11. As shown, these thrust areas dealt with: (1) loss models and their relationship to stakeholder decision making, (2) earthquake ground shaking and ground deformations, and the transmission of these effects into the structure through foundations, (3) development of the overall PBEE assessment and design methodologies, (4) simulation and information technologies, including *OpenSees* and online databases, and (5) performance of structural and nonstructural components. While this research management structure was an effective mechanism to formulate the PBEE methodology and its underlying components and technologies, as the research matured, the PEER Research Committee felt that a reorganization of the thrust areas would strengthen the research. In particular, the proof-of-concept testbeds (Section 2.1.2.3) , which were undertaken in Years 5–7, demonstrated the unique aspects of the PBEE implementation to bridge and building systems. For example, whereas the three categories of decision variables (dollar losses, functionality, and casualties) are general, the relative emphasis on each and their role in decision making is distinct for bridges and buildings. Further distinctions between bridges and buildings extend to other areas of the methodology, beginning with basic modeling attributes for the system simulations.

After thoughtful deliberation, consultation with the PEER Scientific Advisory Committee, and with the endorsement of the NSF Visiting Committee, in Year 7 the PEER Research Committee reorganized the research management around the four thrust areas shown in Figure 2.12. Aside from the reduction from five to four thrust areas, the reorganization reflects an emphasis on the two major application areas: TA I *Building Systems* and TA II *Bridge and Transportation Systems*. TA I and II encompass all major aspects of the PBEE methodology and enabling technologies related to their respective applications. Thrust Area IV on *Simulation and Information Technologies* provides a strong link between validation testing and simulation of structural and geotechnical components. Thrust Area III encompasses the *Lifelines Program*, whose primary focus is on investigation of seismic reliability of lifelines, including transportation systems and electric utility components and networks.

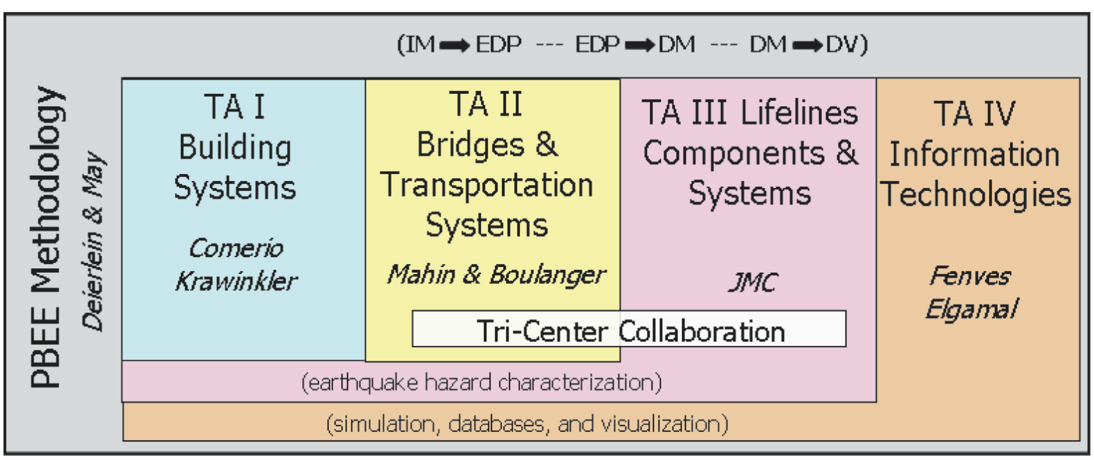

Figure 2.12 – Realignment of research thrust areas (Years 7–10)

As further illustrated in Figure 2.12, the hazard characterization of TA III and the simulation technologies of TA IV have directed links to the application areas of TA I and TA II. Additionally, TA II and III share close collaboration with the Tri-Center initiative on geographically distributed transportation and electric utility systems. Finally, all four thrust areas are encompassed by the common PBEE methodology, which provides a consistent linkage from ground motion *Intensity Measure (IM)* through system demands and damage (*EDP* and *DM*) to the decision variables (*DV*).

2.2.2 Research Needs, Outcomes, and Integrative Milestones

Figure 2.13 shows an overview of how various components of the research program are coordinated to respond to the needs for PBEE. At the top of this figure are eight specific topics, which articulate the specific PBEE Needs. Directly below these PBEE Needs are a series of Integration Milestones, which are the culmination of specific research achievements by one or more thrust areas. The Integration Milestones are organized from left to right in time, and the vertical arrangement represents in some sense a hierarchy among the milestones (i.e., with ones on the bottom tending to feed into those above). Below the Integration Milestones are the four research thrust areas and the topical areas within each. Demonstration Milestones are at the bottom of the figure.

To maintain readability of Figure 2.13, graphical links connecting the topical research areas to *Integrative Milestones* to the *PBEE Needs* are not shown. However, linkages are considered in PEER's strategic planning and are evident in the detailed thrust area strategic plans discussed later in this chapter. Further details on the *PBEE Needs*, *Integration Milestones*, and *Demonstration Milestones* are given in the following subsections.

2.2.2.1 Research Needs and Outcomes

As described earlier, the overall needs for PBEE are to address three levels of earthquake risk decision making. To meet these global needs, the following specific needs and desired outcomes of the PEER research program have been defined:

- *Earthquake Hazard Characterization:* Data, improved models, and guidelines to more accurately describe earthquake hazards due to ground shaking and ground deformation (including liquefaction and fault rupture). Included are the definition of appropriate seismic hazard Intensity Measures (*IM*) and input ground motions.
- *Geotechnical and Structural Simulation Tools:* Computational models, data, and criteria for accurate simulation of building and bridge facilities, including (where necessary) the foundations and surrounding site.
- *Building Performance Assessment:* Comprehensive methodology with supporting data, models, and computational tools to conduct detailed probabilistic earthquake loss assessment. Losses are characterized in terms of direct financial losses, downtime (loss of functionality), and casualty predictions. Primary emphasis is on new and existing reinforced concrete buildings.
- *Bridge Performance Assessment:* Comprehensive methodology with supporting data, models, and computational tools to conduct detailed probabilistic assessment of earthquake losses to reinforced concrete bridges. Loss emphasis is on bridge damage leading to bridge closure or reduced functionality, and estimates of restoration time and costs.

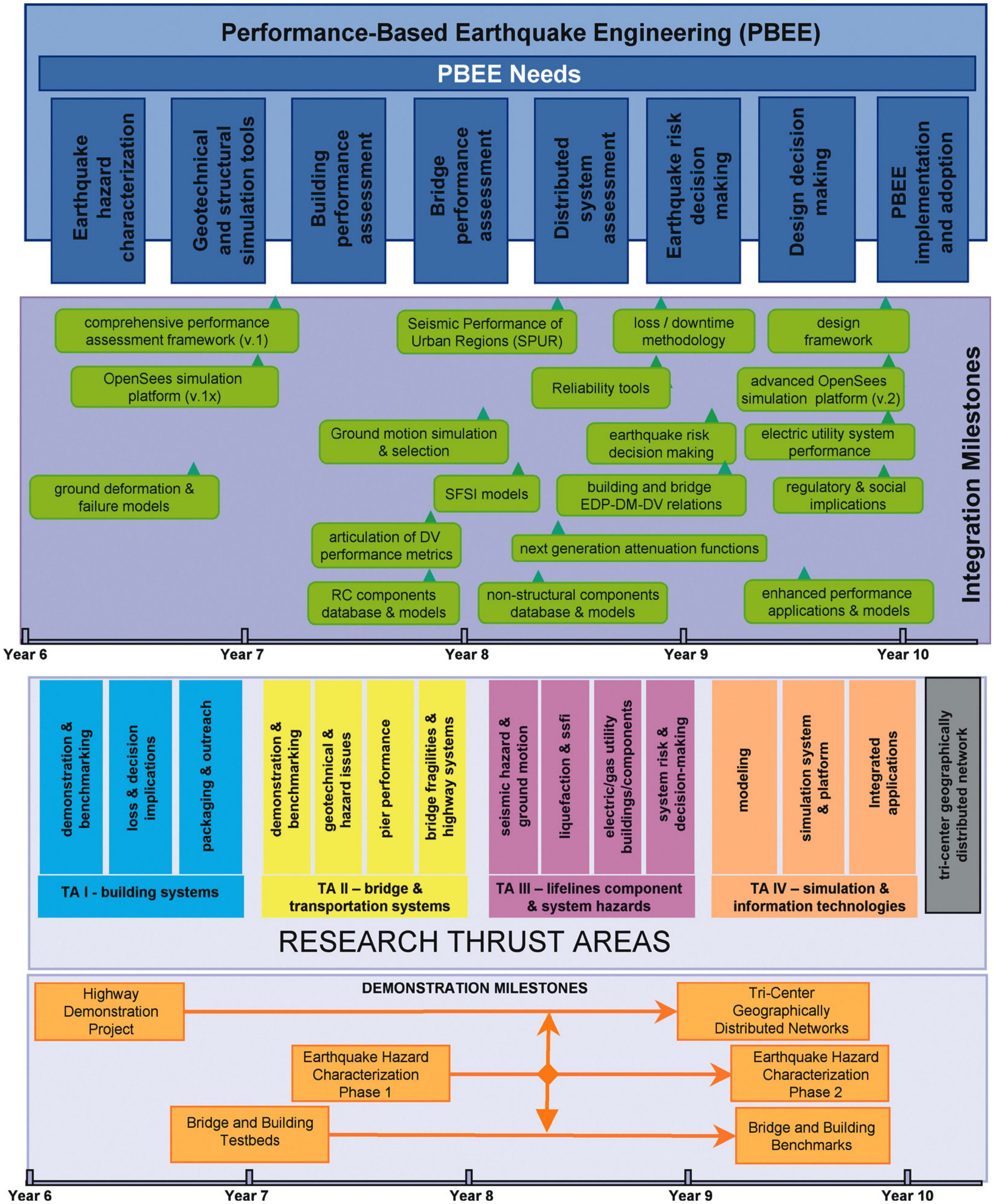

Figure 2.13 – Outcomes, integrative milestones, and thrust areas

- *Distributed System Assessment*: Methodology with supporting data, models, and computational tools to conduct probabilistic assessment of earthquake losses to geographically distributed lifeline systems. Emphasis is on (a) reduced traffic capacity (leading to delays and other disruption) to major arterial transportation networks in California due to bridge damage and (b) disruption of electric utility networks due to earthquake damage to substation equipment and buildings.
- *Earthquake Risk Decision Making:* Collection of methodologies, case studies, and financial models to assist stakeholders in utilizing PBEE to make more informed decisions concerning earthquake risk management.
- *Design Decision Making:* Methodologies and modeling simplifications to apply PBEE assessment techniques to make design decisions for new buildings and bridges. Emphasis is on guidelines on evaluating trade-offs in performance objectives by altering of engineering demand parameters, which relate to key decision variables.
- *PBEE Implementation and Adoption:* Background information, guidelines, and strategies to facilitate implementation of PBEE techniques in practice and building codes and standards.

2.2.2.2 Integrative Milestones

The *Integrative Milestones* shown in Figure 2.13 are significant outcomes resulting from the efforts of researchers in one or more thrust areas. The tick marks associated with each milestone indicate approximately when (measured with respect to the horizontal axis) the research is at the point where an identifiable product has been achieved. As implied by the term "milestone," these achievements are not viewed as final end products, but rather as stages in an ongoing development where we can claim a certain degree of consensus on approaches and techniques for PBEE. The highlights of each milestone are as follows:

- *Comprehensive performance assessment framework* — detailed specification of all major steps in determining input data, conducting simulations, and processing uncertainties for comprehensive performance assessment of facilities, employing the *IM-EDP-DM-DV* path.
- *Loss/downtime methodology* — methodology for probabilistic assessment of direct dollar losses and facility downtime, intended to improve upon due-diligence evaluations (e.g., Probable Maximum Loss, *PML*) of facilities for better-informed risk management decisions by owners and financial/insurance institutions.
- *Design framework* — methodology, criteria, and guidelines for performance-based design of new and existing structures. Emphasis is on ways to alter and target desired performance objectives by design parameters for the foundation, structural and nonstructural components, and contents.
- *Earthquake risk decision making* — guidelines and examples for utilizing seismic performance metrics to make risk management decisions, based on multiple considerations including benefit-cost, investment trade-offs, business interruption planning, etc.
- *Regulatory and societal implications* — evaluation and benchmarking of present building code regulations and other societal factors related to the adoption and acceptance of performance-based building codes. Included will be critiques of PBEE relative to current design practice, considering observations from testbed and benchmark studies.

- *Building and bridge EDP-DM-DV relations* — data and models to relate engineering parameters to damage and quantifiable decision variables for buildings and bridges. For buildings, emphasis is on collapse and losses associated with damage to structural and nonstructural components, repair costs, and occupancy interruption. For bridges, the major decision variables relate to traffic closure and restoration times.
- *Articulation of DV performance metrics* — consensus on key decision variables and preferred ways of articulating these decision variables for different stakeholders.
- *OpenSees simulation platform (v1, v2)* — version updates of *OpenSees* with new modeling and computational capabilities. The final version 2 will have advanced network-enabled computational, database, and visualization features.
- *Seismic performance of urban regions (SPUR)* — demonstration of integrated simulation and visualization platform for earthquake ground motions and their effects on urban infrastructure facilities.
- *Reliability tools* — toolbox of semi-automated procedures implemented in *OpenSees* to facilitate probabilistic assessment of PBEE parameters *IM-EDP-DM-DV*.
- *Ground motion simulation and selection* — data, models, and procedures for defining seismic hazard and input ground motions for simulation and performance assessment of buildings, bridges, and other facilities.
- *Ground deformation and failure models* — data, models, and procedures to predict ground deformations as a function of seismic hazard intensity and ground characteristics.
- *Next-generation attenuation models* — culmination of work to incorporate expanded and improved ground motion data into improved attenuation models for spectral acceleration and other *IMs* as a function of earthquake magnitude, site-to-source distance, local site condition, among other parameters.
- *Soil-foundation-structure-interaction (SFSI) models* — implementation, validation, and documentation of *OpenSees* simulation models for shallow and deep foundations, with applications to bridges and buildings.
- *RC component database and models* — data and models for simulation of structural response and damage to reinforced concrete components, including beams, columns, joints (column splices, beam-column, slab-column), and walls.
- *Nonstructural component database and models* — data and models to evaluate seismic damage and consequences to nonstructural building components and contents. Organized around a comprehensive taxonomy, data and models are based on published literature and selected tests conducted by PEER.
- *Enhanced performance applications and models* — component models, simulation tools, and benchmark studies to evaluate performance of enhanced reinforced-concrete systems, which through use of new concepts or materials provide cost-effective alternatives to conventional systems.

2.2.2.3 Demonstration Milestones

Referring to the *Demonstration Milestones* at the bottom of Figure 2.13, PEER has emphasized demonstrations of the PBEE methodology in two major areas: (1) individual bridge and building facilities and (2) transportation networks and other distributed systems. In addition, a third milestone relates to PEER's efforts (particularly through its *Lifelines Program*) to dramatically improve methods to characterize earthquake ground shaking hazards for PBEE.

The Year 7 demonstration milestone in Buildings and Bridges marked the completion of a two-year focus on the four proof-of-concept testbeds, described previously in Section 2.1.2.3. Since Year 7, the demonstration projects have shifted to generalized studies on performance assessment and benchmarking of modern reinforced concrete buildings and bridges. Like the proof-of-concept testbeds, the benchmarking exercises are serving to integrate and package the interdisciplinary research and assessment methodologies in a consistent format.

The benchmark studies are also providing data on the reliability and implied performance of current codes and practice, which was a high-priority research need identified in discussions with researchers and industry partners at the 2003 PEER Annual Meeting. In addition to providing a benchmark against which to gage socially acceptable performance targets, these studies will highlight opportunities for improving design procedures, with emphasis on understanding how changes in key design parameters (strength, stiffness, and ductility) affect the seismic performance. For buildings, the benchmark studies are a natural vehicle for outreach to industry initiatives to implement improved seismic design standards, such as the FEMA-funded ATC 58 project on performance-based design and ATC 63 project on quantification of building system performance and response parameters. For bridges, the benchmark studies will (a) provide opportunities for interaction with Caltrans and other agencies involved with implementing performance standards for bridges and (b) lead to improved fragility models for use in highway network studies to help establish appropriate performance targets for bridges.

The second major demonstration area concerns the inter-relationship between the performance of individual facilities and the networks of which they are a part. Year 6 marked a major milestone for the Highway Demonstration Project, which involved a seismic risk analysis of the San Francisco Bay Area highway network. This effort involved developing and applying computational tools to assess bridge damage and the resulting transportation delays (travel times) under various earthquake scenarios. Beginning in Year 6, research on the highway network performance has been coordinated under the Tri-Center initiative on geographically distributed networks. Evaluation of highway networks is continuing under this initiative, but with an expanded focus to adapt and combine aspects of risk analysis for other lifeline networks.

The third demonstration milestone concerns the characterization of earthquake hazards for PBEE. A major component of this milestone is the Next-Generation Attenuation project, which is a major initiative of the Lifelines Program (under Thrust Area III) to dramatically improve attenuation models used as the basis for probabilistic seismic hazard analyses. Related efforts in TA I and II are addressing issues associated with the choice of ground motion intensity parameters, ground motion scaling procedures, site effects, and soil-structure interaction as they relate to performance predictions of buildings and bridges. The outcome of the Phase I and Phase II milestones will be validated consensus models for quantifying ground motion hazards, and procedures for selection and calibration of ground motion records as input to simulation models of buildings and bridges.

In Year 10, new application studies will be initiated to apply the PBEE methodology to investigate problems of immediate interest to the earthquake engineering community and stakeholder groups. One of these studies will address the seismic performance of high-rise residential buildings, which are being planned to fill critical needs for housing demands in San

Francisco, Los Angeles, Seattle, and other urban centers in the U.S. and throughout the world. Another proposed study will examine performance of engineered buildings and critical transportation and infrastructure under earthquake scenarios for the Hayward fault, which poses a major risk to the San Francisco Bay Area. This scenario study is motivated by interest raised by a scenario study conducted as part of the centennial of the 1906 San Francisco earthquake. These initiatives will exercise the PBEE methodology together with technologies for ground motion modeling and facility response simulation, such as *OpenSees*, developed through the PEER research. Apart from their immediate practical outcomes, these studies will serve to engage the practicing engineering community and important stakeholder groups (e.g., building officials, lifeline system owners) in applying performance-based engineering to important problems that cannot be solved using current earthquake engineering methods.

2.2.3 Years 9 and 10 Research Project Summary

Detailed summaries of all current (Year 9) projects are included in Volume II of this report. Each project is identified with a project number, principal investigator (PI), and title. These project identifiers are referenced in the thrust area research summaries in Sections 2.3–2.6. Project numbers of the form xyz200a refer to projects that are administered through the Core Research Program. Projects with other three digit numbers (e.g., 701), or three digits plus one letter (3G02) are those administered through the Lifelines Program.

2.2.4 Research Management Committees and Personnel

The PEER research program is jointly administered by two committees: the *Research Committee,* which has primary responsibility for managing the *Core Research Program,* and the *Joint Management Committee*, which has primary responsibility for the *Lifelines Research Program*.

The *Research Committee* is chaired by Gregory Deierlein, *Deputy Director for Research*, who is a professor of Structural Engineering at Stanford University. Together with another research committee member, Professor Peter J. May (Political Science, Univ. of Washington), Deierlein oversees the integration of the research under the PBEE methodology and its relationship to decision making by key stakeholder groups (see Fig. 2.12). Thrust Area I, *Building Systems*, is led by Professors Mary Comerio (Architecture, UC Berkeley) and Helmut Krawinkler (Structural Engineering, Stanford). Thrust Area II, *Bridges and Transportation Systems*, is led by Professors Stephen A. Mahin (Structural Engineering, UC Berkeley) and Ross Boulanger (Geotechnical Engineering, UC Davis). Thrust Area III, *Lifelines Component and System Hazards,* is managed by a *Joint Management Committee* of the *Lifelines Program* (see below) and is represented on the PEER *Research Committee* by Jack Moehle and Yousef Bozorgnia, PEER *Director* and *Associate Director*, respectively. Thrust Area IV, *Simulation and Information Technologies*, is led by Professors Gregory L. Fenves (Structural Engineering, UC Berkeley) and Ahmed Elgamal (Geotechnical Engineering, UCSD).

The *Lifelines Program* contractual agreements require a close coordination among the researchers and sponsors. To meet those requirements, PEER has established a series of Topic Area Leaders to provide close oversight and coordination of those projects funded through the Lifelines program. These topic leaders provide a natural technology transfer mechanism to industry. Director Moehle works directly with Dr. Yousef Bozorgnia, *Associate Director,* to provide overall coordination of the program. Topic Leaders are as follows: *Earthquake Ground*

Motion, Dr. Norman Abrahamson (Seismologist, PG&E) and Dr. Brian Chiou (Seismologist, Caltrans); *Site Response* and *Permanent Ground Deformation,* Mr. Thomas Shantz (Geotechnical Engineering, Caltrans); *Electric Substation Equipment Vulnerability,* Mr. Eric Fujisaki (Structural Engineering, PG&E); *Electric System Building Vulnerability,* Mr. Kent Ferre (Structural Engineering, PG&E); *Network System Seismic Risk*, Dr. Stuart Nishenko (Seismology, PG&E). These topics are managed under Thrust Area III and are coordinated through a series of quarterly coordination meetings and workshops. As the scope of TA III is being expanded, a new topic, *"Bridge Structures,"* is envisioned to be added to TA III.

