Pacific Earthquake Engineering Research Center

an NSF-administered Engineering Research Center
under cooperative agreement number EEC-9701568

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(Lead Institution)

California Institute of Technology

Stanford University

University of California, Davis

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University of Washington

8th Year Progress Report and Renewal Proposal

Volume 1

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PROJECT SUMMARY

The Pacific Earthquake Engineering Research (PEER) Center is an Earthquake Engineering Research Center administered under the National Science Foundation Engineering Research Center Program. The mission of PEER is to develop and disseminate performance-based procedures, tools, and data for seismic design and construction of facilities and infrastructure to meet the diverse needs of owners and society. Current approaches to seismic design do not make optimal use of seismic hazard information, use simplified response simulation procedures, and fall short in providing information about expected future performance. These current approaches produce facilities and infrastructure whose performance may not meet the needs of owners and society. The PEER program is developing a performance-based earthquake engineering approach that can be used to produce systems of predictable and appropriate seismic performance.

To accomplish its mission, PEER has organized a program built around research, education, and technology transfer. The research program merges engineering seismology, engineering, and socio-economic sciences in coordinated studies to develop fundamental data, tools, and methods that are tested and refined by using testbeds in collaboration with practicing professionals. The primary emphases of the research program at this time are on older and new concrete buildings, bridges and highways, and electric power distribution and transmission systems. The education program promotes engineering awareness in the general public and attracts and trains undergraduate and graduate students to conduct research and implement research findings. The technology transfer program involves practicing earthquake professionals, government agencies, and specific industry sectors in PEER programs to promote implementation of appropriate new technologies. Technology transfer is enhanced through a formal outreach program.

The ***intellectual merit*** of the proposed program lies in the multi-disciplinary challenge of understanding performance metrics for complex systems and how they can be simulated and controlled. This requires collaborative, cross-disciplinary research among earth scientists, engineers, and social scientists.

The ***broader impacts*** of the proposed program are extensive. The research program tackles an important and challenging problem, the pursuit of which will advance discovery and understanding of earthquake engineering. Integration of research and education components demonstrates a commitment to teaching, training, and learning at multiple educational levels. The project has a diverse group of principal investigators (PIs) and constitutes a multi-disciplinary research partnership that did not exist before. The education program will expose a diverse population of undergraduates to the program and promote top candidates into graduate research. The project contributes to NSF's Network for Earthquake Engineering Simulation. Results are disseminated in several ways: by involvement of a broad spectrum of faculty, students, and government and industry partners; through the media of print and the Internet; and through broadly used databases and software. By fostering a better understanding of the performance of the built environment under earthquake effects, this project also contributes to knowledge of vulnerability and toughening of infrastructure to the effects of explosive and impact hazards.

PEER PERSONNEL

Key personnel and participating principal investigators are identified below. Participating principal investigators include those who have received funds in the current reporting period or are scheduled to receive funds in the next period. Names with an asterisk (*) denote investigators not funded in Year 8, but funded in the previous year and whose projects were granted no-cost extensions that lasted into Year 8. Biographical sketches are not provided for investigators marked with an asterisk.

KEY PERSONNEL

Jack Moehle, *Director and Thrust Area Leader*, University of California, Berkeley
Gregory Deierlein, *Deputy Director for Research*, Stanford University
Darlene Wright, *Administrative Director*, University of California, Berkeley
Scott Ashford, *Assistant Director for Education Programs*, University of California, San Diego
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Gregory Fenves, *Co–Thrust Area Leader*, University of California, Berkeley
Helmut Krawinkler, *Co–Thrust Area Leader*, Stanford University
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Peter May, *Research Committee Member*, University of Washington

FUNDED INVESTIGATORS

(Names in boldface denote Directors; names in italics denote Thrust Leaders; names with an asterisk (*) denote investigators not funded in Year 8, but funded in the previous year and whose projects were granted no-cost extensions that lasted into Year 8.)

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Roger Borcherdt	*Engineering Seismologist*	US Geological Survey
Raymond Burby	*Professor*	Univ. of North Carolina, Chapel Hill
James Jirsa	*Professor*	University of Texas at Austin
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Robert Bachman	*Consultant*	Private Sector
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David Chambers	*Associate Engineering Geologist*	California Energy Commission
Lloyd Cluff	*Manager, Geosciences Dept.*	Pacific Gas & Electric Company
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CDComartin	*Stockton, CA*	Craig Comartin
Certus Consulting	*Oakland, CA*	Evan Reis
Degenkolb Engineers	*San Francisco, CA*	James Malley
Earth Mechanics	*Fountain Valley, CA*	Po Lam
Exponent Failure Analysis	*Menlo Park, CA*	Akshay Gupta
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Risk Management Solutions	*Newark, CA*	Mohsen Rahnama
Rutherford & Chekene	*Oakland, CA*	William Holmes
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The St. Paul Companies	*Fairfield, CA*	Nesrin Basoz
Wiss Janney Elstner Associates	*Emeryville, CA*	Kent Sasaki

CONTENTS

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 trade-offs 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 trade-offs 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 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 trade-offs 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.

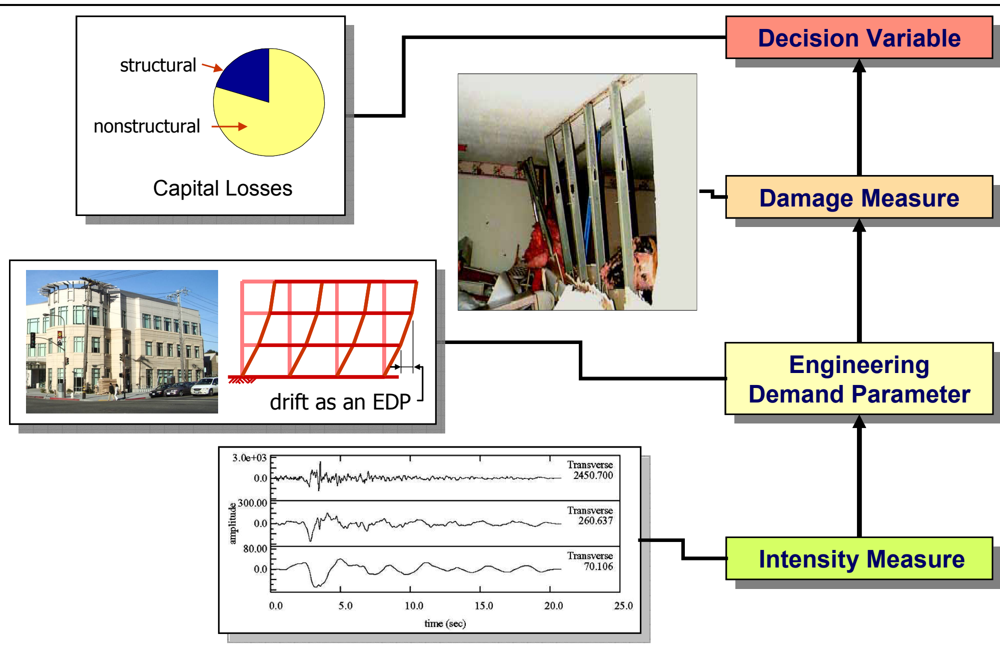

Figure 1.1 – Performance-based earthquake engineering framework. PEER is conducting research on the overall framework (right) and individual elements (left). In this example, building repair costs are broken out so that designers can focus design on those building components that contribute most to cost.

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 event. 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 multi-disciplinary endeavor.

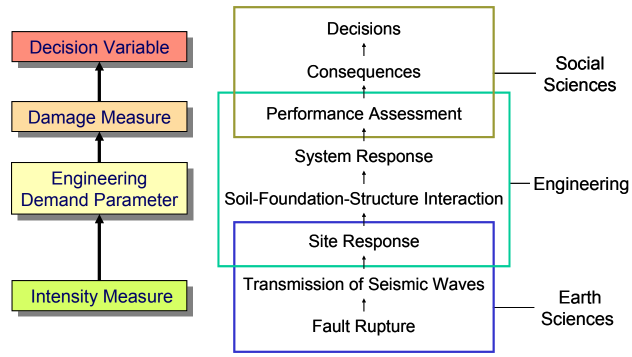

Figure 1.2 – Multi-disciplinary integration in performance-based earthquake engineering. Steps in performance-based earthquake engineering shown center, PEER's framework variables shown left and traditional disciplines shown right.