2.3 Thrust Area I: Building Systems

2.3.1 TA I Goals

The Building Systems thrust area was created in Year 7 to bring focus to the research and implementation issues that were exposed but not completed in the Van Nuys and UC Science building testbeds. In these testbed assessments of existing buildings, researchers demonstrated the capacity of the PBEE methodology to integrate data from a hazard analysis into a structural analysis, and then to use the engineering demand parameters generated to calculate damage and to assess losses in terms of repair costs, casualties, and downtime. These probabilistic assessments were then presented in a variety of formats for decision makers to engage in design and cost trade-offs.

The testbeds demonstrated the present capacity to complete each step in the process, but they also highlighted areas that need further research and development. The most important needs, which form the goals for the Building Systems thrust area for Years 8–10, are:

(1) to improve the capacity to model performance decisions (*EDPs* to *DVs*),

(2) to benchmark the performance of new reinforced concrete building systems, and

(3) to package the PEER performance-based engineering methodology in a way that makes it accessible to the engineering community. This packaging effort is part of a broader outreach effort that is a major component of the Year 10 plan.

2.3.2 TA I Strategic Plan

As illustrated in the strategic planning chart of Figure 2.14, the TA I plan for Years 8 through 10 is organized around the three themes of demonstration/benchmarking, loss assessment/decision making, and packaging/outreach. To make informed "Performance Decisions," an engineer as well as an owner or facilities manager must understand the trade-offs involved in design alternatives in terms of up-front construction costs as well as probable repair costs, injuries to occupants, and time needed for recovery from damage. To improve the translation of engineering demand parameters to economic and human consequences, we have three projects focusing on modeling consequences, and estimating losses from the benchmark study (PIs: Comerio [1202005], Miranda [1302005], and Beck [1362005]. On benchmarking, Deierlein [1382005] is continuing work with input from Lowes [1402005] on structural fragilities and damage models of structural components [1402005]. Stewart [1342005] is continuing work on ground motions, site effects, and soil-foundation-structure interaction. His project is complemented by a collaborative effort by Hutchinson and Kutter [1412005] on shallow foundation modeling and performance. Cornell [1312005] has a related study on characterizing earthquake Intensity Measures (IM) and ground motion scaling procedures. Krawinkler [1292005] is responsible for the overall packaging of the methodology for practicing engineers, while May [1332005] will focus on the role of performance engineering in the regulatory systems and mechanisms for outreach for early adopters in the engineering community.

In addition to the ongoing projects, the Year 10 plan includes a new initiative [1422006] to collaborate with professional organizations and building department officials on a detailed application study utilizing PEER's research methodology to examine the seismic performance of high-rise residential buildings in urban regions. This project was motivated by a need voiced by local and regional building officials in California and strong interest by the engineering community to apply performance-based methods to address the problem. From PEER's perspective, the project is an ideal opportunity to accelerate the implementation and adoption of PBEE by the engineering community.

2.3.3 TA I Critical Mass and Level of Effort

Overall, all TA I researchers will work across the spectrum of the performance equation, but each will contribute to the methodology as well as to specific benchmarking case studies. There is a critical mass in each area of emphasis: characterization of earthquake input motions (Cornell, Stewart), structural analysis and design (Deierlein, Lowes, Krawinkler), foundation performance (Hutchinson, Kutter), and loss assessment, performance decisions, and implementation (Comerio, Miranda, Beck, and May). While each Principal Investigator will be asked to complete specific components of the work, each is expected to coordinate and contribute to the overall thrust area effort.

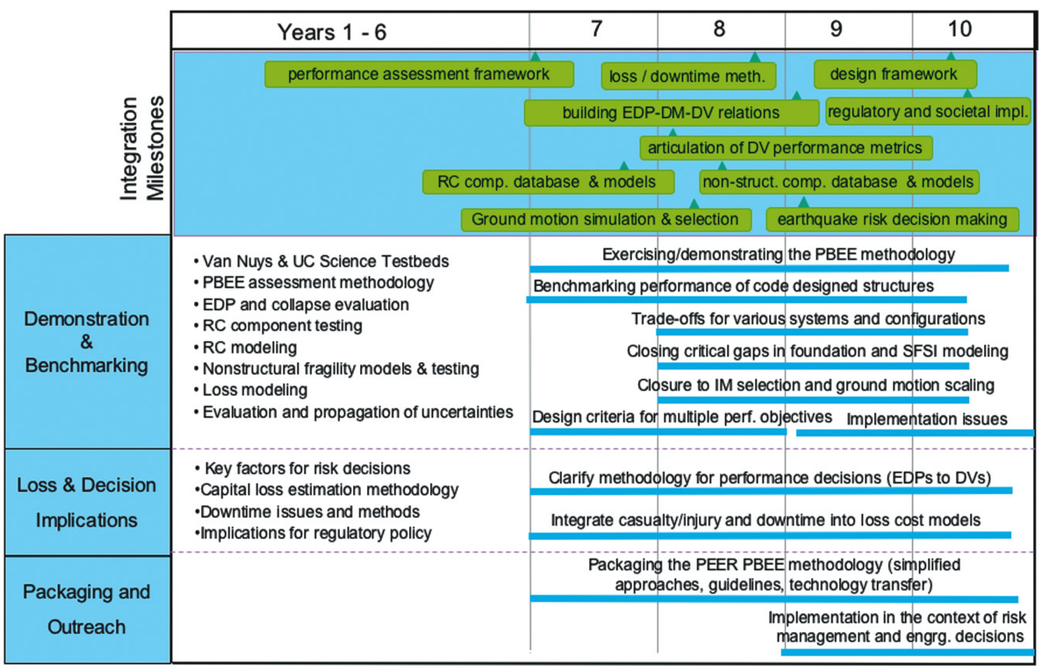

Figure 2.14 – Strategic plan: Thrust area I — Building systems

Below, each Year 9 research project is briefly described.

Comerio [1202005] is working on a method to estimate time needed to re-occupy a building based on factors unrelated to the repair of physical damage. These include the importance of the space to operations, the ability to finance, and the ability to secure "surge" space for construction. The methodology is being integrated with casualty and cost estimating, with a specific focus on the translation from engineering demand parameters to loss consequences.

Miranda [1302005] has developed a sophisticated method for estimating probable loss costs based on engineering demand parameters. He has applied the model to the benchmarking study and has developed ways to simplify the analytic approach for comparing alternative design concepts. For Years 9 and 10 the objective is to develop a toolbox of procedures and models that will enable practicing structural engineers to conduct loss assessments of buildings. Specific objectives of this research are: (a) development of fragility functions for generic nonstructural components; (b) development of generic loss curves for building stories; and (c) development of tools to facilitate loss estimation calculations and delivering loss information to decision makers.

There will be considerable coordination between these "performance decision" researchers and those involved in benchmarking and methodology development. The larger goal is to develop methods that translate engineering outputs into decision parameters—issues that force design and performance decisions.

May's project [1332005] is focusing on a review of the societal implications of PBEE, taking a systematic look at the benefits of performance engineering, particularly in the regulatory context. May has focused on mechanisms to transfer performance engineering methods to engineering practitioners and the regulatory community. As an example of successful societal adoption of regulatory innovations, May is focusing attention on "green buildings" and the growing movement for adoption of the green building voluntary standards. He is collecting documents and data about the factors that have led states to adopt the voluntary standards for public and other buildings. This serves as a useful case study from which lessons can be drawn for PBEE.

Deierlein [1382005] is conducting the lead project in the benchmarking effort. He is applying the PEER methodology and tools to assess the performance of RC buildings that conform to current code standards. He is (a) benchmarking the performance of building code compliant RC frames, (b) contributing to the development and "packaging" of the PBEE methodology and enabling data and technologies through their application to the benchmarking exercise, (c) conducting studies to use PBEE assessment tools to ascertain how building performance is affected by key design criteria for minimum strength, stiffness, and ductility, and (d) evaluating trade-offs, using the PBEE decision metrics, for various systems and configurations.

Beck [1362005] is using the structural performance information generated in the benchmark project [1382005] to perform loss estimation. In support of this goal he is focusing on the following objectives: (1) coordinate further development of his loss estimation toolbox with Miranda [1302005] so that a single packaging of PEER's EDP to DV methodology results, (2) in coordination with Comerio [1202005] further develop the PEER methodology for estimation of indirect losses arising from downtime, (3) further develop the PEER methodology for estimating deaths and injuries, and (4) in coordination with May begin developing a decision analysis framework that uses the "3Ds" (dollars, downtime, and deaths) as DVs but also allows the decision maker to account for his/her risk attitude.

Lowes [1402005] is developing comprehensive information to support modeling of reinforced concrete beam-column joints (Year 9) and walls (Year 10) for performance-based earthquake engineering. The project scope includes (1) development and posting to a website of information and data from experimental testing of beam-column joint and walls, (2) documentation of response-prediction models developed as part of the PEER research effort, (3) documentation of performance-prediction models developed as part of the PEER research effort, and (4) examples demonstrating the application of response and performance-prediction models.

Stewart's emphasis is the integration of geotechnical/seismological uncertainties into a unified analysis of system performance [1342005]. The uncertainties that are being considered include epistemic uncertainty in the site hazard, aleatory uncertainty in the variation of ground motion from the free-field to the foundation (i.e., the so-called "kinematic interaction" effect), and aleatory uncertainty in the soil flexibility/damping associated with inertial soil-structure interaction. Stewart [1412005c] also is involved in coordinating and complementing the work done by Hutchinson and Kutter on shallow foundation modeling.

Hutchinson [1412005a] and Kutter [1412005b] are focusing on establishing engineering criteria and guidelines for design and performance assessment of the interface between the superstructure and the supporting soil for shallow foundations. The goal of this joint project is to develop the necessary tools to predict rotations and translations at the soil – shallow foundation interface and to allow engineers to assess, through quantitative analysis, the trade off between the benefits (energy dissipation and isolation) and the detriments (e.g., permanent and cyclic settlement and/or tilt) associated with foundation nonlinearity.

Cornell [1312005] is in the process of bringing closure to the all-important issues of intensity measure (IM) selection and ground motion scaling. Included are both scalar and vector schemes for IMs. Cornell's objective is to produce comprehensive IM and record selection recommendations for loss estimation and collapse evaluation. This includes (1) completion and packaging of the use of inelastic displacement as an IM, (2) quantification of near-fault effects and of characteristics of near-fault ground motions, and (3) development of selection and scaling procedures to deal with the evaluation of bi-directional effects, i.e., orthogonal directions with very different first-mode periods.

Krawinkler [1292004] is taking the lead in facilitating the use of the PEER PBEE methodology in engineering practice. His project is a major step of the building systems packaging/outreach program, whose objective it is to communicate the PEER methodology to the users. He is completing a design decision support system that facilitates the selection of effective structural systems by simultaneously evaluating economic loss and collapse safety considerations. He is developing a set of guidelines for carrying out a performance assessment, summarizing processes and data for simplified approaches for performance assessment, and refining and summarizing data and criteria that can form the basis for performance-based design.

2.3.4 TA I Research Advances and Deliverables

The Building Thrust Area combines researchers from four of the five Years 2–7 thrust areas—Loss Modeling and Decision Making, Geotechnical Performance, Assessment and Design Methodology, and Structural and Nonstructural Performance. The advances made in each thrust area and in the proof-of-concept testbeds shaped the decision to create the Building Thrust Area, which is now in its second year of existence.

In the previous Thrust Area 1, Loss Modeling and Decision Making, the majority of the research focused on three areas: (1) Identification of decision making factors, (2) Gaging losses and costs, and (3) Loss Modeling. Work by several researchers identified what we called the "3Ds"—death, dollars, and downtime—as the key decision factors. Metrics were developed for measuring structural, nonstructural, economic, human and institutional losses by Beck, Chang, Comerio, Ince, Maszaros, Miranda, Porter, and Shoaf. The various approaches were applied in the Van Nuys and UC Science Testbeds. These have been published in numerous scholarly articles and documented in the PEER testbed reports. In Years 6–7 we developed a clear understanding of the economic framework needed for decision making, and basic approaches to estimating casualties and downtime. This work serves as the basis for the goals articulated for Years 8–10: to refine and simplify the methodology for understanding losses and making performance decisions. In Years 8 and 9 much progress was made in downtime modeling, and the various approaches for loss modeling were unified so that the two basic approaches proposed by Miranda and Beck follow a consistent pattern that varies in details but not in concepts.

In a parallel effort, May focused on the larger policy issues of adoption and implementation. His work up to Year 7 looked at performance standards in a societal context, including the barriers to adoption of performance standards as well as the implications of performance standards on regulatory systems. He has published several articles comparing performance standards in a variety of regulatory models. In Years 8–10 he is focusing on broader societal benefits derived from performance engineering and mechanisms for outreach to "early adopters." He is using green building as a case study for collecting data about the factors that have led states to adopt the voluntary standards for public and other buildings.

Similarly, in the previous Thrust Areas 2, 3, and 5, geotechnical and structural engineers developed and tested performance models for building systems. Much progress has been made in quantifying structural component response (Moehle, Lehman, Wallace, Robertson), nonstructural components and contents (Miranda, Restrepo, Makris, Hutchinson), soil-foundation-structure interaction effects (Stewart), geotechnical uncertainties and their effects on engineering demand parameters (Kramer), and behavior of shallow foundations (Kutter and Hutchinson). The work on shallow foundation modeling has matured to the degree that two different but complementary models are being implemented in the OpenSees platform. Stewart has developed models to enable site-specific data to be utilized in PSHA, and those models are implemented in OpenSHA.

At the end of Year 6 most basic concepts of a comprehensive performance assessment framework had been put in place. Different methods for uncertainty propagation had been explored and evaluated, ranging from simple first-order second-moment approaches to full Monte Carlo simulation (Beck, Porter, Cornell). Work was performed on quantifying sensitivities and identifying those uncertainties that significantly affect the decision variables on which performance assessment is based (Der Kiureghian, Conte, Krawinkler). In Years 7 and 8, more emphasis began to be placed on performance-based design (Krawinkler) and benchmarking (Deierlein). At the same time, work on insufficiently resolved issues of performance assessment, such as collapse prediction (Krawinkler) and EDP-DM-DV relationships (Beck/Porter, Lowes), was integrated through the Van Nuys testbed study and the ongoing benchmark study (Deierlein, Stewart). The effort on simplified performance assessment and performance-based design (Krawinkler) has led to a semi-graphical design decision support system that facilitates selection of an effective structural system based on quantitative loss and collapse mitigation strategies.

Testing of the performance assessment methodology forms a crucial part of the development effort. During Years 5–7, the two building testbeds (the UC Sciences Building and the Van Nuys Building) were the center of focused studies in which the PBEE assessment methodology was tested, additional research needs identified, simplified approaches developed, and the socio-economic impact of different performance objective formulations demonstrated. The second "testing" effort took shape in Year 8 and is expected to continue until Year 10. It is concerned with benchmarking and packaging the PEER PBEE methodology for buildings. This effort ties in with the needs of the community (e.g., ATC 58, ATC 63, ASCE 7) to carry out an assessment of the performance of buildings designed according to present code requirements. In this work the PBEE methodology is applied to selected subsets of reinforced concrete frame and wall buildings in order to assess current code design procedures and find out how the methodology has to be packaged in order to be useful to the engineering profession.

2.3.5 TA I Future Plans

In Year 10, the *Building Systems* Thrust Area will bring to a closure the work started in Years 8 and 9. This will include (1) a clear presentation of the PEER performance methodology through the benchmarking studies, (2) completion of the methodology for performance decisions in the translation of engineering demand parameters to decision variables, (3) simplified design decision tools for practitioners, (4) continued investigations of policy and implementation hurdles, and (5) outreach strategies to enhance the adoption of performance-based engineering. The primary emphasis in Year 10 will be on refinement, implementation, and packaging of the PEER PBEE methodology and on communicating the methodology to the users and stakeholders. From a more global perspective, the emphasis will be on outreach activities to professional groups and on illustrations of the methodology.

The only newly proposed project for Year 10 is one to involve researchers and practicing engineers in an application study to apply PBEE to help establish appropriate design criteria and procedures for high-rise residential buildings. This project will respond to an important practical need among engineers and building officials in regions of high seismicity. At the same time, we envision that it will further inform the ongoing research efforts and facilitate the implementation and adoption of PBEE methods in engineering practice. Detailed planning for the project, including negotiations for external matching funds to support ground motion modeling, workshops, and design guidelines, is presently under way.

2.3.6 TA I Publications

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Baker J.W. and Cornell C.A., 2004. Choice of a vector of ground motion intensity measures for seismic demand hazard analysis. *Proc. 13th World Conference on Earthquake Engineering, Vancouver, Canada*, 15 pp.

Baker J. W., Cornell C. A., and Tothong P. 2005. Disaggregation of seismic drift hazard. *9th Intl. Conference on Struct. Safety and Reliability (ICOSSAR05), Rome, Italy*, 7 pp.

Beck, J.,Goulet, C., Haselton, C., Mitrani-Reiser, J., Stewart, J., Taciroglu, E., Deierlein, G. April 2006. Evaluation of the seismic performance of a code-conforming reinforced-concrete frame building - Part I: Ground motion selection and structural collapse simulation, *Proc. 8th National Conference on Earthquake Engineering, San Francisco, CA.* Paper No. 1576 EERI.

Beck, J., Mitrani-Reiser, J., Haselton, C., Goulet, C., Porter, K., Deierlein, G. April 2006. Evaluation of the seismic performance of a code-conforming reinforced-concrete frame building — Part II: loss estimation. *Proc. 8th National Conference on Earthquake Engineering, San Francisco, CA. /* Paper No. 969. EERI.

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Haselton, C., Baker, J. 2006. Ground motion intensity measures for collapse capacity prediction: choice of optimal spectral period and effect of spectral shape. *Proc. 8th National Conference on Earthquake Engineering.* Paper ID 461. 10 pgs. EERI.

Haselton, C. B., Deierlein, G. G. 2006. Toward the codification of modeling provisions for simulating structural collapse. *Proc. 8th National Conference on Earthquake Engineering.* Paper ID 1348. 10 pgs. EERI.

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2.4 TA II: Bridges and Transportation Systems

2.4.1 TA II Goals

The *Bridges and Transportation Systems* research program is directed toward further developing the performance-based earthquake engineering (PBEE) methodology developed by PEER, and demonstrating its utility through application to difficult bridge design problems that integrate structural and geotechnical considerations. Previous proof-of-concept testbed projects (Humboldt

Bay and I-880) demonstrated the application of the PBEE methodology to two very complicated large bridge structures. The results were well received by business and industry representatives, but it was noted that the utility of the methodology now depended on further development and implementation in simpler and more transparent procedures. This effort would require further clarification of the procedures and methodologies used to derive the various components of the methodology (e.g., fragility curves, damage measures, decision variables).

Accordingly, the goals for the Bridges and Transportation Systems research program are to: (1) further develop the PBEE methodology and package it in ways that are accessible to the engineering community, (2) demonstrate the PBEE methodology by applying it to more common bridge configurations, including cases involving the use of performance-enhanced columns and cases involving liquefaction and lateral spreading hazards, (3) address the knowledge base and enabling technology needs for the above demonstration problems, and (4) advance our capabilities to model seismic risk for transportation and geographically distributed systems.

2.4.2 TA II Strategic Plan

The strategic plan for TA II, as depicted in Figure 2.15, defines a coordinated sequence of research projects over Years 8–10 to achieve the goals described above. The strategic plans for the current Year 9 and the following Year 10 are largely unchanged from the plans that were originally developed in Year 8 except for a few project changes that were made in response to Year 8 findings and progress and a new application study initiative.

There are four application testbed projects that are demonstrating the PBEE methodology for variations from a common baseline bridge structure (Stojadinović 2442004, Mahin 2402004, Kramer/Arduino 2412004, Bray 2422004/Martin 2432004). The variations that each testbed project is addressing will exercise the methodology for very different purposes, thereby illustrating its usefulness in different ways. The researchers for these projects are working closely together, sharing components and models, and bringing different technical expertise to the group effort.

This group effort includes a lead project on clarifying, simplifying, and communicating the PEER methodology that included a detailed report in Year 8 that clearly specified recommended procedures for implementation of the PEER methodology for bridge systems (Stojadinović 2442004). The draft of this detailed report provided a synthesis of best practices that the other projects are utilizing and building upon. This lead effort on the methodology is continuing its complete demonstration for a baseline bridge structure (Stojadinović 2442004) that was selected with input from our BIP representatives (Ketchum 2522004). The baseline bridge configuration is a five-span bridge with earthen abutments and typical Caltrans detailing. By focusing on a prototypical baseline bridge, this project is providing a complete demonstration of the PEER methodology in advance of the other parallel testbed projects, and therefore providing the framework for them to utilize and build upon.

The benefits of performance-enhanced piers are being evaluated using PEER methodology (Mahin 2402004), thereby illustrating both the utility of the performance-enhanced piers and the utility of the PEER methodology for evaluating new technologies. This project builds upon the experimental and computation efforts on performance-enhanced piers, as described later. In addition, this project will address the impacts of near-field motions.