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, ATC 40, FEMA 354). PEER is working closely with other organizations, including the Applied Technology Council and the Federal Emergency Management Agency, to develop and implement methodology that will form the basis of next-generation performance-based guidelines. 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 multi-disciplinary effort involving earth scientists, engineers, social scientists, and experts from other related disciplines. It also requires development of a framework that can link the 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 have significantly improved integration of the different aspects (and disciplines) of the performance-based earthquake engineering problem, and have helped focus attention on modeling, simulation, and data gaps that require additional development in Years 8–10. They also provide a model for benchmarking studies that will be a major focus of future 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

PEER's Student Leadership Council led the effort to organize the first annual Undergraduate Shake Table Competition. In 2004, the first year of the competition, teams from PEER's Core and Educational Affiliates participated in an exciting "shake-off." The program was so successful that teams from MAE and MCEER decided to join the 2005 competition. Participating teams are judged by a team of practitioners on factors including performance, technical merit, economics, and oral presentation. This competition gives students not only the opportunity to apply what they've learned in the classroom, but also to gain an introduction to research and education in earthquake engineering.

Figure 1.3 – Participants in PEER's 2004 Undergraduate Shake Table Competition

2005 EERI Distinguished Lecturer

The annual Distinguished Lecture Award of the Earthquake Engineering Research Institute is awarded to individuals to recognize and encourage communication of outstanding professional contributions of major importance for earthquake hazard mitigation. In 2005, PEER Director Moehle was named the Distinguished Lecturer, speaking on the subject of performance-based earthquake engineering. The lecture draws from the work of PEER, covering aspects of earthquake ground motion, structural response simulation, damage evaluation, quantification of losses, and implementation. The award provides travel support so that the lecture can be delivered to a broad audience throughout the year. Already, the lecture has been given in Ixtapa, Mexico; UC Berkeley; U. of Illinois, Urbana-Champaign; U. of Texas, Austin; Purdue Univ.; U. of Michigan, Ann Arbor; and at the New Madrid Chapter of EERI, St. Louis.

Figure 1.4 – Director Moehle meets students following EERI Distinguished Lecture at U. Texas

PEER ground motion working community

Figure 1.5 – PEER ground motion working meeting

A goal of performance-based earthquake engineering is to express the probability that earthquake ground motion will reach or exceed a design value. PEER's Next Generation Attenuation (NGA) project is aiming to accomplish that goal. The project is generating a lot of excitement and interest — a recent two-day meeting attracted more than 75 participants, mostly volunteers, including geologists, seismologists, geotechnical engineers, structural engineers, government representatives, and various consultants, drawn from academia, government, and private industry. Sensing the unique nature and value of the program, other organizations such as the Southern California Earthquake Center (SCEC) have begun to develop partner programs that leverage PEER funding. The open process and broad participation are leading to consensus on the new ground motion models, so the outcomes will be broadly accepted by the earthquake community. The types of facilities that will be affected include buildings, bridges and transportation systems, components and networks of electric systems, and other lifelines.

IDEAS:

Self-centering bridges

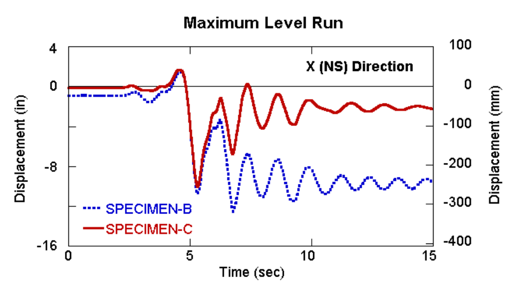

Figure 1.6 – Self-centering column C returns to near original position after earthquake, whereas conventional column B does not.

Following an earthquake, highway bridges are required for emergency response and long-term recovery of the affected region. If the bridge is leaning after the earthquake, expansion joints will not align so the bridge will be unusable. PEER researchers Mahin (Berkeley) and Billington (Stanford) have developed a self-centering bridge column that ensures the bridge will be plumb following a major earthquake. The self-centering column is constructed using unbonded post-tensioned reinforcement rather than conventional bonded reinforcement. Construction costs are about the same for both types of columns, but shake-table tests demonstrate the superior performance of the self-centering column.

Building repair costs

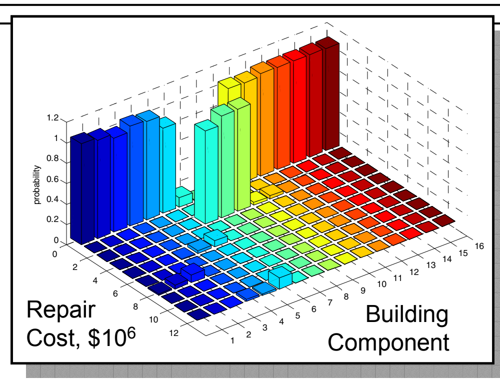

Figure 1.7 – Repair costs broken down by building components

When major buildings are constructed, a complete set of building specifications defines all the components of the building and their installation. Building construction costs are broken out according to a compatible scheme. Working with PEER Business and Industry Partners, PEER researchers defined a similarly compatible scheme for categorizing and computing repair costs following an earthquake. By using a compatible scheme, the repair cost algorithms can be quickly generated as part of the building design process. This makes it easy to incorporate downstream costs into the design process not only because the data are compatible, but because designers will be familiar with the concepts and therefore more willing to adopt them.

Using explosives for basic science research

When he heard that the explosives were being charged, PEER Professor Scott Ashford (UCSD) took a front-row seat. The theater was a soft soil deposit in Hokaido, Japan. Such deposits are prone to liquefaction, a condition in which, under strong ground shaking, the soil behaves as a heavy liquid susceptible to lateral movement. Structures situated in such soil deposits can be destroyed by the movement. The Hokaido experiment involved a series of underground explosions that shook the ground as an earthquake does. Before the experiment, Professor Ashford installed a series of test models, including bridge foundations and underground pipes, equipped with essential instrumentation to record the phenomenon. Data recorded during this staged earthquake enable earthquake engineers to understand basic behavior of structures in liquefied soil, and help them develop models for simulating real structural response during earthquakes.

Figure 1.8 – After the explosion, the test structures are found in haphazard conditions as they would be following an earthquake.

<u>TOOLS:</u>

OpenSees Navigator

PEER developed OpenSees (Open System for Earthquake Engineering Simulation) to enable cross-disciplinary research in seismic response simulations. OpenSees has rapidly become the leading international open source computational simulation framework for researchers. A major new application, OpenSees Navigator, was developed to accelerate the use of OpenSees and to expand the range of its applicability. Developed by PEER graduate students Tony Yang and Andreas Schellenberg under the direction of Profs. Mahin and Moehle, OpenSees Navigator enables users to quickly build and validate computational models, and carry out and graphically visualize the results of complex nonlinear dynamic analyses. This application has tremendously expanded the use of OpenSees by students, researchers, and practitioners. Since OpenSees has been adopted as the computational framework within NEES,

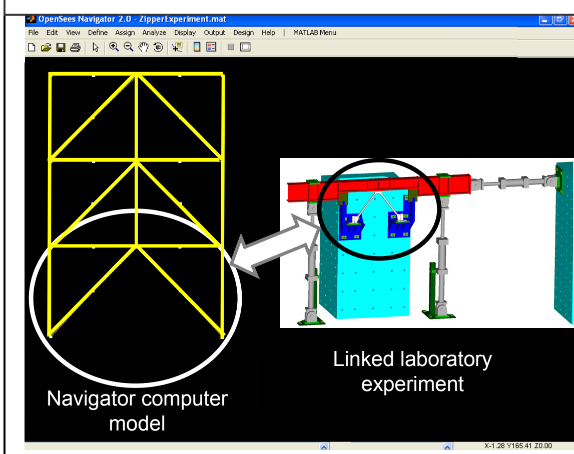

Figure 1.9 – OpenSees Navigator provides easy NEES link between computer and laboratory simulations.

it is expected that OpenSees Navigator will have a large impact in the future on the adoption of high-performance computing by the NEES community. Anticipating this, OpenSees Navigator adds new modules to support hybrid simulations, in which part of a simulation are carried out based on computer models of portions of the structure and the rest of the simulation consists of one or more physical specimens tested in the laboratory. This new capability has been developed to work with any NEESit compliant laboratory in the U.S. or elsewhere, opening up new opportunities to carry out integrated experimental and computational studies using NEES and other resources.

Shallow foundation models

An interdisciplinary team of PEER researchers completed a program of centrifuge modeling, theoretical developments, and OpenSees implementations to produce simulation tools for the seismic response of shallow foundations. These models had been identified as a high-priority need for improving performance-based design procedures for buildings. For example, foundation compliance can affect the distribution of inelastic demands in a superstructure during an earthquake, and, in some cases, the incorrect modeling of shallow foundation compliance has led to ineffective retrofit design strategies. A series of 60 model footings were tested in a geotechnical centrifuge to provide the required experimental data for defining the interaction mechanisms between vertical, lateral, and overturning loads on shallow foundations. These data provided the basis for theoretical development of contact element models, which were subsequently numerically implemented in OpenSees. Subsequent comparisons of computed and recorded responses for the centrifuge models completed the validation process. The accelerated progression from experiments to theoretical modeling to implemented simulation tools on this problem of fundamental and practical importance was facilitated by the Center's ability to coordinate interdisciplinary research teams.

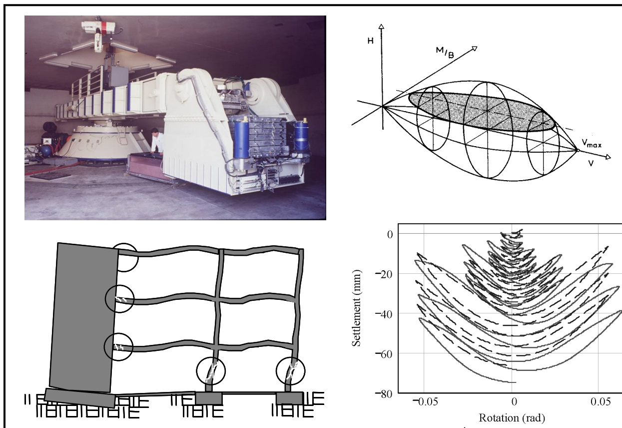

Figure 1.10 – Shallow foundations — Centrifuge testing, to model development, to implementation

Nonstructural test protocol

Performance-based earthquake engineering aims to predict performance of a facility as a function of the seismic actions to which it is subjected. Knowing how nonstructural components (e.g., partition walls, sprinkler systems, etc.) behave under earthquake loading is key to the process. PEER proposed and then

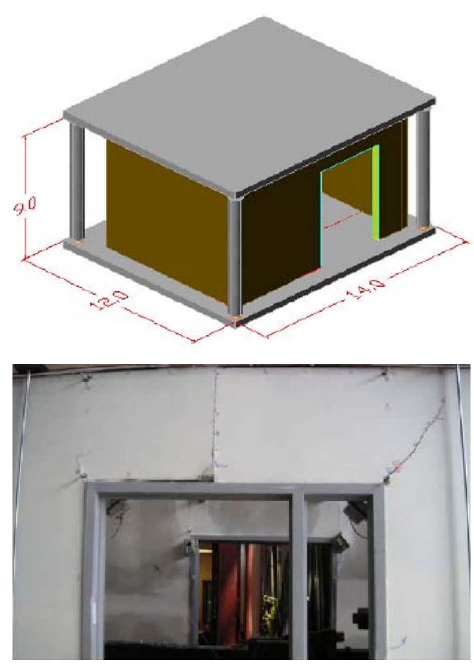

Figure 1.11 – New test protocol improves usefulness of nonstructural tests

participated with MAE, MCEER, and the Applied Technology Council in a project to develop consensus on a testing protocol for nonstructural components. The protocols were debated during a two-day workshop involving participants from equipment manufacturers, regulatory agencies, engineering professionals, and academia. The resulting protocols, which are already in use, make it feasible to perform testing in a consistent way and to document test data in a manner that permits direct utilization for the development of fragility curves of nonstructural components.

1.3 NSF Engineering Research Center Quantifiable Outputs and Benchmarking

The National Science Foundation Engineering Research Centers (ERC) Program has established fixed parameters for measuring the outputs of ERCs. PEER emphasizes quantifiable outputs such as publications and data, tools, and methods implemented in professional practice, with reduced emphasis on licenses, patents, and spin-off companies. More information on PEER products can be found at http://peer.berkeley.edu.

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 performance-based earthquake engineering 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), as the research matures. 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 specific 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

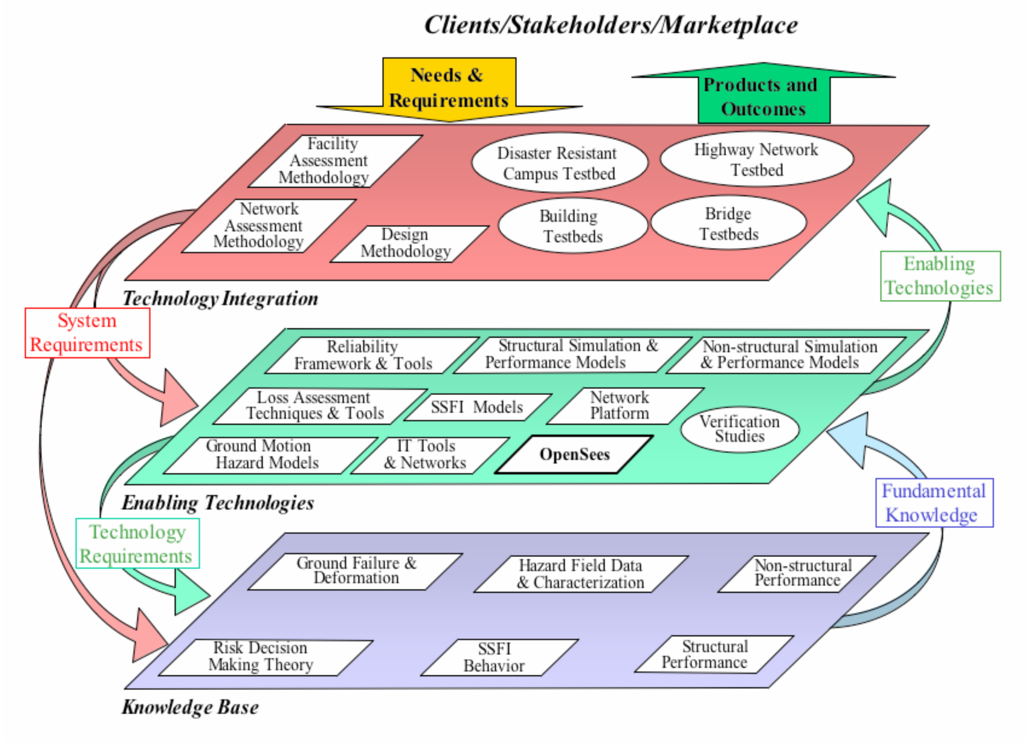

Figure 2.1 – Systems Level Strategic Plan

improvements within such systems by making clear trade-offs among improved performance of the system elements.

- 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.

It is our view that a unified approach to characterize performance can be developed to satisfy each of these types of decisions. To achieve this approach, a more fundamental definition of performance is required than has been used in the past. This unified approach aims to characterize performance in terms of probabilities of exceeding a specified loss during a specified exposure period, or for a scenario event. This differs from the current approach for seismic design or assessment of individual facilities, which aims to meet specified component criteria for loadings associated with specific hazard levels.

A conceptual illustration of the approach we envision is shown in Figure 2.2. The upper portion of the curve illustrates the load-displacement envelope for an individual facility such as a bridge or building. Two readily defined points on the curve correspond to the linear-elastic and collapse limit states. 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 based on the individual 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 themselves were based considerably on judgment and have been the subject of continuing debate and discontent. 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.

The PEER 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 losses of interest are direct dollar loss, casualty loss, and loss of function. Notably, these are applicable to individual facility design and assessment, facility rating systems, portfolio analyses, and regional loss studies, and thereby provide a unifying means of assessing performance for the range of needs and requirements of the clients, stakeholders, and marketplace for PBEE.