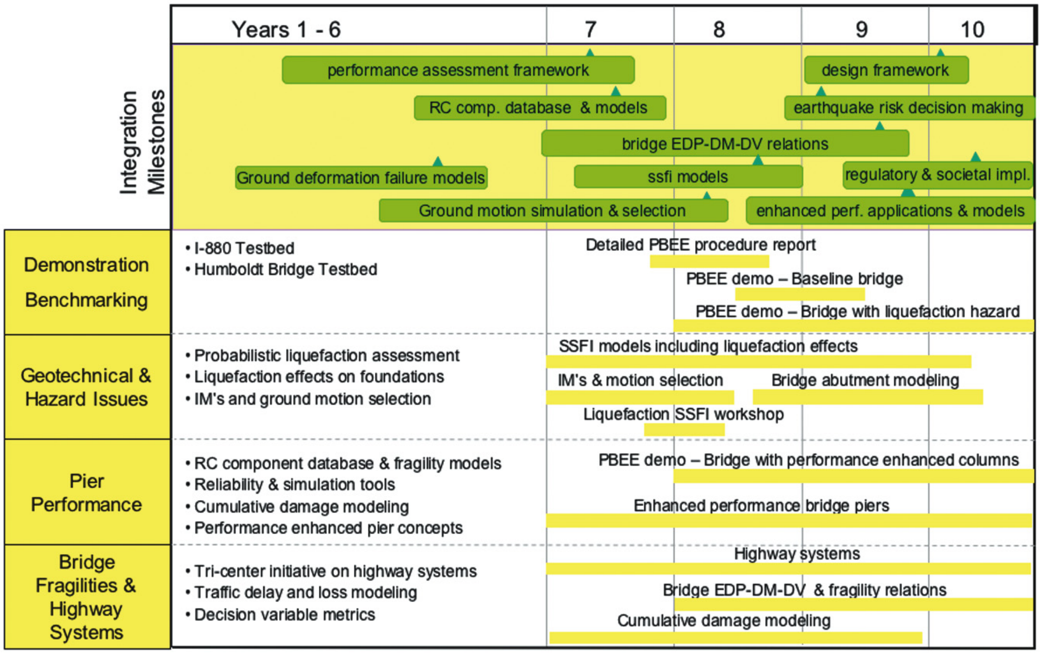

Figure 2.15 – Strategic plan: Thrust area II — Bridge and transportation systems

The effects of liquefaction and lateral spreading on bridges are being evaluated through two parallel testbed projects. The first project (Kramer/Arduino 2412004) is utilizing continuum soil modeling capabilities in *OpenSees* as part of the numerical model of the prototype bridge system. This project is providing additional insights into the physical effects of liquefaction of bridge performance through the numerical modeling, and also demonstrating how to effectively utilize the PEER methodology in making informed decisions as to whether remediation is warranted or not.

The second testbed project regarding liquefaction effects on bridges (Bray 2422004/Martin 2432004) includes the evaluation of simplified design recommendations and procedures, and is expected to evaluate alternative remediation schemes. This project will translate various PEER research findings into forms that are quickly adopted in design practice, and thus fill an urgent need for Caltrans and industry. In addition, this project will demonstrate how the PEER methodology can be effectively used with simpler design-level analysis methods to make informed decisions.

Fragility curves that relate damage measures to engineering demand parameters and decision metrics are being further developed for a broader range of structural components, as needed for the bridge testbed projects (Eberhard 2452004). Fragility curves for implementation in transportation systems analyses will also be further developed (Stojadinović 2442004, Brandenberg 2572005).

Research on cumulative damage associated with low-cycle fatigue buckling and fracture of longitudinal reinforcement will continue (Lehman 2472004). This cumulative damage research includes testing and model development (Lehman 2472004) and computational implementations in TA IV (Kunnath 4232004).

The innovative idea of enhancing the performance of bridge piers by applying vertical post-tensioning is being further developed through experimental and analytical studies (Mahin

2402004, Billington 2462004). These studies are motivated by the observation that post-earthquake residual displacements are one of the primary contributors to bridge closure and replacement. The objective of the investigations is to show how post-tensioning, combined with mild steel reinforcement, can reduce residual drifts. The results of these studies will be fed into the testbed project, wherein the utility of PEER methodology to evaluate new technologies will be demonstrated.

Experimental and computational studies of soil-foundation-structure interaction will continue for pile foundations in liquefying and laterally spreading ground (Boulanger 2392004, Kramer/Arduino 2412004). Dynamic centrifuge model tests are being performed for pile supported abutments embedded in a laterally spreading soil profile (Boulanger 3F03 in TA III). These centrifuge tests are focused on evaluating the restraining effect of piles on abutment deformations, which is an important mechanism upon which designers are increasingly beginning to rely. Numerical analyses of these and other centrifuge data are contributing to calibration of *OpenSees* models and simpler design analysis models. These studies continue PEER efforts in advancing this field through parallel experimental, computational, and performance-based design projects.

The modeling of earthen abutments in seismic analyses of bridges is being evaluated (Ashford 2552005) in conjunction with some large-scale testing funded separately by Caltrans. This project is providing essential support for the testbed application studies.

Continuing advances in OpenSees capabilities will also support the bridge systems thrust area. Specifically, the advances in computational capabilities will be exercised by performing three dimensional modeling of soil-pile interaction in liquefied ground (Elgamal 4242004), for which the ability to do coupled modeling in OpenSees is essential (Jeremić 4262004).

Research on transportation systems is progressing in several ways. Decision variables for individual bridges are being developed that account for the influence that the bridge has on the transportation network (Kiremidjian 2562005). A companion project (Fan 2502004) is addressing two related problems: (1) from a transportation operational viewpoint, how to route traffic through damaged transportation networks so that emergency response tasks can be carried out effectively; and (2) from a disaster management and mitigation viewpoint, how to develop and support effective strategies for recovering and retrofitting transportation systems to ensure reliable movement of emergency vehicles and to minimize the total societal disruption. A third project was initialized to provide improved fragility relations for bridges founded in liquefiable deposits (Brandenberg 2572005) for use in the transportation network analyses (Kiremidjian 2562005). The above projects have required close collaboration and exchanges of data, algorithms, and findings, and have involved collaborations across centers and industry (Stu Werner; Caltrans). These efforts all contribute directly to Tri-Center collaborations (Moehle 2532004).

2.4.3 TA II Critical Mass and Level of Effort

The strategic plan brings together PEER researchers with the appropriate critical mass and expertise to achieve the goals for the *Bridge and Transportation Systems* thrust area. The four bridge application (testbed) projects bring together six researchers (Stojadinović 24492004, Mahin 24022004, Kramer/Arduino 2412004, Bray 2422004, Martin 2432004) with complementary skills, such that their close coordination and collaboration provide opportunities for more rapid advancements in the PBEE methodology and its packaging for the engineering community. The other projects provide support for the testbed projects by addressing key knowledge base needs and by enabling technology needs. For performance-enhanced columns, the supporting projects include experimental and computational efforts by Mahin (2402004), Billington (2462004), and Lehman (2472004). The role of the earthen abutments is being addressed by Ashford (2552005), while the effects of liquefaction are being supported by Boulanger (2382004). In addition, the bridge testbed project involving liquefaction effects will leverage past accomplishments by PEER researchers and their close connections with major efforts at MCEER and in Japan. Several *OpenSees* efforts will address needs for this thrust area (e.g., Elgamal 4242004, Jeremić 4262004, Kunnath 4232004). The work on *EDP-DM*-DVs by Eberhard (2452004), bridge fragilities (Stojadinović 2442004), and abutment modeling (Ashford 2552005) provide support across all bridge testbed projects, and the work by Fan (2502004), Kiremidjian (2562005), Brandenberg (2572005), and Moehle (2532004) contribute to transportation systems and the Tri-Center initiative. All projects will benefit from close communications with practitioners and Caltrans.

2.4.4 TA II Research Advances and Deliverables

The four testbed application projects have made significant advances toward demonstrating the application of the PBEE methodology in the various ways intended. The methodology has been advanced and the expected performance of the prototypical Caltrans five-span bridge has been benchmarked. The two projects involving liquefaction effects have advanced the utilization of OpenSees as a modeling tool, while simultaneously advancing our ability to effectively apply the PBEE methodology with either advanced or simplified analysis procedures to bridges in areas of liquefaction.

Significant advances continue to be made regarding the seismic performance of pile foundations in liquefied ground, with contributions coming from researchers across thrust areas II, III, and IV (TA II testbed teams, Boulanger, Ashford, Conte, Elgamal, Jeremić). Contributions have included original experimental data, identification of fundamental mechanisms of interaction, development of computational modeling tools, and guidance on simplified design methodologies. Many of these contributions are included in the proceedings of the March 2005 workshop held at UC Davis (Boulanger 2372003). This workshop brought together engineering practitioners and researchers from across the U.S. and internationally to summarize the most current understanding of fundamental mechanisms, numerical modeling abilities, and design recommendations for practice. The proceedings were published as an ASCE Geotechnical Special Publication.

Advances have been made experimentally and computationally in performance-enhanced columns (Mahin and Billington) and cumulative damage in reinforcing bars (Lehman).

Damage models and decision models have been advanced, including an electronic online database of column tests and fragility relationships between *EDPs (*such as column ductility ratios, plastic hinge rotations, and strains) and damage states (Eberhard) and the translation of field damage observations into decision making for bridges (Porter).

The Tri-Center initiative has advanced the network modeling of transportation and distributed network systems (Kiremidjian, Fan, Moehle) and identified key areas where improved fragility relations and inventory knowledge is needed.

2.4.5 TA II Future Plans

The future plans for the Bridges and Transportation Systems Thrust Area follow from the previously established plan for Years 8–10. The project by Fan was expanded to cover the issues that were important to the collaboration with Kiremidjian. The project by Brandenberg was recently added to ensure the timely provision of fragility relations to Kiremidjian's and Fan's network models. Ashford's project was re-directed toward providing more support regarding the behavior of earthen embankments, which had become an urgent need in the testbed projects. A couple of other projects may warrant redirection based upon progress in Year 9, but for the most part it is expected that the testbed and supporting projects will require extensions through Year 10 (as tailored to specific project needs). The success of these testbed studies will show that the PBEE methodology can be used to assess existing bridge design procedures, assess new performance enhancing technologies, and assess challenging geotechnical hazards like liquefaction.

Funds have been allocated for a new Year 10 initiative (2582006) that will further explore PBEE applications to bridges and lifeline systems. A major portion of this effort will be directed toward a study to evaluate the implications of a large earthquake on the Hayward fault in the San Francisco Bay Area. This scenario study will leverage ongoing efforts of the transportation network study to examine damage to buildings, bridges, lifeline systems, and their inter-connections. The value of an earthquake scenario in attracting the interest of government agencies, facility owners, and the public was demonstrated with a recently completed scenario study of a repeat of the 1906 earthquake on the San Andreas fault. The proposed study will be an effective vehicle for integrating PEER's research projects in ground motions, simulation of geotechnical and structural systems, and loss modeling. This, along with the other bridge testbed application studies, will exercise the PBEE methodology in ways that are accessible to the engineering community and will provide opportunities for post–Year 10 efforts on utilizing the PBEE methodology for other classes of bridge structures, other technologies, and other hazards.

2.4.6 TA II Publications

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2.5 Thrust Area III: Lifelines Component and System Hazards

2.5.1 TA III Goals

The Lifelines Components and Systems research program is directed toward increasing the reliability and safety of geographically distributed lifelines systems including transportation and utility lifelines. The performance of a lifeline system is governed by three considerations: (1) the regional distribution of earthquake ground motion and ground failure, (2) the performance of individual components to ground shaking and ground failure, and (3) the interaction among the multiple components of the lifeline system and the impact of damage on flow through the lifeline system. The research program is designed to address these aspects within the confines of a limited set of lifelines systems determined by the external funding agencies. At present, the lifelines systems are restricted to highway networks and to electric and gas transmission and distribution systems. PEER is currently communicating with other major lifelines organizations to formulate new collaborative research programs. This will enable us to expand our lifelines funding agencies and research projects related to performance of lifelines components and systems.

The goals for the Lifelines Components and Systems research program are: (1) to improve the ability to estimate distributions of strong ground motion considering the range of earthquake mechanisms, earthquake magnitudes, path, distance, site and basin effects expected especially in California; (2) to improve the ability to estimate the extent of ground failures that may affect distributed and/or buried lifelines systems; (3) to develop practical analytical methods, including fragilities, for assessment of the performance of lifelines components, including electric utility equipment and buildings (bridge substructures and superstructures are excluded, as they are covered under TAII and other programs); and (4) to develop models for assessing system risk, and to use those models to understand where the greatest uncertainties and research benefits may lie, and to query risk-decision processes to better understand how to influence performance decisions about lifelines.

2.5.2 TA III Strategic Plan and Milestones

The strategic planning graphic for TA III (Fig. 2.16) defines a coordinated sequence of research projects to address some of the goals described above. The plan, however, is not shown fully populated in future years in the same way as done for the other thrust areas because of the different funding sources. Unlike TA I, II, and IV, which are funded by the NSF and core matching funds, TA III is funded primarily by the Lifelines Program sponsors. Continuation proposals to those sponsors are pending, and it would not be appropriate to provide proposed details until funding decisions are made.

The research plan for Years 9–10 includes two main, multi-investigator projects on ground motions. The first of these will continue work to improve our ability to predict earthquake ground motion for design application through better attenuation relations. A series of projects referred to as "NGA-E" ("Next-Generation Attenuation — Empirical") culminates a major coordinated effort to develop improved attenuation relations for horizontal ground motions based primarily on empirical ground motion data (1A03, 1L01–1L10b). NGA-E will continue to deal with issues of fault-normal and fault-parallel ground motions as well as attenuation of vertical ground motion. The next major phase, NGA-H, will involve a hybrid of empirical and simulation data. Additionally, the plan is to add new attenuation relationships for subduction earthquakes (relevant to northern California and the Pacific Northwest), vertical motions, and other "intensity measures" beyond elastic response spectra (e.g., duration, inelastic spectra, etc.).

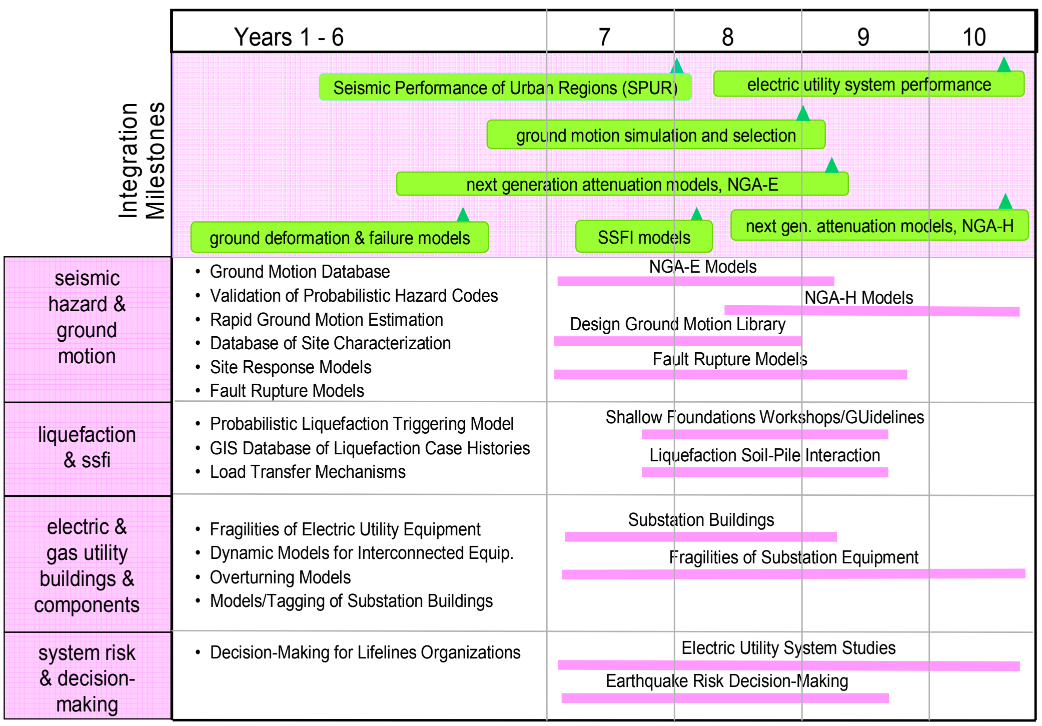

Figure 2.16 – Strategic plan: Thrust area III — Lifelines component and systems hazards

The results should significantly improve estimates for near-field and basin conditions through incorporation of emerging major advances in earthquake simulation. It will also add a "fling-step" model that accounts for relative timing of static offset motions with vibratory shaking. The fling-step model will be used in the practical analysis and design of facilities located close to active faults.

The second set of projects on ground motions will be the selection and scaling of ground motion records for nonlinear analysis. A specific project in this category is the Design Ground Motion Library (DGML). The project aims to develop convenient, standard, and transparent methods for the selection and scaling of earthquake ground motion histories for use in nonlinear dynamic structural analysis. The design application of nonlinear analysis for lifeline structures is expected to increase in the next several years, especially for cases involving near-fault locations, unusual structural geometries, or special details including energy-dissipation devices. Current selection procedures have proven unreliable, demonstrating the need for improved standard procedures. While this activity is being driven by the lifelines applications in TA III, the work will be coordinated closely with the other thrust areas where the same product is needed. Recent communications with other lifelines organizations in California revealed that besides Caltrans, other agencies may also co-fund this set of practical research projects.

An additional project on seismic hazard will develop a fault rupture model to improve our ability other lifelines crossing fault zones. The new design tools are being designed to account for the distribution of offset as a function of distance from the mapped fault, and to account for variations in mapping uncertainty, the distribution of slip along the fault strike, the likelihood of secondary faulting, and the size of the facility footprint. This work will be an extension of ongoing work that has established the fundamental methodology, and will provide an initial design tool for strike-slip earthquakes. This next phase will add a new model for reverse faults and improve on the Phase-1 model for strike-slip faults by better accounting for recognized zones of rupture complexity (e.g., fault bends, step-over zones).

In the area of soil liquefaction and SSFI, work will continue to improve our ability to predict earthquake ground deformation caused by liquefaction and to develop improved methods for evaluating the SSFI impacts of liquefaction deformations on bridge foundations and abutments. Earlier work in TA III included significant advances in predicting liquefaction demands and better SSFI modeling of loads imposed by liquefied ground. The liquefaction-demands research has yielded a comprehensive suite of triggering assessment techniques, demonstrated the potential for regional deformation mapping, and initiated work on improved prediction of lateral spread displacements. Related SSFI modeling research has provided unprecedented experimental data sets from both full-scale field experiments and a range of centrifuges and shake tables to serve as new constraints on numerical models. In the next phase, SSFI research will focus on synthesizing the array of experimental findings, filling remaining data gaps, calibrating numerical models, and developing practical design guidelines. Liquefaction demands research will focus on completion of improved displacement estimation tools.

For electric and gas utilities buildings and components, additional work is anticipated with substation buildings and equipment, as well as in preparing practical guidelines for utilities. A new element in this topic is technology transfer to disseminate the research finding to a wider engineering community. A series of open workshops will be conducted, followed by drafting and distributing practical guidelines. Additional private research funding from PG&E and Bonneville Power Administration (BPA) are being added to TA III for future seismic testing and analysis of electric components.

For TA III a new source of funding has been San Francisco Bay Area Rapid Transit (BART). Recently PEER signed a new contract with BART to the study seismic response of partially embedded structures. This will include centrifuge tests and analyses. The project will be concluded in Year 10, and the possibility of a follow-up funding will be explored.

2.5.3 TA III Critical Mass and Level of Effort

Since its inception, the lifelines portion of the program has involved researchers from both within and outside the Core Universities. In the case of the NGA projects, we have involved five of the leading attenuation relation developers; 1- and 3-D ground motion simulation experts from PEER, SCEC, and others; practicing engineering seismologists; and an international team of researchers providing data on ground motions and site conditions. In addition, the work has been guided by a series of two-day workshops involving typically 50–80 researchers and practitioners. Work on liquefaction and its effects on foundations has involved PEER researchers (e.g., Seed, Elgamal, Ashford, Boulanger) working in collaboration with international partners to leverage ongoing activities. Studies of earthquake-risk decision making will involve lifelines organizations and may be conducted by one of the researchers who has been active in another thrust area. Finally, work will continue to be conducted as part of the Tri-Center activity.

2.5.4 TA III Research Advances and Deliverables

PEER has made important advances in previous research in this topical area. We have assembled the premier strong ground motion database, consistently processed with detailed information on site, distance, and rupture mechanisms, and have made it widely available to the community online. The PEER strong motion database has been considerably expanded. The updated strong motion database is being linked to the PEER Internet website, where users can search and download the processed ground motion records as well as extensive information compiled on the source, path, and site condition. Progress in improving ground motion simulation techniques has enabled us to begin to fill gaps, especially for large magnitude and small distance. The USGS is currently reviewing the available NGA models for adopting into the next U.S. National Hazard Maps. The Maps include basic data for various seismic deign codes, including the IBC. Additional models will be submitted to the USGS in the early summer of 2006. This work will support ongoing studies in other thrust areas, as well as earthquake engineering research and practice worldwide.

In the areas of ground failure we have gathered and made available extensive data sets from laboratory and field research, which is providing a basis for new triggering models, some of which have been produced through PEER research, and result in significant reduction in uncertainty. We have gathered important data on the interaction between piles and liquefied flowing soils that will serve as a basis for continuing development in Years 9–10.

Research on utility components has produced standards for testing as well as fragility relations for critical equipment, overturning models, and models for equipment interaction, all of which are widely used by utility companies in the western U.S. Work on utility buildings has led to new concepts on building tagging, effects of aftershocks, and building evaluation that are currently being tested by practicing engineers.

Deliverables for the next phase of research have been described in Section 2.5.2, and include new attenuation models, liquefaction triggering models, models for SSFI for foundations in liquefied soils, and improved models for electric utility components and systems.