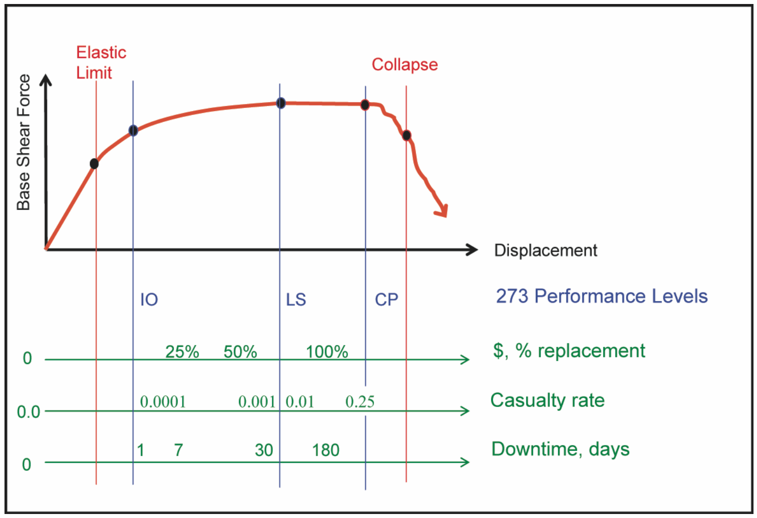

Figure 2.2 – Idealized relation between performance and load-deformation response (after Holmes, PEER 2001 Annual Meeting)

PEER's research focus is toward developing an accepted "performance engine" or "means of verification" to evaluate the performance metrics (dollar losses, downtime, and casualty rates), and thereby 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 underlying approach 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-tectonic, infrastructure, and socio-economic components of earthquake engineering into a system that can be analyzed and on which rational decisions can be made. These methodologies should be applicable to individual facilities and to inventories of interacting facilities. Testbeds are established to exercise the methodologies, to identify additional needed research, to lead to simplified approaches, and to demonstrate the socio-economic impact of different performance objective formulations.

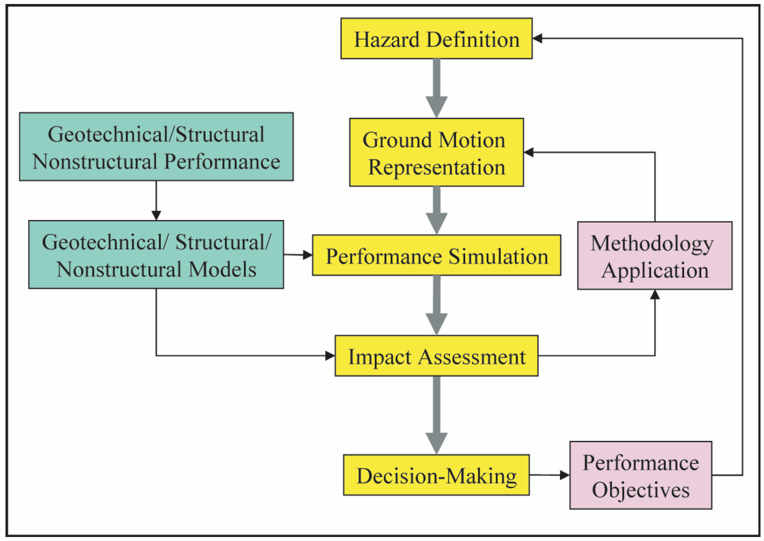

Figure 2.3 – Research elements in the performance-based earthquake engineering methodology

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 being developed by PEER involves the application of all the steps of the process identified in Figure 2.3. As a convenience for the graphic only, the term Methodology Application is shown within an inner loop that corresponds to assessment of a facility, as opposed to design. Assessment has been a primary focus of PEER research up to Year 7. As PEER moves forward in Years 8–10, this focus is being expanded to include design. As this occurs, the Methodology Application will move to the outer loop to encompass the entire process.

2.1.2.2 Formalization of the Methodology

Two unifying features of the PEER program are the integration of the simulation/information technology tools and the formalization of a common methodology for performance assessment. Given the inherent uncertainty and variability in seismic response, it follows that the assessment methodology should be 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), 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).* Recognizing the inherent uncertainties involved, these variables are expressed in a probabilistic sense as conditional probabilities of exceedance, i.e., $p[A \mid B]$. Underlying the approach in Figure 2.4 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 probability 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

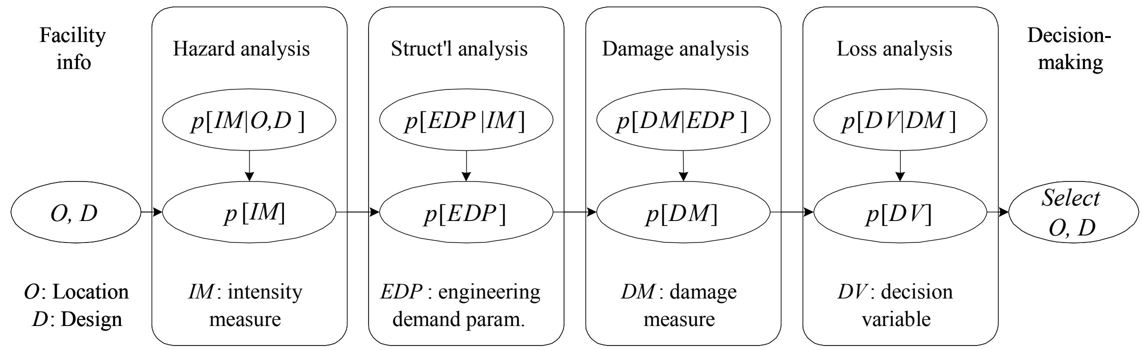

Figure 2.4 – Underlying probabilistic framework of PEER's performance-based earthquake engineering framework

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 probabilities 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 probability of exceedance for the *DM*, i.e., $p(DM)$.

The final step is to calculate *Decision Variables*, *DV*, described in terms of mean annual probabilities 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 previous 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.

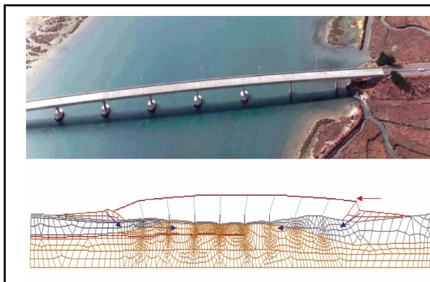

Figure 2.7 – Humboldt Bay Bridge

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), has been designated a FEMA Disaster-Resistant Campus and has an extensive seismic retrofit program under way. Testbed studies include: documentation of the potential losses; design criteria; quantifying the change in potential losses based on enumerated performance standards; and study of decision-making processes associated with setting 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.

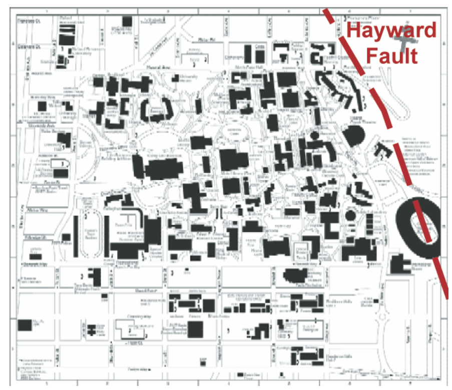

Figure 2.9 – UC Berkeley Campus

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.

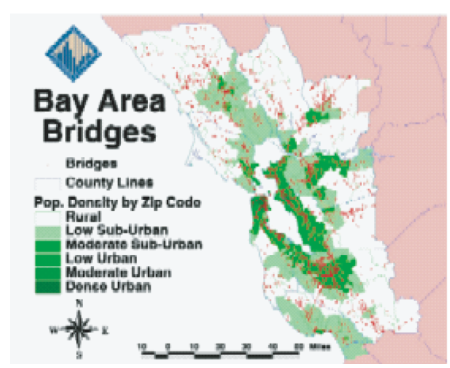

Figure 2.10 – Highway Network

These testbeds were a major focus and served an important role to help integrate the PEER research in Years 5–7. They culminated with summary presentations at PEER's Year 7 Annual Meeting. Technical reports and details of the studies are available at *http://peer.berkeley.edu/04tb_review/index.html*. 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 software has been assembled for simulating the seismic performance of highway networks. The platform is set up for the San Francisco Bay Area highway network, and incorporates detailed data describing geographically distributed seismic hazards, bridge descriptions, and transportation links. This platform is unique from other geographically distributed loss analysis systems in that it links transportation network analysis software with data on damaged bridges obtained from a comprehensive seismic risk analysis. Beginning in Year 6, development of the Network Platform has been incorporated under an EERC Tri-Center Initiative on Geographically Distributed Lifeline Systems. One focus of the Tri-Center initiative is on highway and electric utility lifeline systems. In addition to the core programs of the three EERCs (PEER, MAE, and MCEER), the initiative involves the PEER-Lifelines Program, the MCEER-FHWA program, and externally funded Caltrans research. As part of the Tri-Center collaboration, PEER is orienting its bridge performance and highway risk analysis efforts to be compatible with a seismic risk assessment program, called "REDARS," whose core development is supported by MCEER-FHWA. PEER's research focus is toward developing improved modular components of REDARS and using REDARS in studies of system performance. PEER's specific research contributions will 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 both the Tri-Center initiative and PEER 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 defined largely by the research needs of the middle and upper planes of Figure 2.1.

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

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* P*lanes* 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).

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 program. The Lifelines Program was established 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 on-line databases, and (5) performance of structural and nonstructural components. While this research management structure has been 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.

During Years 5–7, the proof-of-concept testbeds (Section 2.1.2.3) served an important role to synthesize the methodology components; and, in many respects, provided a natural framework to manage the research. In particular, the testbeds proved to be an effective means to focus the research to address specific needs of the PBEE applications to buildings and bridges and the networks of which they are a part. While the PBEE methodology and components, as shown in Figure 2.11, are generic in concept, the testbed exercises demonstrated that important aspects of the PBEE implementation to bridge and building systems are unique. For example, whereas the three categories of decision variables (dollar losses, functionality, and casualties) are general, the relative importance of each is quite different for buildings and bridges. For buildings, all three metrics tend to have equal importance (though differences exist between various stakeholder groups). On the other hand, for bridges post-earthquake functionality tends to be the metric of overriding importance, particularly with respect to how the bridge performance impacts the transportation network. These differences in emphasis lead to differences in how the PBEE methodology and tools are applied to bridges versus buildings. Further distinctions between bridges and buildings extend to other areas of the methodology, beginning with basic modeling attributes for the system simulations.

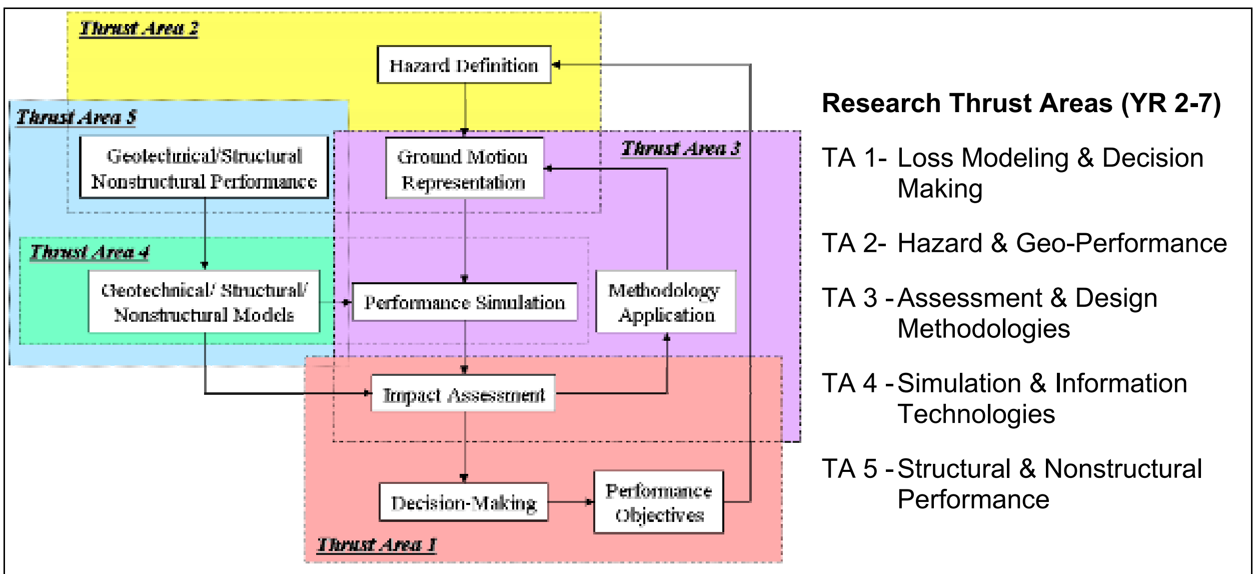

Figure 2.11 – Research thrust areas (Years 2–7)

After thoughtful deliberation and consultation with the PEER Scientific Advisory Committee, the PEER Research Committee decided in Year 7 to reorganize 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* has much the same emphasis as the previous Thrust Area 4, a key concern being the development of *OpenSees*. One change with the new TA IV is a stronger linkage to validation testing and simulation of structural and geotechnical components. Whereas the validation activities were previously managed through TA 2 (geo-performance) and TA 5 (structural performance), now these are managed from TA IV. Finally, the new TA III encompasses the *Lifelines Program*, whose primary focus is on characterization of earthquake ground motions and ground deformation and their effects on transportation systems, electric utility components, and other lifelines.

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. Immediately 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

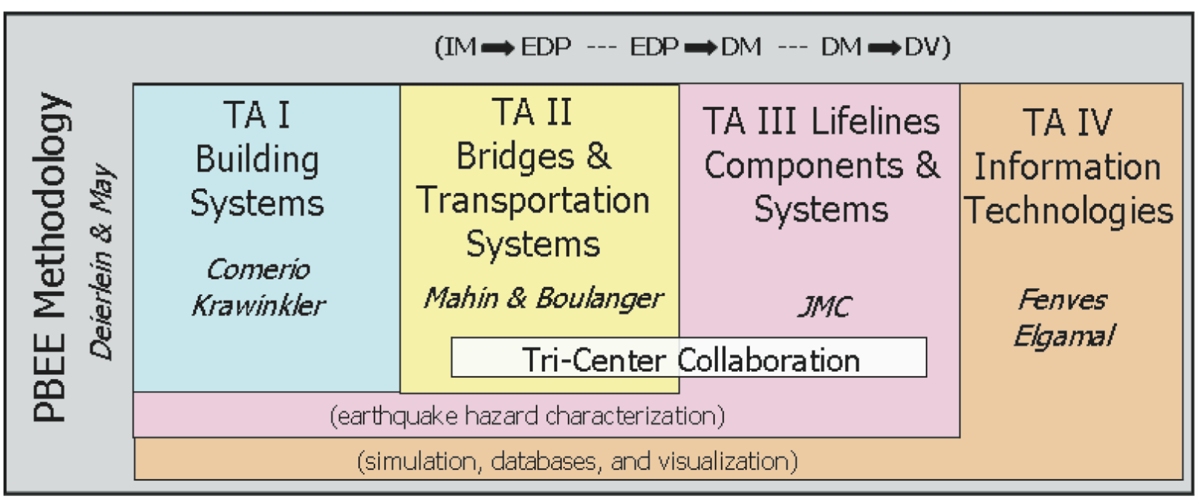

Figure 2.12 – Realignment of research thrust areas (Years 7–10)

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 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.
- *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.