2.5.5 *TA III Future Plans*

The future plans for TA III follow directly from the strategic plan and milestones described in Section 2.5.2. Details of the funded projects will be determined by the level of funding and the decisions of the Joint Management Committee (JMC) working in collaboration with the PEER Research Committee. The PEER Lifelines Program research will continue beyond Year 10. For example, on July 2005, a new five-year contract was signed between PEER and the California Department of Transportation (Caltrans) for $2,250,000 funding. The new contract includes various topics ranging from ground motions to nonlinear site response to permanent ground deformations. In the near future, this contract will be likely amended to expand the level of funding and scope to include projects on nonlinear analyses of bridge structures. PEER is also signing a new contract with the California Energy Commission (CEC) to carry out a comprehensive technology transfer initiative for a wider engineering community, and a series of workshops and practical guidelines will be developed. PEER is also working on contractual details to get more funding from PG&E and Bonneville Power Administration (BPA) to study the fragility of components of electrical networks. This will provide an opportunity for PEER to collect more data and carry out tests for the fragility of nonstructural components. As of this time, the scopes of the next phase of long-term projects related to the performance of electric networks are still pending, as contractual negotiations are under way with the funding agency. It is anticipated that some of the future TA III studies will tie into the bridge, transportation, and Hayward fault scenario application study of TA II.

PEER Director Moehle and PEER Associate Director Bozorgnia are members of both the JMC and the PEER Research Committee. This ensures more coherent collaboration between TA III and the other thrust areas.

2.5.6 *TA III Publications*

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Chiou, B., Roblee, C., Abrahamson, N., and Power, M. 2004. The research program of next generation of ground-motion attenuation models. Geotechnical Special Publication No. 126, Geotechnical Engineering for Transportation Projects, *Proc. Geo-Trans 2004,* Los Angeles, CA, Geo-Institute of ASCE, V. 1, p. 768–77.

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Stewart, J. P., Goulet, C., Bazzurro, P., and Claassen, R. 2006. Implementation of 1D ground response analysis in probabilistic assessments of ground shaking potential, in *GeoCongress 2006 —Geotechnical Engineering in the Information Technology Age*, D.J. DeGroot, J.T. DeJong, J.D. Frost, and L.G. Baise (eds.), Atlanta, GA, Feb. 26–March 1, 6 pages (electronic file).

2.6 Thrust Area IV: Simulation and Information Technologies

2.6.1 TA IV Goals

A central requirement of PEER's research mission on performance-based earthquake engineering methodology is the need to simulate the performance of structural and geotechnical systems. The simulation models must represent the modes of behavior and types of damage that are ultimately important in framing decisions for stakeholders. There are substantial problems and open questions on how to model the highly nonlinear behavior of structural systems with degrading components, or soil undergoing large deformation because of liquefaction, and the interaction between foundations and soils during large deformation. To address these challenges, the rapid advances in information technology can be used in developing the next generation of earthquake engineering simulation applications and also in educating the next generation of earthquake engineers. These advances include high-end computers for solving large-scale problems; databases for searching for new information from experimental data, simulation data, or observed data such as ground motion and field data; and visualization technology for providing engineers, design professionals, and stakeholders understanding about the performance of their systems.

The goal of Thrust Area IV is to develop new simulation models and new methods for performance-based earthquake engineering assessment and design methodologies, to develop modern simulation software tools taking advantage of information technology advances, to deliver the software tools to the community, and to educate students in simulation methods and information technology applications in earthquake engineering. The goal of this thrust area continues through the re-organization of the research program in Year 7 with the application focus spanning building systems (TA I) and bridge systems (TA II). Lifeline systems are considered to a lesser extent, but provide a fertile future area, particularly as lifeline systems research moves toward consideration of lifeline networks. The incorporation of uncertainty in the simulations is essential, and the research in this thrust area has resulted in important developments in the methods and software for reliability computation.

The principal software technology to support all of these activities is the *Open System for Earthquake Engineering Simulation*, "*OpenSees*," which has enabled research on simulation and provided a platform for PEER participants and others to conduct advanced simulations. The *OpenSees* software framework uses object-oriented methodologies to maximize modularity and extensibility for implementing models for behavior, solution methods, and data processing and communication procedures. The framework is a set of inter-related classes, such as domains (data structures), models, elements (which are hierarchical), solution algorithms, integrators, equation solvers, and databases. The classes are as independent as possible, which allows great flexibility in combining modules to solve simulation problems for buildings and bridges, including soil and soil-structure-foundation interaction, and most recently including reliability computational modules. The open-source software is managed and made available to users and developers through the *OpenSees* website at http://opensees.berkeley.edu .

As an advanced platform for computational simulation, *OpenSees* provides an important resource for the National Science Foundation-sponsored George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES), and it has now been adopted by NEES Inc. and the NEES information technology services (NEESit) as the NEES simulation component. PEER will be providing the maintenance and operations for use of *OpenSees* in NEES through a subaward with UCSD's San Diego Supercomputer Center. The NEES decision to utilize *OpenSees* and incorporate it in the NEESit suite of services for earthquake engineering research will increase the user base and the range of simulation applications for the software. The modular design of *OpenSees* means that it can be customized for integrating physical and computation simulation through data repositories, visualization, and hybrid control for advanced experimental methods, all of which meet important NEES objectives. OpenSees has proven to be an excellent platform for a new generation of hybrid simulations—combination of physical testing and computational simulation—which will significantly enable new types of experimentation and collect valuable data about the seismic performance of systems. With the broader community support through NEES, *OpenSees* provides long-term opportunities that include: (1) improvement of model-based simulation using data from advanced experimental facilities, (2) extensions to include grid-based and other high-end computing for earthquake engineering, and (3) integration with structural health-monitoring systems using widely distributed MEMs sensors and processors.

2.6.2 TA IV Strategic Research Plan, Milestones and Deliverables

Figure 2.17 shows the strategic research plan for TA IV, emphasizing Years 7–10 and identifying the system-level integration milestones. The first six years of research in the thrust area were largely devoted to the development of new models and computational methods needed for structural and geotechnical simulation and implementation in the *OpenSees* software framework. The testbed projects in Years 5–7 provided an opportunity to expand the usage of *OpenSees*, identify problems as it was used for simulation in the building and bridge testbeds, incorporate improvements, and identify future research and development needs. *OpenSees* is currently in version 1.6.2, which was released in April 2005. As a result of much user experience within PEER and by the broader community, improvements have been made in solution robustness, testing combinations of element models and solution algorithms.

NEESit efforts are addressed by high-end computing and hybrid experimental methods using the simulation technology, and visualization, all of which are important for NEES. Additional capabilities will be released early in summer 2006 with the latest version of parallel solvers.

For Years 8–10, the strategic plan for TA IV is divided into three categories: Modeling, Simulation System and Platform, and Integrated Applications. These areas are described below.

Much of the model development and implementation research will be completed by the end of Year 9, leaving model validation to be completed in Year 10, including structural models for degrading cyclic behavior of RC components (including shear interaction in columns and joint behavior); improving models for low-cycle fatigue, bar buckling, and fracture; and understanding how these behaviors are affected by loading history. Year 10 modeling research will be on evaluating RC systems at incipient collapse and the validation of system models using experimental data such as from shake table tests. The other modeling thrust is to develop improved models for nonlinear response and soil liquefaction suitable for large-scale simulation, with substantial challenges in modeling SFSI for large-diameter shafts and bridge abutments to address needs in TA II. These two areas, among others, remain a topic for further experimental research and computational validation, and include major 3D response mechanisms that must be accounted for. The results of this research will provide insights that can translate into design revisions, with most significant economical outcomes (in view of the involved large expenditures on these two bridge components). Overall, the modeling research contributes to the milestones SFSI, *EDP-DM-DV* relations for building and bridge systems, and enhanced performance models.

The second category is Simulation System and Platform. Through the collaboration between PEER and NEESit, we will integrate *OpenSees* with the NEESit data repositories, which are currently being revised from the NEESgrid versions. This will provide *OpenSees* users the ability to access NEES data on experiments and simulation data, and to upload simulation results into the repository. In addition, we will address what has become an important need: providing integrated PBEE tools based on advanced simulation. To meet this strategic need, new projects are being initiated to focus on the application of advanced simulation using OpenSees for geotechnical systems, high-rise buildings, and bridge structures. These application studies will involve PEER's industry partners, who are leading efforts in improved simulation for engineering practice, and in developing projects for application of OpenSees to demonstrate its capabilities for difficult seismic projects. The goal of these is to both further develop the simulation tools while supporting a cadre of early adopters of these technologies from the practicing engineering community.

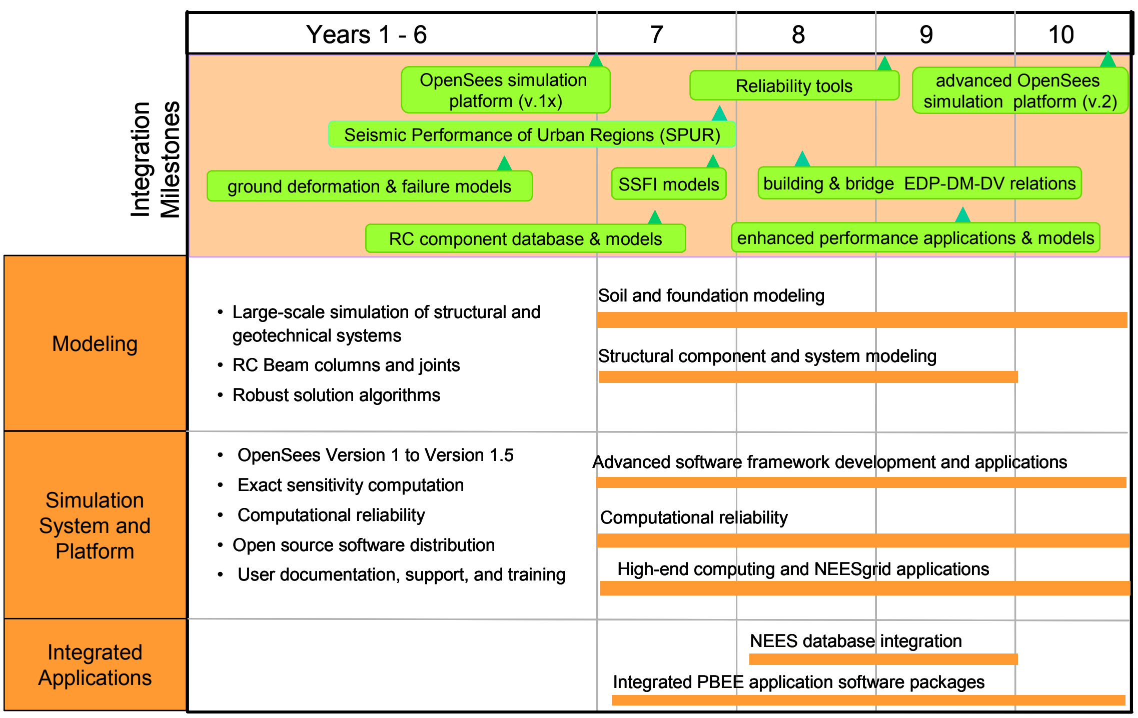

Figure 2.17 – Strategic plan: Thrust area IV — Simulation and information technologies

Finally, PEER will convene the first international symposium on OpenSees in summer 2007. This follows the annual OpenSees workshops and the successful developer symposium in 2005. The objective of the international symposium is to communicate and exchange the large amount of development and application of OpenSees over the past several years. Participants will submit papers and the proceedings will be published as a PEER report.

2.6.3 TA IV Critical Mass and Level of Effort

The research team for TA IV includes experts on modeling for reinforced concrete components and systems and geotechnical systems. For development of the software framework, several of the thrust area researchers have computer science backgrounds, and in many cases collaborate with computer scientists on research related to the simulation framework. As the simulation methods are being used in the bridge and building testbeds, PEER researchers and industry partners are providing feedback on the effectiveness of the research products in simulation and the usefulness of the databases. Many of the graduate students conducting research in the thrust area are taking courses in computer science, generally as a minor program of study. This breadth of graduate education in computer science is unusual in earthquake engineering, and it has brought new technology and computer science methods into the PEER research program.

Over the past three years, we have developed important collaborations with the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). The NEES system integration project has selected *OpenSees* as the simulation component for the NEESgrid. In addition to the core simulation capability, PEER is contributing to the development of data models for simulation data for use in the NEESgrid data repositories, a web-based portal for simulation services, and porting of *OpenSees* to grid-based computing resources. In collaboration with the NEESit group at the UCSD Super Computing Center, the *OpenSees* development team at UC Berkeley has a contract with the NEES Consortium to provide ongoing maintenance and operation of the simulation component. This support, along with PEER's continuing commitment to simulation and information technology, will expand the users and development opportunities for *OpenSees*.

2.6.4 TA IV Research Advances and Deliverables

Highlights of accomplishments in Year 9 include:

- Soil-foundation-structure interaction in bridge systems, including deep foundations in liquefiable soil and new research on shallow foundations.
- Component models for reinforced concrete with an initial examination of damage measures for performance evaluation. A new plastic hinge model that provides objective response for degrading behavior.
- Simulation for reliability computation, including exact computation of response gradients for highly nonlinear systems.
- Database applications to support simulations for the bridge and building application (testbed and benchmarking) projects.
- Completion of a collaboration with seismologists and computer scientists to develop an integrated methodology for understanding the Seismic Performance of an Urban Region (SPUR).

- Application of *OpenSees* to hybrid experimental-computational simulation, including use of grid-based communication, and demonstration of a hybrid test at the University of Kyoto as controlled by OpenSees running at UC Berkeley.

Over the past three years, significant effort in the thrust area has been devoted to the support of the simulations in other PEER projects using *OpenSees*. The support entailed the following activities: (a) training of students and researchers on *OpenSees*; (b) improvement of *OpenSees* user documentation; (c) assistance with development of models and scripts; (d) responding to bug reports and technical assistance; and (e) review and feedback of experience with *OpenSees* models, facilities, and computational efficiency.

In combination with application studies of TA I and II, *OpenSees* models are being evaluated against test data from large-scale experiments. In one case, soil continuum models for simulating ground deformations are being evaluated against a large-scale test in Japan, where explosives were used to trigger liquefaction in a test field containing pile foundations and a buried pipe (Ashford 2342003). In another case, *OpenSees* frame models have been validated against a full-scale pseudo-dynamic frame test, results of which are made available through collaboration with the National Center for Research in Earthquake Engineering (NCREE) in Taiwan (http://rcs.ncree.gov.tw/). In several TA II projects, simulation results from *OpenSees* are being extensively compared and validated against data from previous and ongoing tests of RC beam-columns (Mahin 2402004, Billington 2462004, and Eberhard 2452004); and in TA I, shallow foundation models have been implemented and compared to centrifuge test data (Hutchinson and Kutter 1352004).

Year 9 has seen the completion of a number of efforts for the models and computational features of *OpenSees*. A range of hierarchical models for beam-column elements is now available, including flexure, axial, and shear effects (Fenves and Filippou) and generalized hinges (Deierlein). The models include material and component behavior for cyclic degradation and large-displacement analysis. To support reliability and other applications, a new efficient algorithm for computing the response sensitivity for force-based elements has been developed and implemented (Fenves and Filippou). In addition, a beam-column element using force-based interpolation has been developed that is objective under degrading behavior, which had been an open problem. To solve large-scale systems with degrading components, a new quasi-Newton solution method based on a Krylov subspace has proven to be very efficient and robust when used in the testbed projects. New models under development include reinforcing bar buckling (Kunnath 4232004) and improved building collapse analysis (Mosalam 4252004).

Continued progress has been made with integrating reliability computation into *OpenSees*. Der Kiureghian has extended the first-order reliability method, and many of the element and material models now support direct differentiation for computing response sensitivities for reliability computation. The research has also made progress on importance sampling for Monte Carlo simulations and extending a library of distributions and correlation structures for random variables. Conte has used these methods to begin probabilistic evaluation of the Humboldt Bay bridge with the completion of a complete model of the SFSI system. In addition, significant sensitivity analysis procedures have been developed this year for a class of nonlinear plasticity-based soil models for seismic applications. Progress on these projects responds to concerns raised in previous years' site visit reports about the need in *OpenSees* for reliability tools that facilitate application of the PEER PBEE methodology and are not generally available in other earthquake analysis software.

2.6.5 TA IV Future Plans

Support and continued development for *OpenSees* will continue as a high priority, given the central role *OpenSees* plays as an enabling technology in PEER. During Year 10, the substantial progress in OpenSees software will be integrated into the framework (Fenves 4102004). Version 2.0 will include advanced capabilities using the parallel computing resources at SDSC.

Model development for RC members will continue with cyclic degradation of RC members including low-cycle fatigue (Kunnath 4232004). There will be increased focus on RC building systems, with new research on simulation for incipient collapse (Mosalam 4252004) and validation of system models using shake table data (Moehle 4282004). For geotechnical models, Elgamal (4242004) will begin research on modeling and simulation of large-diameter pile shafts and abutments for bridge systems, and Jeremić (4262004) will develop coupled (solid-fluid) models for liquefiable soils and large-scale simulations. These efforts integrate the structural and geotechnical elements of *OpenSees* and address topical challenges in seismic SFSI research. Conte (4132004) will conduct such integrated studies (PBEE framework applied to the Humboldt Bay bridge Testbed), and further introduce sensitivity analysis tools for geomechanics applications.

Computational reliability research will continue with Der Kiureghian (4142004) beginning research on non-ductile systems based on the completion of methods for ductile systems, and Conte (4132004) developing reliability methods for large-scale models of SFSI systems.

Finally, we will have news application impact projects (4272005) to demonstrate the OpenSees capabilities for geotechnical systems, buildings, and bridges. BIP members will be identified to carry out these projects. PEER expects that these projects will substantially speed the adoption of OpenSees in earthquake engineering practice. To communicate the developments of OpenSees, an international symposium will be held to disseminate recent work and discuss future directions.

2.6.6 TA IV Publications

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3 EDUCATION PROGRAM AND PRE-COLLEGE OUTREACH

3.1 Strategic Education Plan, Methodologies, Milestones, and Deliverables

The Education Program is designed to introduce, stimulate, cultivate, and educate undergraduate and graduate students with the knowledge that will enable them to contribute to the earthquake-engineering profession from a variety of disciplines and perspectives. The program attracts students to earthquake engineering early in their academic careers and aims to retain them through graduate study. While the principal audience of the Education Program is undergraduate and graduate students, K–12 students also benefit directly from the program. PEER's Education Committee, composed of representatives from all nine Core and six Educational Affiliate Universities, is charged with planning and implementing the program.

Several specific programs have been instituted. Our overall objective is to build a culture within PEER, starting at K–12 and extending through graduate school, where students are excited about earthquake engineering learning and realize the need to contribute to the learning of others. Figure 3.1 illustrates the overall strategic plan with focus areas and milestones. Programs and deliverables cover the range from K–12, undergraduate students, and graduate students. Detailed descriptions of programs and projects are provided in subsequent sections of this chapter.

Table 3.1 – Leaders of the Education Program

Name	Affiliation	Role
Scott Ashford	UC San Diego	Edu. Director
Pedro Arduino	U Washington	Edu. Committee
James Beck	Caltech	Edu. Committee
Nazaret Dermendjian	CSU, Northridge	Edu. Committee
Tara Hutchinson	UC Irvine	Edu. Committee
Erik Johnson	USC	Edu. Committee
Amit Kanvinde	UC Davis	Edu. Committee
Abraham Lynn	Cal Poly, SLO	Edu. Committee
Kurt McMullin	San Jose State U	Edu. Committee
Eduardo Miranda	Stanford	Edu. Committee
Jack Moehle, *Ex Officio*	UC Berkeley	Edu. Committee
Khalid Mosalam	UC Berkeley	Edu. Committee
Ian Robertson	U Hawaii	Edu. Committee
Jonathan Stewart	UC Los Angeles	Edu. Committee
Mark Tufenkjian	Cal State U LA	Edu. Committee
Solomon Yim	Oregon State U	Edu. Committee

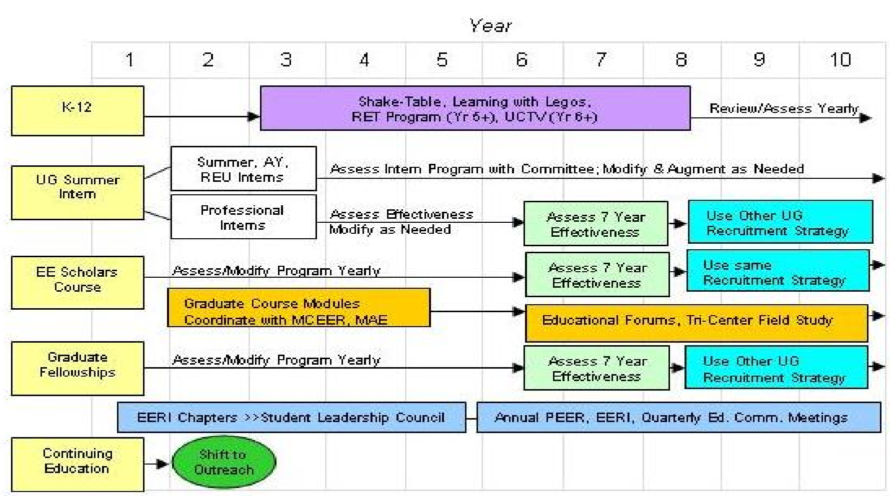

Figure 3.1 – Education Program strategic plan

3.2 Current Education Projects and Curriculum Innovations

3.2.1 Current Education Projects

3.2.1.1 PEER Summer Internship Program

The ***PEER Summer Internship Program*** is intended to interest, attract, train, and retain promising undergraduates who have expressed an interest in earthquake engineering research. Each student works under the direction of a PEER faculty mentor over a period of ten weeks in the summer on a PEER-funded research project, and submits a report during the fall term detailing the research experience. During the past eight years, PEER sponsored participating students to attend the EERI annual meetings in St. Louis, Portland, Los Angeles, and Ixtapa, Mexico, and this year in San Francisco at the 100th Anniversary Conference of the Great San Francisco Earthquake. Prior to a Friday evening reception, students present posters about their summer research experience in an informal setting, while interacting with practitioners and academics in earthquake engineering. PEER's internship opportunities provide students with experience in hands-on individualized laboratory and field research, and increase opportunities in academia and professional practice. The students who participated in the PEER Summer Internship Program during summer 2005 submitted their final research reports on November 1, 2005. The Education Program is currently recruiting 15 students to participate in the PEER Summer Internship Program during summer 2006.