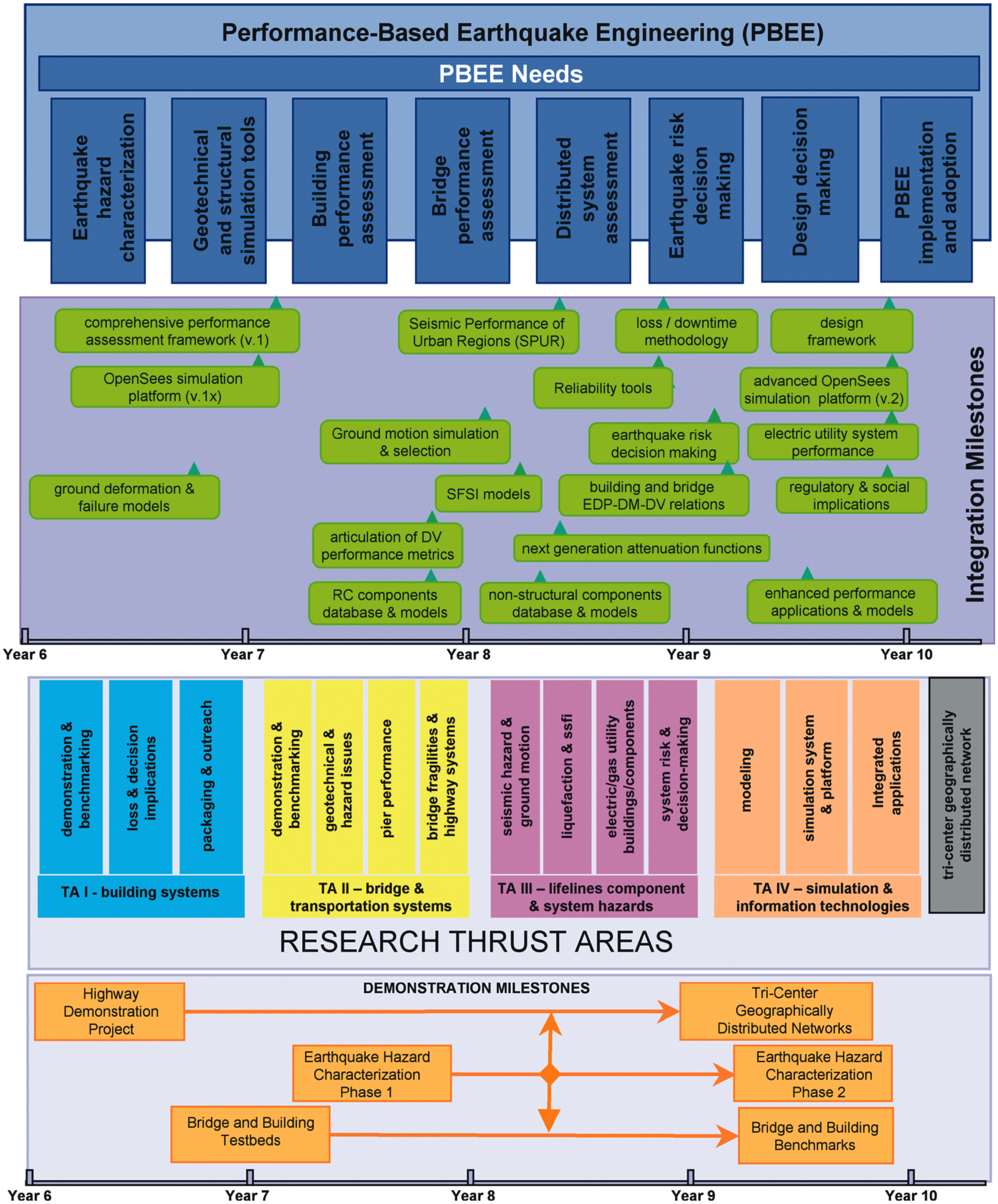

Figure 2.13 – Outcomes, Integrative Milestones, and Thrust Areas

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 individual 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 will be 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 will be 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. Section 2.6 provides further details of this collaborative project, which utilizes earthquake hazard and simulation research from Thrust Areas III and IV.

- *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 will be developed 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. Beginning in 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 will serve to integrate and focus the interdisciplinary research and provide a mechanism for packaging the assessment methodologies in a consistent format. Additionally, the change in emphasis from studies of specific testbed facilities to generalized classes of facilities will serve the emerging needs for design and system considerations.

The benchmark studies will provide 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-III 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.

2.2.3 Years 8 and 9 Research Project Summary

Research projects for the current Year 8 and those proposed for Year 9 are summarized according to thrust areas. Detailed summaries of all current (Year 8) 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 xyz2004 (or xyz2005) 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 coordinated through a series of quarterly coordination meetings and workshops.

2.3 Thrust Area I: Building Systems

2.3.1 TA I Goals

The Building Systems thrust area was created at the end of Year 7 to bring focus to the research and implementation issues that were exposed but not completed in the building testbeds. Work on the Van Nuys and the UC Science building testbeds illustrated the PBEE methodology developed by PEER. In these two assessments of existing buildings, researchers demonstrated the capacity of the 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 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 frame and wall systems, and

(3) to package the PEER performance-based engineering methodology in a way that makes it accessible to the engineering community. This is part of the outreach effort that will become a major aspect of the PEER effort for the next three years.

2.3.2 TA I Strategic Plan

To achieve the three-part goal, the research for Years 8–10 is organized around these three themes, as is outlined in the strategic plan chart in Figure 2.14. To make informed "Performance Decisions," an engineer as well as an owner or facility 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, four projects focus on modeling consequences and estimating losses (Comerio [1202004], Miranda [1302004], Beck [1362004], and Ince [1322004]). On benchmarking, Deierlein [1382004] is continuing work with input from Lowes [1392004] on structural fragilities and a proposed project on damage models on structural components [1402005]. Stewart [1342004] 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 [1352004] on shallow foundation performance and a proposed project on performance design of foundations

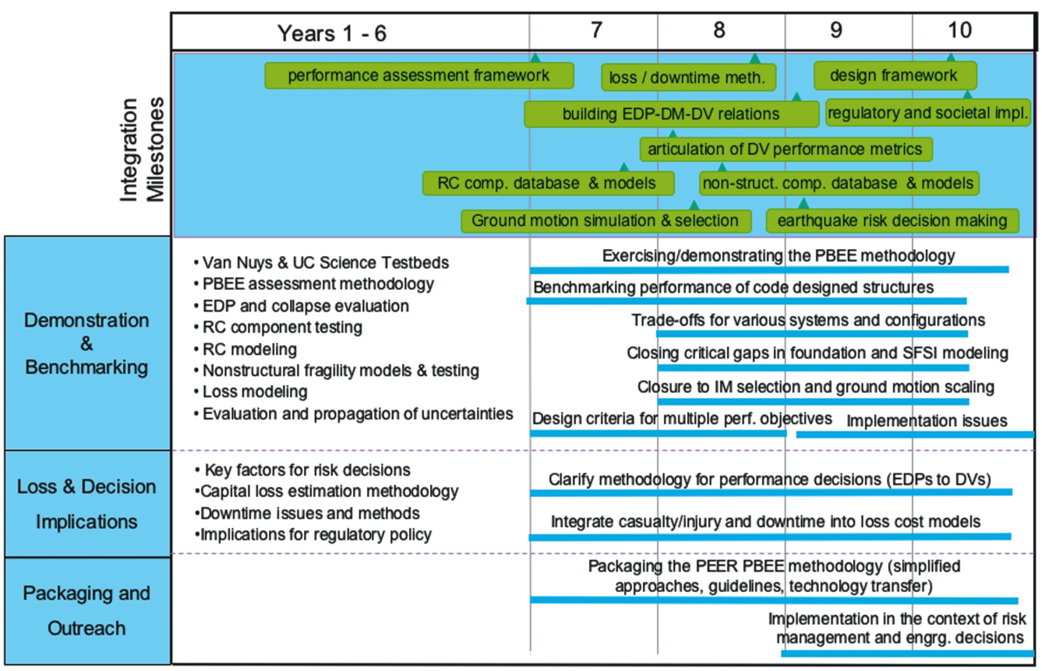

Figure 2.14 – Strategic Plan: Thrust Area I — Building Systems

[1412005]. Cornell [1312004] has a related study of the Intensity Measure *(IM)* selection and ground motion scaling procedures. Krawinkler [1012004] will be responsible for the overall packaging of the methodology for practicing engineers, while May [1072004] will focus on the role of performance engineering in the regulatory systems and mechanisms for outreach for early adopters in the engineering community.

2.3.3 TA I Critical Mass and Level of Effort

All Principal Investigators will work across the spectrum of the performance equation and each individually will contribute to the methodology and 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, Ince, 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.

Below, each Year 8 research project is briefly described.

Comerio [1202004] is working on a method to estimate the time needed to re-occupy a building based on factors unrelated to the repair of physical damage. These factors include the importance of the space to operations, the ability to finance, and the ability to secure “surge” space for construction. The approach was articulated at the end of Year 7, and two articles are in press. In Years 8–9, the methodology will be integrated with casualty and cost estimating, with a specific focus on the translation from engineering demand parameters to loss consequences.

Miranda [1302004] has developed a sophisticated method for estimating probable loss costs based on engineering demand parameters. In Year 8, 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 9–10 the objective is to develop knowledge and tools that will enable practicing structural engineers to conduct loss assessments of buildings using PEER’s performance-based methodology. 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.

Ince (and Meszaros, if available) [1322004] will continue to work with Miranda to integrate financial parameters into the loss model and to formalize appropriate financial decision mechanisms needed from performance assessments. The project will formalize appropriate financial decision mechanisms needed from performance assessments.

There will be considerable coordination between these “performance decision” researchers and those involved in benchmarking and methodology development. The larger goal, not only in Year 9, but throughout the work, is to clearly develop methods that translate engineering outputs into decision parameters—issues that force design and performance decisions.

May was funded in Years 6–7 to consider the regulatory system implications of PBEE. These are published, and in Year 8 he began a review of the societal implications of PBEE, taking a systematic look at the benefits of performance engineering, particularly in the regulatory context [1332004]. In Year 9, May will focus on mechanisms to transfer performance engineering methods to engineering practitioners and the regulatory community.

Deierlein [1382004] is conducting the lead project in the benchmarking effort. He is applying the PEER methodology and tools to assess the performance of RC frame and wall 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 [1362004] is using the information generated in project 1382004 on *EDP*s for the benchmark buildings to perform loss estimation. In support of this goal he will focus on the following objectives: (1) coordinate further development of his loss estimation toolbox with Miranda [1302004] so that a single packaging of PEER's *EDP* to *DV* methodology results, (2) in coordination with Comerio [1202004] 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 and Ince begin developing a decision analysis framework that uses the "3 D's" (dollars, downtime, and deaths) as *DV*s but also allows the decision maker to account for his/her risk attitude.

Stewart's emphasis is the integration of geotechnical/seismological uncertainties into a unified analysis of system performance [1342004]. 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.

Cornell [1312004] 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 *IM*s. Far and near-source situations are being considered. The recommended process includes record selection, recommended number and kinds of nonlinear time history analyses, plus post-processing of response output.

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 developing a set of "guidelines" to be followed in 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.

We also have two placeholders for projects on "Database of Damage and Loss Models for Structural Components" [1402005] and "Performance-based Design of Soil-Foundation Interface in Buildings" [1412005]. The first project [1402005] will be concerned with synthesizing the available knowledge and data on structural *DM*s and loss models and establishing a database that makes this information readily available to the engineering profession. The second project [1412005] will focus on establishing engineering criteria and guidelines for design and performance assessment of the interface between the superstructure and the supporting soil.

2.3.4 TA I Research Advances and Deliverables

The new Building Thrust Area combines researchers from four of the five previous thrust areas—Loss Modeling and Decision Making, Geotechnical Performance, Assessment and Design Methodology, and Structural and Nonstructural Performance. This is similar to the structure of the testbeds, which also combined researchers across thrust areas. The advances made in each thrust area and in the testbeds shaped the decision to create the Building Thrust Area.

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 "3D's"—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 then applied in the Van Nuys and UC Science Testbeds. These have been published in numerous scholarly articles and documented in the testbed results. In Years 6 and 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 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 will focus on broader societal benefits derived from performance engineering and mechanisms for outreach to "early adopters."

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).

At the end of Year 6 most basic concepts of a comprehensive performance assessment framework were in place. Different methods for uncertainty propagation were 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 7–8, 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, Miranda) was integrated through the Van Nuys testbed study.

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 focus of studies in which the PBEE assessment methodology was tested, additional research needs were identified, simplified approaches were developed, and the socio-economic impact of different performance objective formulations was 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 we are selecting a small set of buildings, applying the PBEE methodology, and in the process finding 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 Years 9–10, the *Building Systems* Thrust Area will refine the work started in Year 8. 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 and decision tools for practitioners, (4) continued investigations of policy and implementation hurdles, and (5) outreach strategies to enhance the adoption of performance-based engineering. At this time there are no plans to start a major new effort that has not been identified in the Year 9 research plan. The emphasis will continue to 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. In this respect, TA I is receptive to suggestions for targeted initiatives that will contribute significantly to improvements of the PBEE methodology and its impact on related developments by professional groups.

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. The testbed projects related to bridges (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 (fragility curves, damage measures, decision variables, etc).

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 planning graphic for TA II, Figure 2.15, defines a coordinated sequence of research projects to address the goals described above.

The research plan for Years 8–10 include four projects that are demonstrating the PBEE methodology for variations from a common baseline bridge structure (Stojadinovic 2442004, Mahin 2402004, Kramer/Arduino 2412004, Bray 2422004/Martin 2432004). The variations that each demonstration project is addressing will exercise the methodology for very different purposes, thereby illustrating its usefulness in different ways. The researchers for each of these projects are working closely together, sharing components and models, and bringing different technical expertises to the group effort.

This group effort includes a lead project on clarifying, simplifying, and communicating the PEER methodology that includes a detailed report in Year 8 that clearly specifies recommended procedures for implementation of the PEER methodology for bridge systems (Stojadinovic 2442004). This detailed report will provide a synthesis of best practices that the other projects can utilize and build upon.

This lead effort on the methodology will be followed by a complete demonstration for a baseline bridge structure (Stojadinovic 2442004) that was selected with input from our BIP representatives (Ketchum 2522004). The tentative baseline bridge configuration is a five-span bridge with earthen abutments and typical Caltrans detailing. By focusing on a prototypical baseline bridge, this project provides a complete demonstration of the PEER methodology in advance of the other parallel demonstration projects, and therefore provides a framework for them to utilize and build upon.

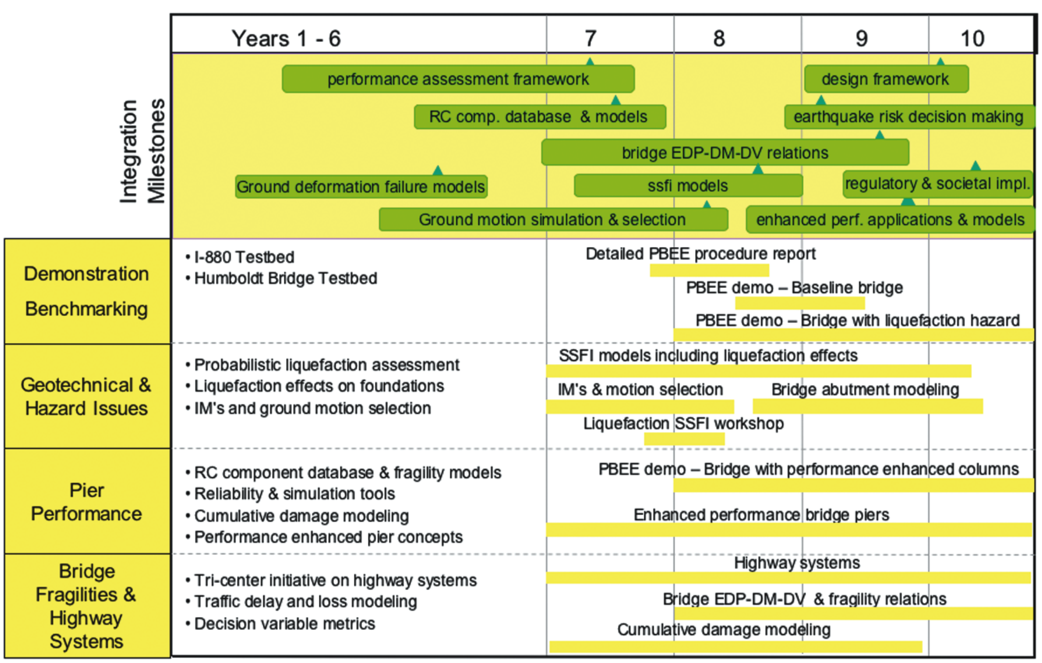

Figure 2.15 – Strategic Plan: Thrust Area II — Bridge and Transportation Systems

The benefits of performance-enhanced piers will be 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, for which performance-enhanced piers may be well suited.