Figure 3.2 – PEER summer interns at the 2005 EERI Annual Meeting in Ixtapa, Mexico

3.2.1.2 Research Experience for Undergraduates Summer Internship Program

In a program that parallels the PEER Summer Internship Program, the ***Research Experience for Undergraduates (REU) Summer Internship Program*** sponsors PEER students working at an institution other than their home campus, or students from campuses outside the PEER consortium, to work on PEER-funded research projects mentored by a PEER faculty member. In addition to the research experience, the REU program offers a one-day Communication Skills Workshop for the faculty to assist interns with oral and written reporting skills. The workshop affords them the opportunity to discuss their ongoing research experience with other engineering and earth science students. The impact of the workshop is evident in the superior quality of the REU students' oral presentations and written reports submitted during the fall term following their internship.

Figure 3.3 – 2005 Tri-Center REU Symposium for Young Researchers held in Reno, Nevada

The REU program also provides an opportunity to meet REU students from the other EERCs and thereby learn how earthquake engineering is perceived in other parts of the U.S. In August 2005, REU students from MAE, MCEER, and PEER met in Reno, Nevada, for a lively discussion of ethics in engineering, as well as an opportunity to hone their presentation skills in PowerPoint to relate their summer research experience to the group.

The PEER Education Program is currently recruiting seven students, focusing on those from groups historically underrepresented in the field, for the summer 2006 REU program. The 2006 REU Symposium for Young Researchers, to be organized by PEER, will be held in Bend, Oregon.

3.2.1.3 Earthquake Engineering Scholars Course

PEER's Undergraduate ***Earthquake Engineering Scholars Course*** (EESC) is a program implemented to showcase the graduate programs at PEER core institutions and to introduce high-ranked undergraduate students to four topics in the field of earthquake engineering including seismology, geotechnical engineering, structural engineering, and public policy. The fall 2005 EESC provided instruction to 30 students from 11 PEER universities during four weekend retreats at PEER campuses [UC Davis (Geotechnical Earthquake Engineering), U Washington (Seismology), USC (Structural Engineering), and UC Berkeley (Public Policy)]. These individual topics were the primary focus of each of the four weekends; however, the students commented on the faculty's success in developing a connection among the four topics that united the course overall and provided the students an opportunity to explore many facets of the earthquake engineering profession. Starting with the 2002 program, the Education Committee invited at least one PEER Business and Industry Partner member to present during each of the retreats. For example, at UC Berkeley, several young BIP engineers gave the PEER Scholars tours of campus seismic retrofit projects, described engineering drawings and engineering practices, and shared experiences about going from school to professional practice. The schools also used the opportunity to conduct tours and "show off" their laboratories and facilities. An objective of the course is to recruit new talent to the field of earthquake engineering. Most students who participate in the program go on to pursue graduate study, often at a PEER institution.

Figure 3.4 – 2005 Earthquake Engineering Scholars Course weekend held at the University of Washington

3.2.1.4 Tri-Center Earthquake Field Study Program for Students

The ***Tri-Center Earthquake Field Study Program for Students*** is an effort, started in May 2002, that focuses on earthquake reconnaissance experience for PEER students. Each summer this project brings graduate students together from MAE, MCEER, and PEER to conduct post-earthquake investigations during a weeklong summer camp at a non–U.S. site. The "new blood and experience" that are gained not only broaden the students' experiences but also train students for future earthquake reconnaissance in programs such as the EERI Learning from Earthquakes Program. The participating students are drawn from a variety of institutions and disciplines. Each student is required to issue a formal reconnaissance report following the field investigation. In October 2003, three PEER students took part in the Italy Earthquake Field Study.

In July 2004, five PEER students, along with two teachers from the Research Experiences for Teachers (RET) Program, joined their counterparts from MAE and MCEER for a field study in Japan. Students from the Southern California Earthquake Center (SCEC) also participated. This Year 7 program was led by PEER and was an outstanding success. Graduate students, teachers, and faculty joined together for tours of beautiful earthquake engineering research facilities in Japan, including the Building Research Institute, the Public Works Research Institute, and the E-Defence Shake Table in Miki, as well as participated in joint U.S.-Japan lecture series at Waseda University and Kyoto University. The PEER students were required to prepare a PowerPoint presentation on the comparison of U.S. and Japan experimental facilities, which was then presented at their home institutions. Perhaps the biggest impact from this field study comes from the bonds formed between the future faculty from the three U.S. EERCs and their counterparts in Japan. This should accomplish a great deal for future international collaboration.

Figure 3.5 – PEER participants in the 2004 Tri-Center Field Study at the Hanshin Expressway Earthquake Museum in Kobe, Japan

In July 2005, MAE organized the Tri-Center Earthquake Field Study to Greece, where the students visited Aristotle University of Thessaloniki, National Technical University of Athens, and the University of Patras. They also toured the Rion-Antiron bridge in Patras.

Figure 3.6 – 2005 Tri-Center Earthquake Field Study participants at the Rion-Antiron Bridge in Patras, Greece.

3.2.1.5 Student Leadership Council

PEER aims to create an environment in which students learn leadership and management skills through independent student organizations. In PEER's first years, we encouraged formation of EERI Student Chapters, with chapters now located at Caltech, Oregon State, San Jose State, Stanford, UC Berkeley, UC Davis, UC Irvine, UC San Diego, and the University of Washington. Starting in Year 2, PEER formed its ***Student Leadership Council*** (SLC) and ***PEER Student Association*** (PSA). Both undergraduate and graduate student representatives on the SLC, from the core and affiliated campuses, provide an active and valuable voice for all PEER students. Over the past six years, PEER's SLC has been an influential contributor to the PEER Education Committee and PEER Administration concerning the needs of undergraduate and graduate students. The SLC president attends each of the Education Committee's quarterly meetings to provide feedback and input on PEER programs. The SLC conducts its own quarterly meetings, which are scheduled to coincide with other PEER Research and Education events to maximize opportunities for networking and discussion. PEER's fifth Student Day, held concurrently with the PEER Annual Meeting in February 2004, was an excellent forum for students to share their intellectual and personal experiences as participants in PEER. The event includes meetings of the SLC and other students, formal poster sessions, and presentations by PEER students and Business and Industry Partners.

To increase the visibility of PEER among undergraduates, the SLC planned a new form of outreach to undergraduates through an **Undergraduate Seismic Design Competition**, in which multi-story balsa wood structures are tested on the Educational Shake Tables. Competitions have been held in 2004, 2005, and 2006. This year, the third annual competition was held in conjunction with 100th Anniversary Earthquake Conference in San Francisco. In addition to teams from PEER schools, MAE and MCEER sent teams. The event was a huge success, drawing large and enthusiastic crowds of students and earthquake professionals.

Our SLC is also active in PEER's K–12 outreach efforts. In 2005, PEER sponsored the SLC's Curt Haselton (Fig. 3.7) to participate in *Minds in Motion*, a K–12 event at California State University, Chico. Nearly 4000 K–12 students and teachers from 63 different Northern California schools learned about opportunities in science and engineering. PEER set up a booth to teach the students about earthquakes and "what structural engineers do to make our buildings safe." The kids learned first hand what it means to be a structural engineer by constructing a building on the shake table, then watching as the building was "put to the test" of an earthquake. In 2006 our SLC President, Judy Mitrani-Reiser (Fig. 3.8), participated in PEER's outreach by working with 70 middle school girls from the Pasadena area who visited Caltech for the "Introduce a Girl to Engineering Day."

Figure 3.7 – K–12 students visit California State University, Chico, for the "Minds in Motion" event.

Figure 3.8 – Middle school girls visit Caltech for an outreach event called "Introduce a Girl to Engineering Day."

3.2.1.6 Tri-Center Ph.D. Candidate Exchange

The ***Tri-Center Doctoral Candidate Exchange,*** a program that started in Year 6, sends two PEER graduate students nearing completion of their doctorates to give lectures at MAE and MCEER, while PEER welcomes two students for lectures from each of these centers as well. In Year 7, Kevin Mackie (UC Berkeley) gave a presentation of his work on fragility and performance-based seismic design of bridges at Georgia Tech, and Bryant Nielson (Georgia Tech) gave his talk on his research at UC Berkeley. Georgia Tech broadcast Kevin Mackie's presentation on the Internet. The program provides valuable speaking opportunities for advanced students and exposes research among the three centers in ways that otherwise would not occur. This spring Curt Haselton (Stanford University) will give a talk at MAE's University of Illinois, Urbana-Champaign on the performance of code-conforming reinforced concrete buildings in a major earthquake. Stanford University will host Jun Ji (MAE/University of Illinois, Urbana-Champaign) who will speak on the probabilistic fragility analysis of highrise buildings.

3.2.1.7 PEER Business & Industry Partners (BIP) Fellows Program

The PEER **Business & Industry Partners (BIP) Fellows Program** is aimed at increasing contacts between our students and practicing professionals by bringing in industry experts for a day of seminars and student-practitioner meetings. In Year 9 we hosted two BIP fellows. In February 2006, Farzad Naeim, vice president and general counsel for John A. Martin & Associates of Los Angeles, California, visited California Institute of Technology. He spoke of the debate on whether more rigid or more flexible buildings fare better during earthquakes, and also on automated post-earthquake damage assessment of buildings. Ronald L. Mayes, Ph.D., of Simpson, Gumpertz and Heger visited Stanford University in March 2006 for a one-day meeting with students and made a presentation on performance-based earthquake engineering.

3.2.2 Curriculum Innovations and Tools

PEER has encouraged and coordinated several curriculum development activities, including:

3.2.2.1 Teaching Modules for Graduate Students

Initiated as a Tri-Center activity, this project has created a series of self-contained, web-based, graduate-level teaching modules. The modules include materials on various subjects and may be shared by a variety of academic institutions that do not have resident expertise in specialized subjects pertaining to earthquake engineering. The modules consist of written text, specifications for experiments, visual materials, and supplementary web information. Modules have been commissioned for the following areas: *Fluid Structure Interaction, Wave Propagation; Earthquake Engineering Design; Seismic Ground Motion and Hazard, Seismic Upgrading: A PBE Case Study, Seismic Behavior of Timber Structures; Earthquake-Resistant Design; Liquefaction; Socioeconomic Aspects of Earthquakes; Putting a Face on Earthquakes: The Human Side of Earthquake Disasters; and Seismic Design of Diaphragms, Chords, and Collectors*. In the early phases of this program, each center was to produce at least one module per year on different aspects of earthquake engineering and hazard-related studies. An inter-center task force of faculty and professional earthquake engineers selects the module topics in consultation with the other two centers. SLC input has been solicited during the beta-testing of each module. Currently many of the modules are being evaluated and distributed for use. Three modules are currently posted on the PEER education website for use by the public: *Wave Propagation, Earthquake-Resistant Design,* and *Interactive Web-Based Learning Modules for Seismic Behavior of Timber Structures.* The three EERC Education Directors have plans to place all earthquake modules on a common website.

3.2.2.2 Instructional Earthquake Simulators

In an effort to increase students' knowledge of earthquake engineering through hands-on experiments, the three EERCs have organized a program for deployment of small earthquake simulators specifically designed for use in a classroom setting. Twenty-three institutions drawn from the three EERCs cooperated in the design of a bench-scale shake table. The initial acquisition was partially supported by an NSF grant and other private funding, and has grown to a consortium of over 40 institutions known as ***University Consortium for Instructional Shake Tables*** (UCIST). The equipment is used to integrate earthquake engineering into the undergraduate curriculum. Classroom demonstrations and "hands-on" experiments are conducted at all levels in order to have a significant impact on the curriculum. In addition, the shake tables are displayed and demonstrated at public awareness events, including state fairs, primary and secondary schools, and local community disaster-preparedness programs. In Year 6 (and beyond), the SLCs from the three centers have been developing plans for two nationwide competitions in earthquake-resistant design: one for undergraduates and one for elementary school children. Also in Year 6, these mini-shake tables were used by middle-school students and teachers through PEER's RET program for demonstrations and for carrying out experiments for science fair projects. These tables will also be used for the Undergraduate Shake Table Competition being organized by our SLC.

3.2.2.3 Curriculum Changes from PEER Activities

PEER is seeking ways to incorporate its research activities into our earthquake engineering curricula. We recently surveyed PEER institutions and found that several new and modified courses have been implemented as a direct result of PEER research. Most encouraging is the widespread adoption of these courses within PEER. One new course is now taught at four PEER universities, and one modified course is taught at six PEER universities. Two examples of classes that have been significantly and positively impacted by PEER research are described below.

- **Earthquake-Resistant Design of Structures (CE 227)** is a major component of the graduate curriculum at UC Berkeley attended by 40–60 graduate students and visiting scholars. The curriculum for this course has changed significantly in the past five years because of activities within PEER. An online course module was developed by PEER covering many aspects of the course, including the PEER PBEE methodology. In addition to containing course-related notes, the module contains a number of Java applets that allow students to rapidly assess the characteristics of ground motions expected at a site, and the effects of differing amounts and types of nonlinearity of structural response. In addition to facilitating the underlying complex computations, these applets allow students to do a lot more "what-if"-type comparisons so that they can begin to develop a better intuitive understanding of the effects of ground motions on structures. In this regard, a computer program BISPEC, partially funded by PEER, has been extensively utilized in class. This program simulates the inelastic response of simple structural systems to up to two horizontal components of ground motion. With its rich graphical interface, students conduct a large number of nonlinear dynamic analyses to assess the effects of various factors such as strength, stiffness, viscous damping, shape of hysteretic loops, geometric nonlinearities, and so on, and develop design response spectra considering the methodologies being developed by PEER. The PEER ground motion database is used extensively in completing classroom assignments. Last, numerous examples of structural response of more complex systems are presented in the course based on results obtained using the PEER-developed OpenSees computational framework. In completing the final design project for the course, a number of students use OpenSees to carryout their analyses.
- **Case Studies in Seismic Design (Architecture 259X)** is a new course (spring 2003) in the Department of Architecture at UC Berkeley. It takes advantage of the campus retrofit program and the PEER Center's studies of PBEE. The class has a mix of students from

Architecture and Civil Engineering. The class introduces the students to performance design principles and requires that each student undertake a case study of the retrofit design of one of the UC campus buildings. The students are investigating the history of the campus program in terms of campus policy and design precedents. In addition, for each case study, they review the design goals, performance objectives, and methods of retrofitting a major building. Collectively, the student work is the basis for a guide to the seismic retrofit program on the Berkeley campus, published to commemorate the 100-year anniversary of the 1906 San Francisco earthquake.

3.3 Progress on Future Plans

In Year 9 and beyond, PEER will continue those programs that have served students well, including the *PEER Summer Internship Program*, *Earthquake Engineering Scholars Course*, *REU Program* (including *Symposium for Young Researchers*), *Student Leadership Council*, *Tri-Center Doctoral Student Exchange, and the Tri-Center Earthquake Field Study*.

While we have implemented several new programs in the recent past, and are busy supporting those, we are still interested in pursuing additional new programs in the near future such as

- ***Earthquake education on UCTV:*** PEER is continuing work with UCTV on developing an Earthquake Education segment that would combine on-demand video and narrowcasting from the PEER Education website, together with broadcasting on UCTV via satellite to reach a broader audience. The pilot for this series is completed and has been broadcast several times in the Greater San Diego Area, and is available online at http://peer.ucsd.edu. The next segment is planned to focus on the Year 9 Undergraduate Shake Table Competition, being held in conjunction with the 8th National Conference on Earthquake Engineering, in recognition of the 100th anniversary of the Great 1906 San Francisco Earthquake. While originally planned as a PEER activity, the three EERC Education Directors have discussed making this another Tri-Center Collaboration.
- ***Increased diversity in student programs:*** PEER has aimed to increase the diversity of students in earthquake engineering, and we are making progress. For the third year, we have added "overcoming adversity" in addition to "academic preparation" as criteria for PEER Summer and REU Internships. We have also increased our visibility to students from traditionally underrepresented groups and undergraduate students in general. In Year 8, a significant accomplishment in this direction was to add two new Education Affiliate universities to PEER—California State University, Los Angeles, and California State University, Northridge—both Hispanic-serving institutions. Other examples of our efforts include directly emailing ASCE student chapters at universities serving underrepresented populations, and sponsoring an information table at a statewide Undergraduate Research Symposium sponsored by the Louis Stokes California Alliance for Minority Participation held at UC Irvine in February 2005. These efforts seem to be making a difference. We have twice the number of internship applications as in previous years, as well as a diverse applicant pool. We continued these efforts with the Earthquake Engineering Scholars Course, including "overcoming adversity" as a selection criterion, as well as making more space available to students outside the PEER Core Universities, including students from our new Education Affiliate Universities.

4 INDUSTRIAL/PRACTITIONER COLLABORATION AND TECHNOLOGY TRANSFER

4.1 Strategic Plan for Industry/Users Collaboration, Outreach, and Technology Transfer

The close collaboration between government, industry, design professionals, and other end-users of PEER products and knowledge is key to the success of the PEER program. These participants help identify and fill gaps in current knowledge; aid in the development and funding of sector-directed research programs; provide critical review of the strengths, weaknesses, opportunities, and threats relative to the PEER program; and facilitate timely and cost-effective outreach and technology transfer. Therefore, we have endeavored to develop an effective program with appropriate government and industry partners.

Figure 4.1 presents the PEER strategic plan for collaboration and technology transfer to industry, practitioner, and government groups. This plan has developed continuously since its introduction in Year 2. The PEER strategy of collaboration is to seek out and engage key players in the government, industry, and business sectors that will be adversely impacted by earthquakes; earthquake professionals with valuable experience in earthquake mitigation that will benefit from enhancing their professional expertise; and organizations with existing earthquake outreach and technology transfer programs that can benefit from technology transfer collaborations with PEER. Part of this strategy is to identify the needs and requirements (Fig. 2.1) for PEER research, including practical delivery mechanisms that can be utilized by the end-users. Another part is to engage practicing professionals with researchers, including students, to enhance the research experience and create lasting partnerships between practitioner and researcher. A third essential part of this strategy is to identify and develop relationships that result in funding of

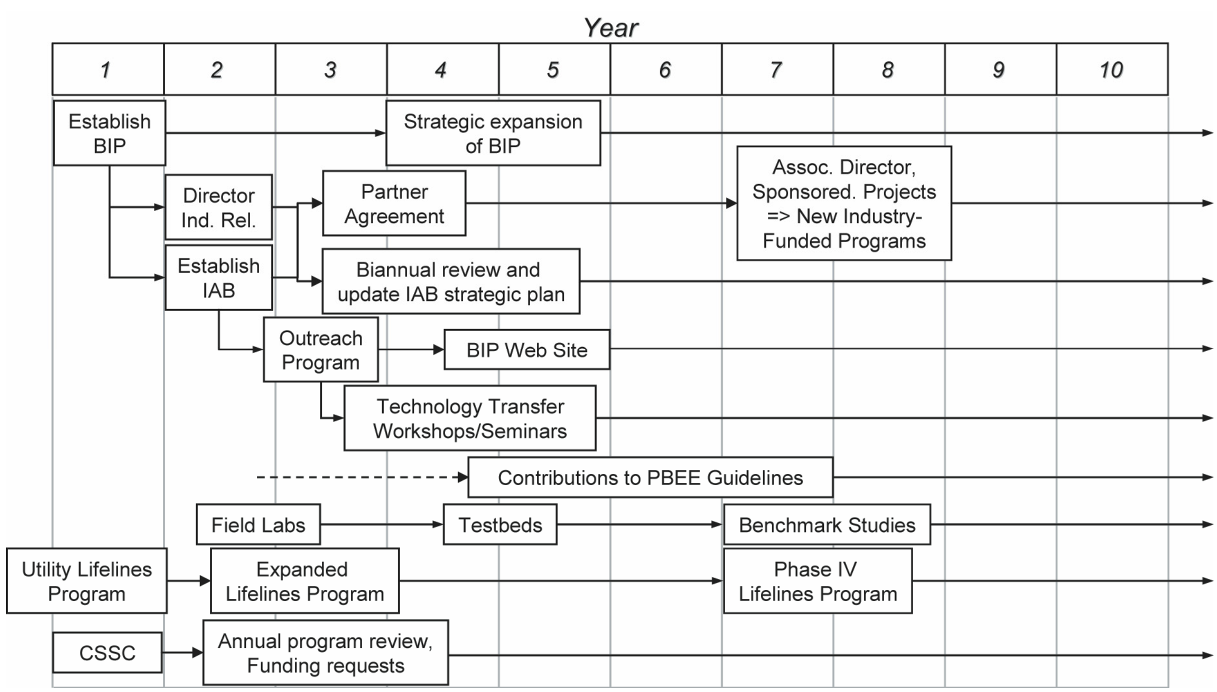

Figure 4.1 – Strategic plan for industrial/practitioner/government collaboration and technology transfer

PEER research and technology transfer programs, with a goal to secure long-term funding to sustain the Center.

With reference to Figure 4.1, the first step in the implementation of our strategic plan was the establishment in 1998 of the Business and Industry Partner (BIP) Program as a mechanism for enhancing the relevance of PEER research. When PEER was reorganized under the NSF ERC program in 1999, PEER formed the Implementation Advisory Board (IAB) as a select group of partners to formalize the review of our research and technology transfer activities.

PEER established the position of Director of Industrial Relations in 1999. Dr. Andrew Whittaker (now Professor at the State University of New York, Buffalo) initially held that position. Following his departure from PEER, this function was temporarily overseen through a combined effort of PEER's Director (Prof. Moehle), Director of Public Relations and Outreach (Mr. Vaziri), and Lifelines Program Manager (Prof. Riemer). In mid-2003, Prof. Riemer returned to his academic position in the Department of Civil and Environmental Engineering at UC Berkeley. In early 2004, we successfully recruited Dr. Yousef Bozorgnia into the newly defined position of Associate Director. Dr. Bozorgnia's responsibilities include development and management of externally funded research programs, and translation and transfer of research results to industry and government partners.

Another important development has been the establishment in Year 3 of the Office for Public Relations and Outreach. Mr. Parshaw Vaziri had the responsibility of managing public relations and outreach until late March 2005. Recently, PEER successfully recruited Ms. Debra Jacob as the new Manager of Communications and Outreach. Ms. Jacob brings to her position several years of marketing communications and PR experience in the engineering field. She has managed communications programs for Carnegie Mellon University's College of Engineering and research centers, Bayer Corporation's Automotive Polymers Division, and the Society of Automotive Engineers (SAE). The outreach program supports a range of functions. It fosters communications within PEER, between PEER and the University, and between PEER and the outside community. In its public relations capacity the office ensures that inquiries are answered promptly and that news releases are prepared regularly and distributed widely. It organizes workshops, seminars, and meetings for a wide audience. Finally, it is responsible for creating web-accessible information for our BIP members, providing access to research results and students.

One of the major objectives of the program is to establish sustained government and industry funding to the PEER research program. On the government side, we have worked continuously with the California Seismic Safety Commission (CSSC) to keep them informed of PEER activities and to keep PEER informed of needs within the State. The CSSC is an important link to the State for the purpose of maintaining the existing State matching funds and for identifying new initiatives that may lead to additional funding. PEER works regularly with the CSSC to update its *California Earthquake Loss Reduction Plan*, thereby ensuring that PEER has a voice in the research and outreach directions of the State. The CSSC prepares written progress reports on PEER to the State legislature, and with those makes funding requests to sustain and grow the PEER program.

On the industry side, we established in 1997 a program known as the Utility Lifelines Program (see Chapter 2 for additional details). The Utility Lifelines Program originally was funded by the Pacific Gas & Electric Company (PG&E). Recognizing the need to expand the scope and funding base of the program, we worked with PG&E managers to propose and secure additional funding from the California Energy Commission (CEC). This was further expanded in Years 2–5 to include funding from the California Department of Transportation (Caltrans) and Federal Emergency Management Agency (FEMA). Given the expanded focus of the program, we have renamed it the "Lifelines Program." The previous funding from CEC was programmed until June 2004. Currently PEER and PG&E are working on a proposal to be submitted to CEC for the next phase of the program. Also, a new five-year contract with Caltrans is being negotiated.

To provide guidance for the next phase of the Lifelines Program, we have assisted in re-establishing the Inter-Utility Seismic Working Group (IUSWG), with membership including Bob Anderson (CSSC), Craig Riker (SempraUtilities), Denny Ostrom (Consultant), Don Willoughby (PG&E), Ed Matsuda (BART), James Wight (SempraUtilities), Leon Kempner (Bonneville Power), Pete Aguila (Southern California Edison), Phillip Mo (Southern California Edison), Ron Tognazzini (LADWP), and Woody Savage (USGS). We have convened two meetings of the IUSWG, in which they have served as the Lifelines Advisory Panel, reviewing our program and making recommendations on future research directions. Recently, the California Energy Commission (CEC) has formed an advisory panel, consisting of several members of IUSWG. The panel advises the Commission on technical issues and funding. Thus, both PEER and CEC are benefiting from the industry experts to form the future plan of applied research on seismic performance of electric components and networks. PEER finished a project with the California Earthquake Authority (CEA) (which provides residential earthquake insurance in California) to fund a program to assess the methods used to set rates. We have successfully completed a $250,000 contract with CEA. The scope of the project was to independently evaluate CEA's methodology for seismic loss estimation of California's insured properties. We are pursuing continued funding from CEA, especially to provide as-needed expertise on various seismic issues. PEER is also exploring external funding from other organizations. For example, we have signed a new contract with the Bay Area Rapid Transit (BART) to carry out a research project on seismic response of partially embedded structures. Additionally, we are contracting with the CEC to carry out for a wider engineering audience a comprehensive technology transfer on the seismic performance of electric components and buildings. PEER is also amending the existing contract with Pacific Gas and Electric Company (PG&E) to increase the level of funding from PG&E to carry out fragility analyses and experiments for electric equipment and components.

An important development in Year 4 was the formalization of the Business and Industry Partner Agreements. In the past, the agreement was an informal written agreement between the BIP partner and the PEER Center. In Year 4, PEER worked with the Implementation Advisory Board, the University of California Sponsored Projects Office, and the National Science Foundation to formalize the agreements to meet NSF and University requirements. Generic language for the agreements including rights and privileges of all parties was approved in April 2001. The new agreements formed the basis for membership in the BIP program starting in 2001.

The PEER leadership has aimed to contribute to the continued development of performance-based earthquake engineering guidelines and regulations. As part of our strategic plan, we have maintained close working relations with organizations responsible for such developments, including the Federal Emergency Management Agency (FEMA) and the Applied Technology Council (ATC). In 2001–2004 we collaborated with ATC/FEMA in the development of improved methods for the nonlinear analysis of buildings. We were also successful in helping establish the structure of the new FEMA-funded program for the Development of Guidelines for

Performance-Based Earthquake Engineering (ATC 58). Two members of the PEER leadership team (Director Moehle and Thrust Leader May) have seats on the six-member ATC-58 Project Management Committee; Deputy Director Deierlein is a member of the Structural Products team. Two of our industry partners head up the Nonstructural Products and the Risk Management teams, ensuring an efficient path to implementation of the PEER PBEE methodology. Our research program efforts on building benchmarking (see Chapter 2) will contribute significantly to ATC 58.

In prior years, the Implementation Advisory Board in its SWOT analyses recommended efforts to improve interactions between BIP members, researchers, and students. A strategic planning committee comprising Vanessa Camelo (Chair, Student Leadership Council), Gregory Deierlein (Deputy Director for Research), Ken Elwood (Berkeley Member of Student Leadership Council), James Malley (Chair, Implementation Advisory Board), Jack Moehle (Center Director), and Gerard Pardoen (Assistant Director for Education in 2001) prepared the plan, including the following elements:

- *Earthquake Engineering Scholars Course* — As described in Chapter 3, PEER has been conducting an Earthquake Engineering Scholars Course for selected undergraduate students. During Year 5 we laid plans to include selected BIP members as presenters or discussion leaders in the course. This new direction has been very positive (see Chapter 3).
- *Methodology Testbeds/Benchmarks* — In Year 5 PEER established the PEER Methodology Testbeds under the recommendation of the Scientific Advisory Committee and the Implementation Advisory Board. These have evolved to the benchmarking study. These efforts have involved BIP members in intensive studies.
- *PEER Annual Meeting* and *Student Day* — The PEER Annual Meetings have attracted as many as 300 participants including researchers, students, BIP members, and the public. Starting in 2002, we convened a Student Day, which included meetings among students and BIP members, including oral and poster presentations about research and practice.
- *PEER Visiting Professional Program* — During Year 5 we developed and began to implement plans for the PEER Visiting Professional Program. Students and faculty at PEER Core Universities identify BIP partners whom they would like to invite as part of the program. The students plan the daylong meeting to include student/faculty/industry interactions and a seminar by the industry representative.

4.2 The PEER Business and Industry Partner Program

The PEER Business and Industry Partner (BIP) Program is the formal mechanism for engaging industry partners in the PEER programs. The program was initiated when the PEER Center was first established in 1998. As first established, PEER personnel recruited potential members annually and secured their membership through signatures on a form prepared by PEER. The agreement established a membership fee linked to company size and secured informal agreement of the partners to participate in PEER programs. The program was very successful in engaging the professional community in PEER activities. However, NSF, and subsequently UC Berkeley, deemed the program unsatisfactory because the agreement was not an officially approved contract of the University and because intellectual property rights were not included in the agreement.

Starting in 2001, PEER established a more formal mechanism for the BIP program through a contractual agreement between the Partner and UC Berkeley. The main aspects of the agreement are:

- Formal statement of the interest of the Partner in joining PEER. The Partner selects a level of participation consistent with the company size and indicates whether interested in intellectual property and licensing agreements. A different membership fee is associated with each membership level. Indirect costs are waived on all membership fees.
- A series of Partner benefits is defined. Those members joining at the Sustaining Member level receive the regular benefits plus early access to intellectual property.
- An Implementation Advisory Board is promised; members joining at the Sustaining Level have automatic membership on the Board.

As in the past, the BIP members are informed of PEER activities through regular mailings. They are encouraged to attend all research meetings, and are invited to the PEER Annual Meeting.

Recently, we have been successful in attracting new BIP members, including EQECAT, Risk Management Solutions (RMS), Certus Consulting, and Exponent Failure Analysis Associates. There are also other firms that have agreed to join and for which the formal membership process is being implemented. The full listing of current BIP members is noted in the Project Summary section of this report.

Table 5 tracks the membership over the life of the BIP program. Note that the formal membership agreement was not executed until 2001. Membership prior to 2001 is based on the less formal partnership agreement.

Table 5: Lifetime Membership History

Table 5: Lifetime Full Membership History		
Organization	**Award Years of Membership**	**Technology Transfer Activities**
AIR Worldwide	2003,2004,2005	Joint Project
Bay Area Rapid Transit (BART)	2005	Joint Project
California Department of Transportation	1997,1998,1999,2000,2001,2002,2003,200	Joint Project
Certus Consulting, Inc.	2005	Joint Project
Degenkolb Engineers	1998,1999,2000,2001,2002,2003,2004,200	Joint Project
Egecat	2005	Joint Project
FM Global Technologies	2005	Joint Project
Forell/Elsesser Engineering	1999,2000,2001,2003,2004,2005	Joint Project
Fugro West	2005	Joint Project
Geomatrix Consultants, Inc.	1998,1999,2000,2001,2002,2003,2004,200	Joint Project
Magnusson Klemencic Associates	2004,2005	Joint Project
Pacific Gas & Electric Company	1997,1998,1999,2000,2001,2002,2003,200	Joint Project
Risk Management Solutions	2005	Joint Project
Rutherford & Chekene	1998,1999,2000,2001,2002,2004,2005	Joint Project
Wiss, Janney, Elstner Associates	1998,1999,2000,2001,2002,2003,2004,200	Joint Project
Bechtel Corporation	2003,2004	Joint Project
California Energy Commission	2000,2001,2002,2003,2004,2005	Joint Project
CDComartin	2004	Joint Project
Earth Mechanics	1998,1999,2000,2001,2002,2003,2004	Joint Project
Exponent Failure Analysis	1999,2000,2001,2004	Joint Project
Pacific Gas and Electric Company	1998,1999,2000,2001,2002,2003,2004,200	Joint Project
Risk Management Solutions, Inc.	2005	Joint Project
St. Paul Companies	2003,2004	Joint Project
Comartin-Reis	2000,2001,2002,2003	Joint Project
URS Corporation	1999,2000,2001,2003	Joint Project
Dynamic Isolation Systems	1998,1999,2000,2001,2002	Other Tech Transfer
Imbsen & Associates	1999,2000,2001,2002	Other Tech Transfer
Skilling Ward Magnusson Barkshire	1999,2000,2001,2002	Other Tech Transfer
Applied Insurance Research	2002	Test Bed
Computers and Structures	2000	Test Bed
Hess Engineering	1998,1999,2000,2001	Test Bed
K2 Technologies/E.W. Blanch	2000,2001	Test Bed
Nevada Institute of Testing	1998,1999,2000,2001	Joint Project
Ove Arup & Partners USA	1999,2000,2001	Test Bed
Anatech Corporation	1998,1999,2000	None Listed
Brandow & Johnston	1999,2000	None Listed
Dames & Moore	1999,2000	None Listed
ENIDINE West	1998,1999,2000	None Listed
Fluor-Daniel	1998,1999,2000	None Listed
Southern California Edison	1998,1999,2000	None Listed
Bridgestone Eng. Products Co.	1998,1999, 2000	None Listed
British Columbia Hydro & Power Authority	1998	Joint Project
EQE International	1998	None Listed
SOHA Engineers	1999, 2000	None Listed
TEAM Corporation	1998	Other Tech Transfer

4.3 Technology Transfer and Interactions with Various Organizations

Technology transfer and the dissemination of PEER research findings, knowledge, developments and products to government, industry, and other end-users are important elements of the PEER program.

Examples of such activities are the deep and broad interactions with numerous participants in the PEER Lifelines project “Next Generation of Attenuation Models (NGA).” In this project, various researchers are working to cast the next-generation ground motion attenuation models. These models will be used in seismic hazard analysis and will form the basic data for seismic design according to the International Building Code (IBC). The NGA quarterly workshops have been attracting an increasing number of participants from various organizations. The participants represent public and private sector organizations such as the California Geological Survey, California Department of Transportation (Caltrans), California Division of Dams, California Energy Commission, Bay Area Rapid Transit (BART), and various universities (such as UCLA, UC Davis, UC San Diego, UC Santa Barbara, University of Nevada at Reno, Caltech, among others), EQECAT, Inc.; Earth Mechanics, Inc.; AIR; URS Corporation; Geomatrix Consultants; Bechtel Corporation; Risk Management Solutions; and Pacific Gas & Electric Company. The success of NGA and other PEER projects is partly due to the high level of interaction among the various sectors involved in earthquake engineering.

PEER is also signing a new contract with the California Energy Commission (CEC) to carry out a comprehensive technology transfer project. The project will include the development of workshops and practical guidelines based on previously completed PEER projects related to seismic performance of electric components and systems. The first of such technology transfer workshops was funded by the American Lifelines Alliance through PG&E, and was held at the PEER center in February 2006. The workshop topic was “Seismic Response of Interconnected Electric Equipment.” Future workshops and guidelines will be funded by the CEC.

Table 5b shows examples of technologies transferred from PEER to industry and other users over the last three years and their impact.

Table 5b: Technology Transfer Examples

Technology	Adopting Organizations	Industrial Application	Impact	When
Performance-based earthquake engineering methodology	Applied Technology Council (ATC-58); SGH; others	To evaluate existing systems and design new systems	Quantifying various seismic performances	Year 8-present
Building Collapse Assessment	Applied Technology Council (ATC-63)	Methodology and tools for assessment of collapse safety provided by modern building code provisions	Validate the adoption of new materials and seismic force resisting systems into the national model building code	Year 9 - present
OpenSees	Various engineering firms and NSF-NEES Inc. Consortium	Software to simulate the nonlinear response of structural and geotechnical systems	Facilitates the development and adoption of new computational methods in research and practice	Year 5 - present
OpenFresco – Open Framework for conducting hybrid experiments	NEESinc, MTS, various universities in the US and abroad	Common framework for conducting hybrid simulations	Scalable, extensible and object oriented framework for collaborative development and deployment of hybrid simulation technology	Year 7 - present
Fragility models of reinforced-concrete building components and database of column tests	American Society of Civil Engineers, Applied Technology Council, Earthquake Engineering Research Institute	Improved guidelines for the seismic assessment of existing buildings that do not meet current building codes	More accurate models to assess collapse safety and thereby lead to more economical strategies for building retrofit	Year 8 - present
Resource documents on public policies related to seismic safety	Federal Emergency Management Agency and various state and local government agencies	Documents that provide research background and guidance for development of public policies for earthquake mitigation	Earthquake risk reduction through policy implementation of seismic risk assessment and mitigation measures	Year 7 - 9
Seismic loading protocols for nonstructural components	Applied Technology Council	To assess seismic performance and fragility of nonstructural components and systems in buildings	Improved design of nonstructural building components to reduce earthquake damage	Years 8-9
Seismic loading protocols for nonstructural components	Applied Technology Council	To assess seismic performance and fragility of nonstructural components and systems in buildings	Improved design of nonstructural building components to reduce earthquake damage	Years 8-9
Seismic Protection for Building Contents	Consulting Engineers, UC Berkeley Campus, Lawrence Berkeley National Lab, Genetech, Bayer	Seismic Risk Management for Building Contents	Procedures for evaluating contents risk and technical approaches to retrofit	Year 8- present
Seismic performance and simulation of bridges in liquefied and laterally spreading ground.	Caltrans.	Improved simulation tools and design guidance for the seismic assessment of bridges subject to liquefaction and lateral spreading.	Development and validation of design procedures.	Year 7 - present
Next Generation Attenuation (NGA) strong-motion database	Various private and government organizations, including the USGS	Selection of strong-motions for analysis and design	Seismic hazard; structural and geotechnical analysis and design	Year 7-present
Next Generation Attenuation (NGA) models	USGS is reviewing to adopt the models	Seismic hazard analysis; National Seismic Hazard Maps; seismic design codes	All seismic design based on codes will be affected; as well as site-specific analysis and design	Year 7-present

Table 5B *continued:* Technology Transfer Examples

Technology	Adopting Organizations	Industrial Application	Impact	When
Shake table input motions for seismic qualification of equipment	IEEE standard; Electric utilities	Seismic qualification of electric substation equipment	Standardized input motions for shake table qualification of electric substation equipment	Year 7-present
Geotechnical Virtual Data Center	Caltrans; USGS; PG&E; (FHWA is also reviewing)	Geotechnical engineering; analysis and design	Geotechnical site data to become available to a wide range of users	Year 8-present
Interaction of electric substation equipment	PG&E; other utilities	Seismic analysis and design of electric substation equipment	Quantification of effects of equipment interaction during an earthquake	Year 8-present
Advance guidelines for seismic evaluation of utility buildings	PG&E	More accurate evaluation of seismic performance of existing utility buildings	Saving money in seismic retrofit of buildings	Year 7-9
Seismic performance of various electric components	PG&E and other utilities	Seismic qualification of wide variety of electric substation equipment	More reliable electric networks	Year 6-8

4.4 Program for Public Relations and Outreach

PEER established its Office of Public Relations and Outreach to serve several functions. It improves communications within PEER and between PEER participants, between PEER and the University, and between PEER and the outside community. The public relations function ensures that inquiries are answered promptly and that news releases are prepared regularly and distributed widely. The Office organizes workshops, seminars, and meetings for a wide audience, and oversees production of PEER publications and the *PEER Technical Report Series* (see Table 4.1 for the number of technical reports published by year). Finally, it is responsible for creating web-accessible information for our BIP members, providing access to research results and students.

Table 4.1 PEER Report Series

Year	# of Reports Published
1998	8
1999	14
2000	10
2001	16
2002	24
2003	17
2004	9
2005	16*

**In production as of 4/06; publication year runs from 6/05 – 5/06*

PEER participated in an outstanding outreach opportunity in April, 2006, the 1906 Anniversary Earthquake Engineering Conference, at Moscone Center in San Francisco. In addition to strong booth presence at the conference (including a demonstration of the enhanced NGA database) and the Student Shake Table Competition, several PEER researchers were heavily involved in organizing sessions and selecting papers. PEER Director Jack Moehle served as chair of the technical committee, in addition to making oral presentations on "Hybrid Simulation Evaluation of Innovative Steel-Braced Framing System" and "Collapse of Lightly Confined Reinforced Concrete Frames during Earthquakes." PEER Associate Director Yousef Bozorgnia served as co-chair of a special session for NGA on "Next Generation of Ground Motion Attenuation Models," and made additional oral presentations. PEER Deputy Director Greg Deierlein chaired a special session on "Performance-Based Earthquake Engineering" and gave a tutorial on "Seismic Performance of Existing Concrete Buildings." Ross Boulanger co-chaired a session on "Key Advances in Liquefaction Evaluation." Several other PEER researchers also made numerous presentations at the conference. PEER's research accomplishments and informational literature were presented to 3,000 worldwide meeting attendees.

Other important presentations throughout the year included a CalNet Seismic Seminar, where Director Moehle was a keynote speaker, and an EERI/PEER Lecture Series on responsive reinforced concrete structures.

Public Relations and Outreach has continued its efforts to increase the level of communication between the Center and its participants, as well to the earthquake engineering community. Highlights of outreach activities during the past year have included:

- Logistical management of PEER's research coordination workshops and meetings, including technical, informational, and organizational events.
- Attending domestic and international major earthquake engineering conferences and meetings with PEER's technical information exhibit. Events where PEER exhibited in the past year included the 1906 Anniversary Earthquake Engineering Conference.
- A major redesign to the PEER website layout, which was rolled out in winter 2004, is still continuing.
- PEER published one Research Digest in 2006 on "Effective Stiffness of Reinforced Concrete Columns," and three in 2005 on "An Application of PEER Performance-Based Earthquake Engineering Methodology," "Input Motion for Earthquake Simulator Qualification of Electrical Substation Equipment," and "Effect of Dynamic Interaction in Interconnected Electrical Substation Equipment."
- PEER has sponsored or co-sponsored several events related to the progress and products of the PEER program as well as those related more broadly to performance-based earthquake engineering. Table 4.2 provides details of events in the past four years.

Table 4.2 Outreach Activities

Date of Event	Title of Event	Location	Type of Event	Description	No. of Attendees
4/06	1906 Anniversary Earthquake Engineering Conference	San Francisco, CA	Conference	PEER Director Jack Moehle served as chair of the technical committee, in addition to doing oral presentations on "Hybrid Simulation Evaluation of Innovative Steel-Braced Framing System" and "Collapse of Lightly Confined Reinforced Concrete Frames during Earthquakes."	3,000
4/06	1906 Anniversary Earthquake Engineering Conference	San Francisco, CA	Conference	Several PEER researchers made numerous presentations at the conference. PEER Associate Director Yousef Bozorgnia served as co-chair of a special session for NGA on "Next Generation of Ground Motion Attenuation Models," and also made other oral presentations. PEER Deputy Director Greg Deierlein chaired a special session on "Performance-Based Earthquake Engineering" and gave a tutorial on "Seismic Performance of Existing Concrete Buildings." Ross Boulanger co-chaired a session on "Key Advances in Liquefaction Evaluation." PEER also co-sponsored the Student Shake Table Competition.	3,000
4/06	1906 Anniversary Earthquake Engineering Conference	San Francisco, CA	Tutorial	"Seismic Performance of Existing Concrete Buildings" presented by Ken Elwood , Greg Deierlein, and John Wallace.	60
3/06	Mid-America Earthquake (MAE) Center Seminar University of Illinois	Urbana-Champaign IL	Seminar	Overview of PEER Next-Generation Attenuation Models of Ground Motion. The audience was given a demonstration of the enhanced NGA models available on PEER's website.	25
1/06	PEER Annual Meeting	San Francisco, CA	Conference	Focused discussion sessions built around themes which crossed over research thrust areas. Poster session for students to explain their projects to members of industry and other meeting attendees.	200
12/06	Developer Interaction Meeting	Richmond, CA	Workshop	Development of new attenuation models.	10
10/05	CalNet Seminar	Sacramento, CA	Seminar	CalNet Seismic Seminar, where PEER Director Jack Moehle was a keynote speaker.	

Table 4.2 *continued:* Outreach Activities

Date of Event	Title of Event	Location	Type of Event	Description	No. of Attendees
10/05	USGS Review Meetings (10/6 and 3/7)	Richmond, CA	Workshop	Review of NGA relationships.	15–20
10/05	USGS Review Meeting	Menlo Park, CA	Workshop	NGA participation at USGS western U.S. attenuation workshop.	15–20
	EERI/PEER Lecture Series		Lecture	Responsive reinforced concrete structures.	
9/05	Developer Interaction Meeting	Richmond, CA	Workshop	Development of new attenuation models.	10
7/05	Developer Interaction Meeting	Richmond, CA	Workshop	Development of new attenuation models.	10
6/05	Developer Interaction Meeting	Richmond, CA	Workshop	Development of new attenuation models.	10
4/05	Developer Interaction Meeting	Richmond, CA	Workshop	Development of new attenuation models.	10
4/05	PEER Workshop Meeting	Richmond, CA	Workshop	Review of NGA relationships.	75–80
3/05	Developer Interaction Meeting	Richmond, CA	Workshop	Review of NGA relationships.	10
3/05	USGS Review Meeting	Richmond, CA	Workshop	Review of preliminary relationships. Presentations	15–20
1/05	Developer Interaction Meeting	Richmond, CA	Workshop	Review of NGA relationships.	10
2/05	EERI Distinguished Lecture at UC Berkeley	Berkeley, CA	Seminar	PEER co-sponsored an invited seminar for Director Moehle to present his EERI Distinguished Lecture at the UCB campus. The event was open to the public and was well attended by members of industry and academia.	125
12/04	PEER Orientation for Docents of the California Academy of Sciences	Richmond, CA	Seminar	A visit to the PEER Center by docents from the California Academy of Sciences, where PEER is co-sponsor of an exhibit titled *Earthquakes!* The group was given a presentation with an overview of PEER's mission and organization, followed by a walking tour of the testing facilities at the University of California, Berkeley's Earthquake Engineering Research Center.	30
12/04	6th Next-Generation Ground Motion Attenuation Workshop	Richmond, CA	Workshop	The NGA is a unique opportunity for the community of strong-motion seismologists and geotechnical engineers to make a significant step forward in predicting strong ground motions for WUS earthquakes.	75

Table 4.2 *continued:* Outreach Activities

Date of Event	Title of Event	Location	Type of Event	Description	No. of Attendees
9/04	Annual OpenSees User Workshop	Richmond, CA	Workshop	This workshop is intended as training for those in academia and industry who wish to begin use of OpenSees. The workshop also covers topics for more advanced users.	32
7/04	ANCER Annual Meeting	Honolulu, HI	Conference	PEER co-sponsored this meeting, which brought together researchers and graduate students from the member institutions of the Asian-Pacific Network of Centers for Earthquake Engineering Research.	
7/04	Guest Seminar by Professor Akira Wada	Richmond, CA	Seminar	Professor Wada, from the Tokyo Institute of Technology, gave a presentation at PEER headquarters titled, "Changes of Seismic Design of Structures in Japan after the Kobe Earthquake."	25
6/04	International Workshop on Performance-Based Structural Design	Bled, Slovenia	Workshop	PEER was a co-sponsor of this workshop, aimed at helping further the field of seismic design by bringing together and international forum aimed at continuing dialog on the implementation of new PBEE ideas.	
6/04	International Symposium on Confined Concrete	Changsha, China	Workshop	PEER co-sponsored this workshop that provided an open forum for experts around the world to exchange information on the topics of confined concrete modeling, testing, design, and implementation.	
3/04	5th Next-Generation Ground Motion Attenuation Workshop	Richmond, CA	Workshop	The NGA is a unique opportunity for the community of strong-motion seismologists and geotechnical engineers to make a significant step forward in predicting strong ground motions for WUS earthquakes.	43
3/04	International Workshop on Nonlinear Soil Properties and Their Impact on Modeling Dynamic Soil Response	Richmond, CA	Workshop	Aimed to improve coordination between the Soil Response testing and modeling communities by addressing the following issues: What is the current status of soil testing for dynamic soil properties, and what are the major sources of bias and uncertainty? What is the current status of nonlinear soil property models? What is the current status of earthquake site-response modeling as it relates to the need for new soil models and the quantification of uncertainties?	48
2/04	PEER Annual Meeting	Palm Springs, CA	Conference and Poster Session	Focused discussion sessions built around themes that crossed over research thrust areas. Poster session for students to explain their projects to members of industry and other meeting attendees.	170
1/04	NEES/OpenSees Workshop	Richmond, CA	Workshop	A workshop aimed at showcasing the OpenSees framework for investigators involved with the NEES program.	35

Table 4.2 ***continued:*** **Outreach Activities**

Date of Event	Title of Event	Location	Type of Event	Description	No. of Attendees
1/04	11 Int'l Conference on Soil Dynamics & Earthquake Engineering/3rd Int'l Conference on Earthquake Geotechnical Engineering* **Co-Sponsor*	Berkeley, CA	Conference and poster session	International Conference on Soil Dynamics and Earthquake Engineering (SDEE), affiliated with the *Journal of Soil Dynamics and Earthquake Engineering*, has been held every two years for the past 20 years. The last conference was held in Philadelphia in the U.S. in 2001. The international community organizing the conference consists of academia and practicing engineers in Singapore, the U.S., and Japan, and China. PEER was a co-sponsor of this event.	300
12/03	4th Next-Generation Ground Motion Attenuation Workshop	Richmond, CA	Workshop	The NGA is a unique opportunity for the community of strong-motion seismologists and geotechnical engineers to make a significant step forward in predicting strong ground motions for WUS earthquakes.	38
12/03	Tri-Center Workshop on Geographically Distributed Network Systems* **organized by MAE*	Las Vegas, NV	Workshop	The second tri-center workshop, focusing on geographically distributed network systems. Working-group sessions included: *bridge performance, transportation networks, earthquake hazard categorization,* and *electric utility equipment and networks.*	55
12/03	ACI: Seismic Bridge Design and Retrofit for Earthquake Resistance* **Co-Sponsor*	La Jolla, CA	Conference	An international conference bringing together some of the world's leading seismic experts.	150
10/03	3rd Next-Generation Ground Motion Attenuation Workshop	Richmond, CA	Workshop	The NGA is a unique opportunity for the community of strong-motion seismologists and geotechnical engineers to make a significant step forward in predicting strong ground motions for WUS earthquakes.	45
9/03	Four Seasons Field Test Workshop	Los Angeles, CA	Workshop	The objectives of the workshop are to inform the community about the testing program, to solicit input from you regarding how our test plan can be optimized, and to identify potential "payload projects" (i.e., tests that could be performed in conjunction with the main test such as instrumentation of a particular nonstructural element, etc.).	14
9/03	5th US-Japan Workshop on PBEE Methodology for RC Buildings	Hakone, Japan	Workshop	An international-level workshop to facilitate the exchange of the latest research and professional practice information on performance-based earthquake engineering.	28
9/03	Int'l Symposium Honoring Professor Shunsuke Otani* **co-sponsor*	Tokyo, Japan	Conference	An international symposium celebrating Professor Shunsuke Otani's retirement from the University of Tokyo. Three PEER Research Committee members were guest speakers.	200

Table 4.2 *continued:* Outreach Activities

Date of Event	Title of Event	Location	Type of Event	Description	No. of Attendees
8/03	4th Annual OpenSees User Workshop	Richmond, CA	Workshop	OpenSees is a software framework for developing applications to simulate the performance of structural and geotechnical systems subjected to earthquakes. The workshop is intended for those who wish to begin use of OpenSees and for more advanced users.	94
8/03	The Sixth US Conference and Workshop on Lifeline Earthquake Engineering (TCLEE)* **co-sponsor*	Long Beach, CA	Conference and Poster Session	Workshop with specialists from all disciplines in the field to discuss what has been learned, to see the latest trends and developments, and to understand how developments in lifeline earthquake engineering can reduce losses from other technological hazards.	200
7/03	2nd Next-Generation Ground Motion Attenuation Workshop	Richmond, CA	Workshop	The NGA is a community of strong-motion seismologists and geotechnical engineers to make a significant step forward in predicting strong ground motions for WUS earthquakes.	40
7/03	Ninth International Conference on Applications of Statistics and Probability in Civil Engineering	San Francisco, CA	Conference	ICASP9 is the ninth in a series of international conferences aimed at bringing together scientists, educators, researchers, and practitioners for a better understanding and management of uncertainty, risk ,and reliability in all aspects of civil engineering.	232
6/03	Tri-Center Workshop* **organized by MCEER*	Los Angeles, CA	Workshop	First tri-center user workshop on application of loss estimation methodologies for transportation systems. Breakout sessions were held on *Damage and Performance Measures for Analysis of Highway Networks and Components* and *Data Availability and Analysis Methods for Bridges and Highway Networks*.	40
6/03	Inter-Utility Seismic Working Group Meeting	Richmond, CA	Workshop	Inter-utility Advisory Panel workshop for PEER Lifelines Program.	23
3/03	PEER Annual Meeting	Palm Springs, CA	Conference and Poster Session	Focused discussion sessions built around themes which crossed over research thrust areas. Poster session for students to explain their projects to members of industry and other meeting attendees.	169
3/03	PEER Workshop Shallow Foundations	Davis, CA	Workshop	To disseminate a summary of research findings from PEER research on shallow foundations and discuss a plan for future related research, and to receive feedback from structural engineers, practicing engineers, and geotechnical peers on helpful direction in the ongoing development of procedures.	20
1/02	1st Next-Generation Ground Motion Attenuation Workshop	Richmond, CA	Workshop	The NGA is a unique opportunity for the community of strong-motion seismologists and geotechnical engineers to make a significant step forward in predicting strong ground motions for WUS earthquakes.	40

Table 4.2 ***continued:*** **Outreach Activities**

Date of Event	Title of Event	Location	Type of Event	Description	No. of Attendees
10/02	4th US-Japan Workshop on Performance-Based Earthquake Engineering for Reinforced Concrete Building Structures	Toba, Japan	Workshop	This workshop brought together researchers and practitioners to discuss developments in performance-based earthquake engineering.	27
9/02	Lifelines Program Research Results and Implementation Briefing	Berkeley, CA	Seminar	This briefing focused on the results and implementation of recent applied seismic research conducted by the PEER Lifelines Program. Emphasis was placed on the immediate and near-term benefits that stem from this research, and on means to maximize the value of these results through broad application by a spectrum of utilities and transportation systems.	50
9/02	OpenSees User and Developer Workshop	Berkeley, CA	Workshop	The first portion of the workshop was geared toward users who have little or no experience using OpenSees. The latter days were aimed at OpenSees code writers.	51
8/02	International Conference on Advances and New Challenges in Earthquake Engineering Research	Harbin and Hong Kong, China	Conference	ICANCEER focused on new advances in earthquake engineering and innovative solution approaches. Research for development and application of advanced technologies, and intelligent infrastructure engineering.	
7/02	Seventh National Conf. On Earthquake Engineering (7NCEE)* **financial co-sponsor*	Boston, MA	Conference and Poster Session	Provides an opportunity for researchers and practitioners to share the latest knowledge and techniques for understanding and mitigating the effects of earthquakes.	750
5/02	UC Berkeley–CUREE Symposium in Honor of Professors Ray Clough and Joseph Penzien	Berkeley, CA	Conference	PEER co-sponsored this conference featuring advances in earthquake engineering in recognition of the notable contributions of the honorees.	193
4/02	Third National Seismic Conference and Workshop on Bridges and Highways	Portland, OR	Conference	PEER co-sponsored this conference featuring current national and regional practices and research on earthquake-resistant bridges.	351
4/02	Large-Scale Unbonded Braced Frame Assemblies Briefing	Berkeley, CA	Workshop	PEER organized this program in collaboration with the UC Berkeley Office of Capital Projects to review a testing program on large-scale unbonded braced frame assemblies.	52
1/02	PEER Annual Meeting	Oakland, CA	Conference and Poster Session	Research digests presented recent results and progress in the PEER research program. A special session was convened for PEER students to present their research to members of PEER's BIP program. A BIP Banquet honored current members.	240

Table 4.2 ***continued:*** **Outreach Activities**

Date of Event	Title of Event	Location	Type of Event	Description	No. of Attendees
10/01	Seismic Risk and Communication: WSSPC Annual Conference 2001	Sacramento, CA	Conference	PEER co-sponsored this conference with primary focus on communication of earthquake risk.	300
9/01	Pier Testing Briefing	Richmond, CA	Workshop	PEER organized this program in collaboration with the UC Berkeley Office of Capital Projects to review an upcoming pier test program.	45
8/01	3rd US-Japan Workshop on Performance-Based Earthquake Engineering for Reinforced Concrete Building Structures	Seattle, WA	Workshop	This workshop brought together researchers and practitioners to discuss developments in performance-based earthquake engineering.	36
5/01	2nd National Earthquake Ground-Motion Mapping Workshop	San Francisco, CA	Workshop	PEER co-sponsored this workshop aimed at providing input to USGS on ground motion mapping.	75

5 INFRASTRUCTURE

5.1 Institutional Configuration

PEER is instituted as a consortium of *Core Institutions* and *Education Affiliates*. The *Lead Institution* is the University of California, Berkeley, where the Center Director and core administration are located. The *Core Institutions* are those universities that initiated founding of the center, collaborated to achieve the matching funds, and are the primary locations for PEER activities. The *Education Affiliates* are those universities that participate primarily in PEER education programs. In accordance with NSF designations, PEER also informally defines *Outreach Institutions* to include (a) institutions that receive funds from PEER to conduct very focused work with or for the center, (b) organizations whose PIs work primarily at their own institutions in partnership with PEER staff but receive no funds from PEER, and (c) organizations directly involved with PEER educational or outreach activities, including the Education Affiliates.

The Education Affiliates designation was initiated in January 2004. Previously, PEER formally included nine *Affiliated Institutions*, which were so designated at the formation of PEER, and which were eligible to participate in PEER research and education programs. That designation was eliminated in January 2004 and the designated universities were released from their involvement with PEER. Simultaneously, PEER initiated the Education Affiliates designation.

Table 6 lists the Institutions executing PEER's research, technology transfer, and education programs. Relative to its early years, PEER aims to involve an increasing number of individuals and institutions in its programs, reflecting the evolving funding base and influence of PEER.

Table 6: Institutions Executing the ERC's Research, Technology Transfer, and Education Programs

Institutions				Participants in ERC Activities				
				Personnel Involved in Research and Curric		REU Students by Source Institutions	K-12 Participants	
Name and Type	Total	Female Serving	Minority Serving	Faculty	Students		Teachers	Students
I. Lead	**1**	**0**	**0**	**13**	**23**	**3**	**0**	**0**
University of California, Berkeley		▪	▪	13	23	3	0	0
II. Core Partners	**8**	**0**	**0**	**26**	**43**	**12**	**0**	**0**
California Institute of Technology		▪	▪	1	1	0	0	0
Stanford University		▪	▪	6	10	0	0	0
University of California, Davis		▪	▪	6	9	1	0	0
University of California, Irvine		▪	▪	1	0	1	0	0
University of California, Los Angeles		▪	▪	3	5	1	0	0
University of California, San Diego		▪	▪	3	8	5	0	0
University of Southern California		▪	▪	0	0	0	0	0
University of Washington		▪	▪	6	10	4	0	0
III. Collaborating (Outreach)	**15**	**0**	**4**	**1**	**1**	**1**	**0**	**0**
California Polytechnic State University, San Luis Obispo ,San Luis Obispo CA		▪	▪	1	0	0	0	0
California State University Los Angeles ,Los Angeles CA		▪	✓	0	0	1	0	0
California State University Northridge ,Los Angeles CA		▪	✓	0	0	0	0	0
Oregon State University ,Corvallis OR		▪	▪	0	0	0	0	0
San Jose State University ,San Jose CA		▪	✓	0	0	0	0	0
University of Hawaii at Manoa ,Honolulu HI		▪	✓	0	0	0	0	0
US Geological Survey ,Menlo Park CA		▪	▪	0	1	0	0	0
Geomatrix Consultants ,Oakland CA		▪	▪	0	0	0	0	0
URS Corporation ,Pasadena CA		▪	▪	0	0	0	0	0
California Division of Mines & Geology ,San Francisco CA		▪	▪	0	0	0	0	0

Pacific Engineering & Analysis ,El Cerrito CA		▪	▪	0	0	0	0	0
EQECat, Inc. ,Beaverton OR		▪	▪	0	0	0	0	0
AIR Worldwide Corp. ,San Francisco CA		▪	▪	0	0	0	0	0
California Department of Transportation ,Sacramento CA		▪	▪	0	0	0	0	0
Pacific Gas & Electric Co. ,San Francisco CA		▪	▪	0	0	0	0	0
IV. Non-ERC Institutions Providing REU Students	**4**	**0**	**0**	**0**	**0**	**5**	**0**	**0**
Calvin College ,Grand Rapids MI		▪	▪	0	0	1	0	0
Manhattan College ,Bronx NY		▪	▪	0	0	1	0	0
Portland State University ,Portland OR		▪	▪	0	0	1	0	0
Purdue University ,West Lafayette IN		▪	▪	0	0	2	0	0
V. NSF Diversity Program Awardees	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**
Alliances for Graduate Education and the Professoriate (AGEP)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
No AGEP Awardees were entered.								
Centers of Research Excellence in Science and Technology (CREST)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
No CREST Awardees were entered.								
Louis Stokes Alliances for Minority Participation (LSAMP)	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**
University Of California-Irvine, Irvine (LSAMP-California Louis Stokes Alliance for Minority Participation)		▪	✓	0	0	0	0	0
Tribal Colleges and Universities Program (TCUP)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
No TCUP Awardees were entered.								
Other NSF Diversity Program Awardees	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
No Institutions were entered.								
VI. K-12 Institutions	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
No Institutions were entered.								
Total	**29**	**0**	**5**	**40**	**67**	**21**	**0**	**0**

5.2 Leadership Team, Faculty, and Student Team and Diversity

Table 7 provides a count of those members of the PEER team during the Reporting Year that are considered to be PEER Personnel by virtue of managing, leading, and carrying out PEER's research, education, technology transfer, and outreach activities. The vast majority of them carry out the center's mission through involvement in projects that contribute directly to the center by fulfilling its strategic plan. Included in this count are all people who worked on a paid or unpaid basis on center research, technology transfer, and education activities funded by all sources.

5.2.1 The Leadership Team

Professor **Jack Moehle** (UC Berkeley) is the *Center Director* and chief executive officer of the center. He is responsible for administering the center in accordance with the requirements of NSF. He also is responsible for creating an atmosphere of intellectual creativity that stimulates innovation and promotes team coordination. He is responsible for staffing, fiscal, and resource management. The Center Director recommends to the Institutional Board the appointment of key individuals. The Center Director reports to the Vice-Chancellor for Research at UC Berkeley.

Professor **Greg Deierlein** (Stanford University) is *Deputy Director for Research*. He manages the research program and is responsible to the Center Director for all research activities. The Deputy Director recommends organization of the research program into thrust areas, and recommends Thrust Area Leaders, who are appointed by the Center Director subject to approval of the Institutional Board. The thrust area leaders along with the Deputy Director compose the ***Research Committee,*** which organizes details of the research program. They are responsible for developing strategic plans, convening coordination meetings, monitoring progress, and preparing written summaries of work in the research program. For membership, see Table 5.1.

Table 5.1 – Research Committee

Member
Greg Deierlein*, Chair*
Ross Boulanger
Mary Comerio
Ahmed Elgamal
Gregory Fenves
Helmut Krawinkler
Stephen Mahin
Peter May
Yousef Bozorgnia
Jack Moehle, ex-officio

Professor **Scott Ashford** (UC San Diego) is *Assistant Director for Education*. He organizes and conducts the Education Program through the ***Education Committee***, and is responsible to the Center Director for all education activities. Membership on the Education Committee is determined by the Assistant Director for Education, and includes representatives from each Core Institution and from Education Affiliates. Table 5.2 lists current members. The Assistant Director for Education also is responsible for oversight of the Student Leadership Council (described later).

Ms **Darlene Wright** (UC Berkeley) is the *Administrative Director*, responsible for assisting the Director in PEER management; acting as guardian of rules, regulations, and policies; serving as information gatekeeper and resource for center members; and providing financial and personnel management.

Dr. **Yousef Bozorgnia** (UC Berkeley) is *Associate Director for Sponsored Projects and Technology Transfer*. He leads efforts to develop and manage externally funded projects, develop the Business and Industry Partner Program, develop technology transfer mechanisms, and interact with the Implementation Advisory Board. Together with the Director he represents PEER on the Joint Management Committee (Table 5.3), which manages the Lifelines Program along with the industry partners. He also represents the Lifelines Program on the Research Committee.

Ms **Debra Jacob** (UC Berkeley) joined PEER in March 2006 as *Communications Manager*. She is responsible for maintaining and developing public relations materials and providing broad visibility for the center and its activities. This position has primary responsibility for events management and regular communications within the center among all participants and sponsors.

Table 5.2 – Education Committee

Member	Affiliation
Scott Ashford, *Chair*	UC San Diego
Pedro Arduino	U Washington
James Beck	CalTech
Nazaret Dermendjian	CSU Northridge
Tara Hutchinson	UC Irvine
Amit Kanvinde	UC Davis
Erik Johnson	USC
Abraham Lynn	Cal Poly State U
Kurt McMullin	San Jose State U
Charles Menun	Stanford U
Jack Moehle, *Ex Officio*	UC Berkeley
Ian Robertson	U Hawaii
Jonathan Stewart	UC Los Angeles
Božidar Stojadinović	UC Berkeley
Mark Tufenkjian	CSU Los Angeles
Solomon Yim	Oregon State U

Table 5.3 – Joint Management Committee for the Lifelines Program

PEER	California Energy Commission
Jack Moehle (Chair)	Lloyd Cibulka
Yousef Bozorgnia	Merwin Brown
California Dept. of Transportation	**Pacific Gas & Electric Co.**
Brian Chiou	Norm Abrahamson
Tom Shantz	Lloyd Cluff
	Stuart Nishenko

5.2.2 Faculty and Student Team

PEER faculty members are spread among the nine Core Institutions plus additional Outreach Institutions where needed expertise exists. PEER endeavors to involve a faculty team that is diverse in gender, ethnicity, and academic age. PEER students working on research projects are selected by faculty researchers to work on individual projects; PEER provides programs and sets requirements to involve the students in multi-disciplinary and multi-institutional research environment. See Table 7.

5.3 Diversity Strategic Plan and Results

PEER initiated a strategic plan to increase diversity beginning Year 2. The Graduates Fellowship program, introduced in Year 2, targeted Hispanic, African American and Native American students, providing up to three years funding to participate in PEER programs. PEER funded students under this program before it had to be discontinued because of state law prohibiting use of ethnicity or race as a criterion. PEER also advertised its intern programs in schools that serve traditionally underrepresented groups, and collaborated with the UC Berkeley SUPERB program. Despite these efforts, the numbers of minority students participating in PEER programs did not grow substantially.

Starting in late 2003, PEER began a new effort to increase diversity, including the following:

- The Affiliated Universities have been discontinued, and the new Education Affiliates designation was initiated to provide improved access for students from underrepresented groups.
- PEER has made contact with two California sites of NSF's Louis Stokes Alliance for Minority Participation. PEER staffed a table at the Louis Stokes California Alliance for

Minority Participation annual undergraduate research symposium in February 2004 and 2005. We will continue to advertise our intern programs through these organizations.

- PEER is working with George Johnson, Associate Dean for Special Programs, College of Engineering, Berkeley, to identify the appropriate means of establishing a partnership among the affiliated Deans of Engineering, other Deans, and the chairs of departments of the affiliated EERC faculty to increase diversity.
- PEER has modified its undergraduate research programs to encourage applications by students from underrepresented groups and to base selection on diversity considerations. Revised materials can be found at http://peer.ucsd.edu/internshipmenu_2006.htm.
- PEER's RET program is by collaborating with CHUM at UCSD to find teachers, with emphasis on seeking teachers from low-performing schools. We are also building relationships with Lapwai High School in Idaho, on the Lapwai Tribe reservation. One of their teachers participated in the RET program and joined us in Japan last summer.
- PEER has successfully reached K-12 students from underrepresented groups through its earthquake simulation competitions using LEGO building blocks (UC Irvine) and Popsicle sticks (UC San Diego) (see http://www.ucsd.tv/library-test.asp?showid=8216 starting at 14:40).

These programs are increasing our exposure to students from underrepresented groups and increasing the diversity of the pool of applicants for our student programs. Table 5.4 summarizes diversity indices for PEER at the time of this writing.

Table 5.4 National Benchmarking Data

	National Data	**Prior Yr Table 1a (EERCs)**	**PEER-2006**
FACULTY			
Women	**7.3%**		**20.0%**
Under-represented Racial Minorities	**3.0%**		**3.0%**
Hispanics	**3.3%**		**0.0%**
DOCTORAL DEGREES			
Women	**17.3%**		**20.0%**
Under-represented Racial Minorities	**1.8%**		**5.0%**
Hispanics	**1.8%**		**5.0%**
MASTERS DEGREES			
Women	**21.9%**		**13.0%**
Under-represented Racial Minorities	**2.7%**		**0.0%**
Hispanics	**2.5%**		**0.0%**
UNDERGRADUATE DEGREES			
Women	**20.5%**		**36.0%**
Under-represented Racial Minorities	**5.1%**		**4.0%**
Hispanics	**6.3%**		**8.0%**
Heading Not Specified			
Women		**25.0%**	
Under-represented Racial Minorities		**5.0%**	
Hispanics		**7.0%**	

Table 7a: Center Diversity, by Institution						
Institution	Females		Underrepresented Racial Minorities		Hispanics	
	#	%	#	%	#	%
Lead Institution						
University of California, Berkeley	15	23%	1	2%	0	0%
Core Partner						
California Institute of Technology	2	50%	0	0%	1	25%
Stanford University	4	21%	1	8%	1	5%
University of California, Davis	4	21%	0	0%	0	0%
University of California, Irvine	4	100%	0	0%	0	0%
University of California, Los Angeles	4	44%	0	0%	0	0%
University of California, San Diego	4	21%	0	0%	4	21%
University of Southern California	0	0%	0	0%	0	0%
University of Washington	7	33%	0	0%	1	5%
Collaborating (Outreach) Institutions						
AIR Worldwide Corp.	0	0%	0	0%	0	0%
California Department of Transportation	0	0%	0	0%	0	0%
California Division of Mines & Geology	1	50%	0	0%	0	0%
California Polytechnic State University, San Luis Obispo	0	0%	0	0%	0	0%
California State University Los Angeles	0	0%	0	0%	0	0%
California State University Northridge	0	0%	0	0%	0	0%
EQECat, Inc.	0	0%	0	0%	0	0%
Geomatrix Consultants	0	0%	0	0%	0	0%
Oregon State University	0	0%	0	0%	0	0%
Pacific Engineering & Analysis	0	0%	1	100%	0	0%
Pacific Gas & Electric Co.	0	0%	0	0%	0	0%
San Jose State University	0	0%	0	0%	0	0%
University of Hawaii at Manoa	0	0%	0	0%	0	0%
URS Corporation	1	33%	0	0%	0	0%
US Geological Survey	1	20%	5	100%	0	0%
Non-ERC Institutions Providing REU Students						
Calvin College	0	0%	0	0%	0	0%
Manhattan College	1	100%	1	100%	0	0%
Portland State University	0	0%	0	0%	0	0%
Purdue University	1	50%	0	0%	0	0%
LSAMP						
University Of California-Irvine, Irvine	0	0%	0	0%	0	0%

5.4 Organization, Management Systems, and University Support for the ERC Culture

The PEER programs are organized and managed to ensure strategic planning and program coordination, project and PEER personnel communications, outreach communications, and effective utilization of program resources. The organizational structure is outlined in the following paragraphs.

5.4.1 Organization

Figure 5.1 shows an organization chart for PEER. This chart depicts management, leadership, and oversight relations. Roles of the *Center Director*, *Deputy Director for Research*, *Research Committee*, *Assistant Director for Education*, *Education Committee*, *Administrative Director*, *Associate Director for Sponsored Projects and Technology Transfer*, and *Communications Manager* are described in Section 5.2.1.

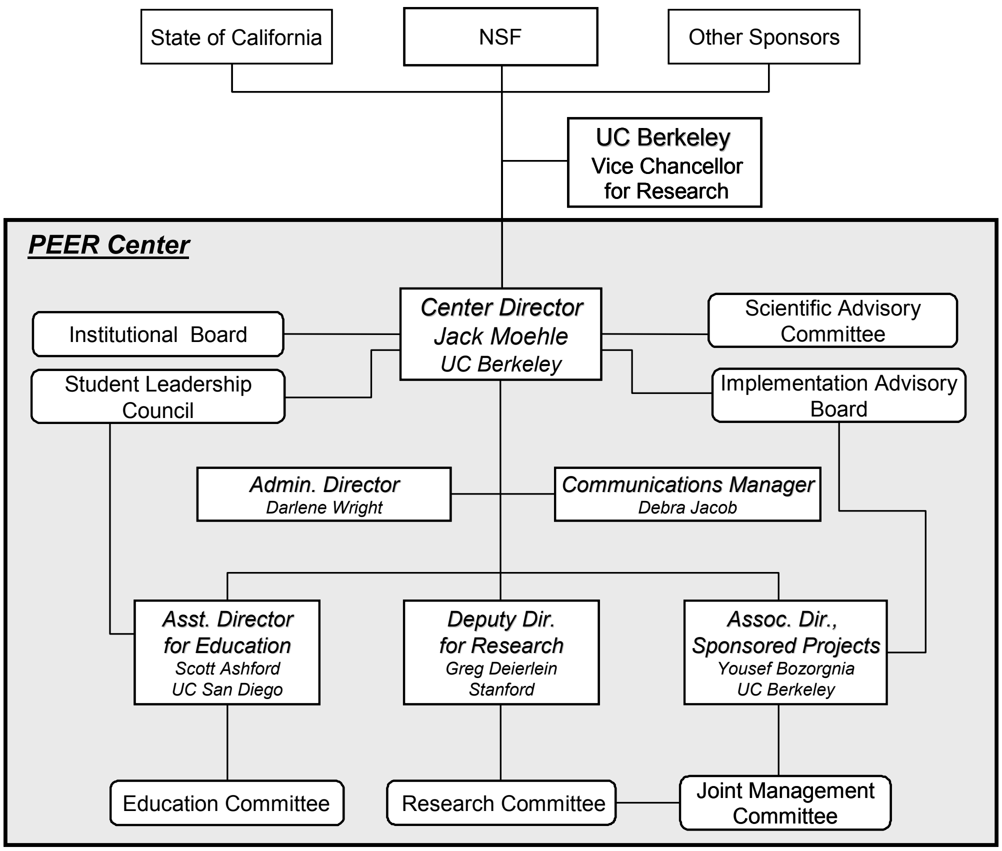

Figure 5.1 – Organization Chart

The ***Institutional Board*** (Table 5.5) represents the participating universities, with one appointed member from each of the Core Institutions and one appointed member to represent all Education Affiliates. The Institutional Board establishes policy and reviews and approves financial and administrative activities as well as all appointments of key individuals for the center. The Institutional Board will recommend to NSF and the host institution any changes in the Center Director if this becomes necessary, and will consider adding or removing member institutions. The Center Director and the Deputy Director for Research are ex-officio members of the Board.

A ***Scientific Advisory Committee*** provides external review of the PEER programs. It advises on center goals, planning, research thrusts, and products relative to regional and national earthquake risk mitigation needs. The membership includes academic, research organization, and advanced applications industry sectors. Current membership of this committee is identified in Table 5.6.

The ***Implementation Advisory Board*** consists of selected members of the Business and Industry Partner Program and other individuals selected by the Director. The IAB reviews PEER's research programs and products, and recommends ways to improve utilization of results in the private and public sectors. Table 5.7 lists current members.

Table 5.5– Institutional Board

Member	Affiliation
Paul Jennings, *chair*	CalTech
Thalia Anagnos[1]	San Jose State
Medhat Haroun	UC Irvine
Anne Kiremidjian	Stanford
Bruce Kutter	UC Davis
Steve Mahin	UC Berkeley
Charles Roeder	U Washington
Joel Conte	UC San Diego
John Wallace	UC Los Angeles
L. Carter Wellford	USC

[1] Education Affiliate Representative

Table 5.6 – Scientific Advisory Committee

Member	Affiliation
Ron Hamburger, *Chair*	Simpson Gumpertz & Heger
Don Anderson	CH2M Hill
Jacobo Bielak	Carnegie Mellon University
Roger Borcherdt	US Geological Survey
Raymond Burby	U North Carolina at Chapel Hill
James Jirsa	University of Texas at Austin
Tom Jordan	SCEC
Ron Mayes	Simpson Gumpertz & Heger

Table 5.7 – Implementation Advisory Board

Member	Affiliation
James Malley, Chair	Degenkolb Engineers
Fadel Alameddine	California Dept. of Transportation
Robert Bachman	Private Sector
Lloyd Cibulka	California Energy Commission/UC Office of the President
Lloyd Cluff	Pacific Gas and Electric Company
John Hooper	Magnusson Klemencic Associates
Chris Rojahn	Applied Technology Council
Tom Shantz	California Department of Transportation
Luong Tran	Washington Dept. of Transportation

The ***Student Leadership Council*** (Table 5.8) organizes student activities and recommends programs to improve student experiences. The SLC is organized and operates according to bylaws it has established, with general oversight from the Assistant Director for Education. The SLC reports jointly to the Center Director and the Assistant Director for Education.

Table 5.8 – Student Leadership Council

Samuel Case Bradford	Caltech	Internet Chair / SWOT Committee
Judith Mitrani-Reiser	Caltech	SLC President
Xin Xu	Caltech	
Curt Haselton	Stanford	Outreach Chair / SWOT Chair
Won Lee	Stanford	Seismic Competition Committee
Griffin Thornock	Stanford	Industrial Liaison
Howard Blecher	UC Berkeley	
Wassim Ghannoum	UC Berkeley	Vice President
Amado Lizarraga	UC Berkeley	
Eric Nguyen	UC Berkeley	Annual Retreat Co-Chair
Dongdong Chang	UC Davis	Seismic Competition Committee
Melissa Pi	UC Davis	Seismic Competition Chair
Shin-tai Song	UC Davis	
Jose Ugalde	UC Davis	Seismic Competition Committee
Stacia Bloom	UC Irvine	
Ben Langhorst	UC Irvine	
Christine Goulet	UCLA	Internet Chair
On Lei Kwok	UCLA	Historian
Vivian Gonzales	UC San Diego	
Alejandro Peña	UC San Diego	
Hyung-Suk Shin	U. Washington	Secretary
Tyler Sprague	U. Washington	
Sarah Upsall	U. Washington	Past President
Dongyu Zhang	USC	

5.4.2 Management Systems

Strategic research planning in PEER is carried out under the leadership of the Center Director and involves the individuals identified in Figure 5.1. Regular teleconference meetings of an Executive Committee (comprising the Center Director, Administrative Director, Deputy Director for Research, Associate Director of Sponsored Projects, Assistant Director for Education, and Communications Manager) ensures that all aspects of the center programs are taken into consideration in strategic and event planning. Various tri-center coordinating committees promote coordination among the three ERCs (see Volume III).

In the core research program, the Thrust Area Leaders are charged with developing thrust area strategic plans, which are then discussed, modified, and coordinated by the Research Committee. In the education program, the Assistant Director for Education is charged with developing an education strategic plan, which is evaluated, modified, and coordinated in discussions within the Executive Committee. Strategic planning is a continual process.

Research project selection is driven by the strategic plan. While primary emphasis is on selecting the most qualified researchers for a task, consideration also is given to building a team of participating faculty and students who are committed to the goals of PEER. PEER also endeavors to fund promising young faculty and faculty from underrepresented groups. Based on the strategic plan, the Deputy Director for Research, with full participation from the Thrust Area Leaders, develops a series of task statements for the next period. If the Research Committee can identify an individual or team specially suited for the task, the task will be directed by mutual agreement to that individual or team. In other cases, a Request for Statements of Interest is distributed and decisions are reached on the basis of responses and negotiations. The Center Director has authority to make final funding decisions.

The Center Director in consultation with the Executive Committee makes strategic and ad-hoc financial decisions. Distribution of funds among programs generally adheres to a strategic allocation plan, which targets percentages of the total budget for specific program areas and attempts to maintain balance in funding among disciplinary areas and among senior and junior faculty. Funding distributions also consider the need to increase participation of individuals from underrepresented groups.

The University of California has an established financial management system that complies with federal, state, and institutional regulations that also govern the PEER Center. Policies and established procedures govern procurement of all goods and services. Knowledge of and adherence to these governmental and institutional regulations is the responsibility of the Administrative Director. Key PEER administrative staff members are aware of cost principles governing expenditures of federal funds (OMB Circular A-21) and procurement procedures prescribed by federal regulations (OMB Circular A-110), and the Cost Accounting Standards. All pre-award activity is channeled through a centralized Sponsored Projects Office, delegated to be the Authorized Institutional Representative for all agreements (grants, contracts, subawards) with the institution. They also make certain that budgets (rates, benefits, overhead and other allowable costs) and terms and agreements are in compliance with institutional as well as governmental regulations. A centralized Extramural Funding Accounting Office is responsible for the university's invoicing of the awarding agency (if applicable). The invoice is usually presented with a financial progress report required by the agency at the time of invoice.

The multi-institutional nature of PEER requires special efforts to foster communications and collaborations. These communications begin with regular (usually twice monthly) meetings of the Executive Committee, usually through telephonic means. The Director and Deputy Director communicate more frequently by email, telephone, or face-to-face meeting. The researchers are brought together quarterly to discuss research strategic plans, research needs, and research accomplishments, and quarterly reports are required for each project. All project PIs or their research students, or both, are required to attend these meetings. Information on PEER programs is documented on the PEER web site, in the quarterly PEER newsletter, and by regular email communications. Video-conferencing units have been installed at six campuses.

5.5 Equipment and Space

The PEER headquarters is at the University of California, Berkeley. Effective June 2006, central offices will be located in Davis Hall on the Berkeley campus in new space designated for PEER. Some space and personnel will be maintained at the original Richmond Field Station facility. One administrative support office at UC San Diego assists in the day-to-day administration and management of the education activities of the center.

The PEER headquarters is responsible for overall administration of the center program. NSF and primary matching funds are held entirely by the PEER headquarters until subcontracts are made to individual principal investigators at PEER institutions. The PEER headquarters also serves as a central clearinghouse for all PEER activities, and publishes research reports, newsletters, and Internet information from the central location.

Overall research coordination and specific responsibility for the core research program funds is the responsibility of the Deputy Director for Research (Gregory Deierlein). Administration of all research activity is through personnel at the PEER headquarters at UC Berkeley.

Education program coordination is carried out partly at the UC San Diego office. This office is responsible to convene the Education Committee and develop an education program, develop program announcements and requests for proposals, and make recommendations for education program funding to the Center Director. This office also is responsible for the day-to-day management of the education program.

The center brings outstanding and unique research facilities together in a single network. Experimental facilities include the largest centrifuge, the largest three-dimensional shaking table, the largest tsunami wave tank, and the largest strong-wall/test floor facilities currently operating in the US. Five NEES equipment sites are at PEER universities. The network of unique facilities, linked by a modern telecommunications system, facilitates multi-institutional coordinated research to be carried out as part of the center.

5.6 Financial Support and Budget Allocations

Annual financial support provided to PEER has been at a fairly consistent level for the first seven years. During Years 3 through 5, three large contracts were awarded under PEER's Lifelines Research Program; two being awarded from separate agencies of the State of California and one from private industry. The funds received under these contracts were intended to support directed research projects beginning in Year 3 and extending for 3-4 years, resulting in relatively large residuals in intervening years. These have been largely spent down by Year 7.

Since Year 1 PEER has planned to develop an excellent relation with outside sponsors with intent to develop funding programs that enhance PEER's overall funding base and sustain the PEER program beyond Year 10. The PEER Lifelines Program (Phase 1), initiated in Year 1 with \$2.4M leverage funding from PG&E Company, was further leveraged with PG&E, California Energy Commission, and California Department of Transportation to provide a stable funding base for lifelines research in Phases 2 and 3. Funding for Phase 4 has been or is being negotiated with Caltrans and the CEC. We are active in developing other contracts the California Earthquake Authority, Governor's Office of Emergency Services, and San Francisco Department of Building Inspection.

PEER also is working to maintain its state funding beyond Year 10. Beginning Year 5, we have worked closely with the California Seismic Safety Commission to maintain PEER's matching fund base from the State of California and have been successful in retaining all the matching funds despite severe State of California budget shortfalls. Director Moehle is a member of the Research Committee of the CSSC, where he is working to develop the basis for continuing State support.

An important component for continuing the State of California matching funds is to identify continuing federal dollars to support PEER programs. In 2004, 2005, and 2006 PEER Director Moehle has led efforts to develop and submit a NEESR Grand Challenge proposals that could serve as a basis for continuing the state matching funds. Substantial international collaborations leverage the proposed program. The 2006 proposal is under review at the time of this writing.