The effects of liquefaction and lateral spreading on bridges will be evaluated through two parallel demonstration projects. The first project (Kramer/Arduino 2412004) will utilize continuum soil modeling capabilities in *OpenSees* as part of the numerical model of the bridge system. This project will consider the effects of varying soil conditions (thickness of liquefiable soil, relative density or penetration resistance for the liquefiable soil, etc.). This project will provide additional insights into the physical effects of liquefaction of bridge performance through the numerical modeling, and also demonstrate how to effectively utilize the PEER methodology in making informed decisions as to whether remediation is warranted or not.

The second demonstration project regarding liquefaction effects on bridges (Bray 2422004/Martin 2432004) includes the development of simplified design recommendations/procedures and the evaluation of 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 will be further developed in Year 8 for a broader range of structural components, as needed for the bridge demonstration projects (Eberhard 2452004). Fragility curves for implementation in transportation systems analyses will also be further developed (Stojadinovic 2442004).

Research on cumulative damage associated with low-cycle fatigue buckling and fracture of longitudinal reinforcement will continue (Lehman 2472004). This cumulative damage research will include 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 will be 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 demonstration 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 the experimental data will contribute to calibration of *OpenSees* models and simpler design analysis models. Similarly, the influence of abutments is a major modeling problem even in the absence of liquefaction, and this aspect will also be addressed (2552005). These studies continue PEER efforts in advancing this field through parallel experiment, computational, and performance-based design projects.

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 (Jeremic 4262004).

In March 2005, a workshop was held on emerging design methodologies for pile foundations in liquefied ground (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.

Research on transportation systems will progress in several ways. The study of uncertainties in the seismic risk analyses for transportation systems (Kiremidjian, Years 7–8) and the economic losses that may ensue for travel disruptions for a Bay Area earthquake (Moore /Fan, Years 7–8) are nearing completion. The outcome of these studies identified the need to develop alternative measures of network systems performance following a major earthquake, with a focus on developing decision support techniques for network managers trying to mitigate seismic risk (Moore 2502004b). Toward that goal, a companion project will address the post-event network design problem, focusing on how to achieve the maximum level of network reliability with limited resources after a major metropolitan earthquake (Fan 2502004a). A third project will study the development and implementation of decision variables for individual bridges that account for the influence that the bridge has on the transportation network (TBA, 2562005). These projects will utilize the REDARS platform and contribute to its development in collaboration with researchers across centers and industry (Stu Werner; Caltrans). Bridge fragility models are a major input to these types of analyses and were identified as requiring further development, and this is being addressed (Stojadinovic 2442004. 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 demonstration projects bring together six researchers (Stojadinovic 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 demonstration 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). For liquefaction effects, the supporting projects include experimental and computational efforts by Boulanger (2382004). In addition, the bridge demonstration 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, Jeremic 4262004, Kunnath 4232004). The work on *EDP-DM*-DVs by Eberhard (2452004), bridge fragilities (Stojadinovic 2442004), and abutment modeling (TBA 2552005) provide support across all bridge demonstration projects, and the work by Moore/Fan (2502004b; 2502004a), TBA (2562004) 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

PEER researchers have made significant advances in the areas that will contribute to the Bridges and Transportation Systems Thrust Area. The reorganization means that the past accomplishments and advances by researchers in this thrust area have come from across the spectrum of past thrust area designations.

The I-880 and Humboldt Bay bridge testbeds (Kunnath and Conte) demonstrated the application of the PBEE methodology to two very complicated, large bridge structures. These projects drew together findings from past PEER research efforts, and were effective in pushing the implementation of the PBEE methodology and in identifying those areas in greatest need of development. The Humboldt Bay bridge testbed exercised newly developed *OpenSees* computational/reliability tools and illustrated the challenges of accounting for liquefaction effects across such a large bridge.

PEER research on liquefaction effects for pile foundations has made great advances, considering this area was poorly addressed only a few years ago. Contributions have included original experimental data, identification of fundamental mechanisms of interaction, development of computational modeling tools, and guidance on simplified design methodologies (Boulanger, Ashford, Conte, and Elgamal).

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 on-line 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, Moore/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 directly from the previously established plan for Years 8–10. A couple of projects may warrant redirection based upon progress in Year 8, but for the most part it is expected that the demonstration and supporting projects will require extensions through Years 9 and 10 (as tailored to specific project needs). The success of these demonstration projects 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. Having demonstrated the PBEE methodology in ways that are accessible to the engineering community provides opportunities for post–Year 10 efforts on utilizing the PBEE methodology for other classes of bridge structures, other technologies, and other hazards.

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, and site effects expected especially in coastal California; (2) to improve ability to estimate extent of ground failures that may affect distributed and/or buried lifelines systems; (3) to develop practical analytical methods including fragilities for assessment of 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, use those models to understand where the greatest uncertainties and research benefits may lie, and 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. TA I, II, and IV are funded by the NSF and core matching funds, whereas 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.

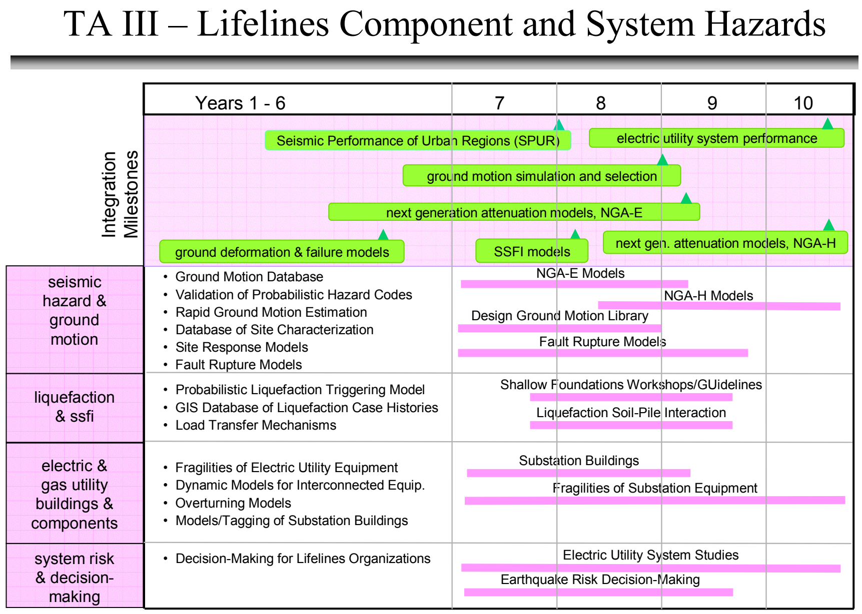

Figure 2.16 – Strategic Plan: Thrust Area III — Lifelines Component and Systems Hazards

The research plan for Years 8–10 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), vertical motions, and other "intensity measures" beyond elastic response spectra (e.g., duration, inelastic spectra, etc.). 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 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 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 to predict earthquake fault surface-rupture displacement for design application to bridges and 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. For this area, recommendations from studies by two of our BIP partners (Maffei 508 and Malley 509) provide guidance on the seismic performance of substation buildings.

In the area of system risk and decision making, the Inter Utility Seismic Working Group (convened at the request of PEER) has recommended that, in addition to continuing work on other tasks mentioned above, PEER should conduct a sensitivity study of a utility system to identify where there is greatest uncertainty and potential for payback. We anticipate that this will be an early project in the next phase, which will build on the previous work of Ostrum (413) and Werner (601). The early study of earthquake risk decision making (604) will be expanded in project 605, where we will endeavor to broaden the number and types of lifelines organizations included in the study.

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 first phase of the NGA project will produce improved models for attenuation relations in the summer of 2005. 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 interaction between piles and liquefied, flowing soils that will serve as a basis for continuing development in Years 8–10.

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. As of this time, the next phase of the Lifelines Program funding is still pending. PEER Director Moehle and PEER Associate Director Bozorgnia are members of both the JMC and PEER Research Committee. This ensures more coherent collaboration between TA III and the other thrust areas. We anticipate that the next phase of Lifelines Program research will extend through Year 10, with new strategic planning taking place during the intervening years to ensure continuation of funding beyond Year 10.

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 substantial 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 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 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. 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 the testbed experience, improvements have been made in solution robustness, testing combinations of

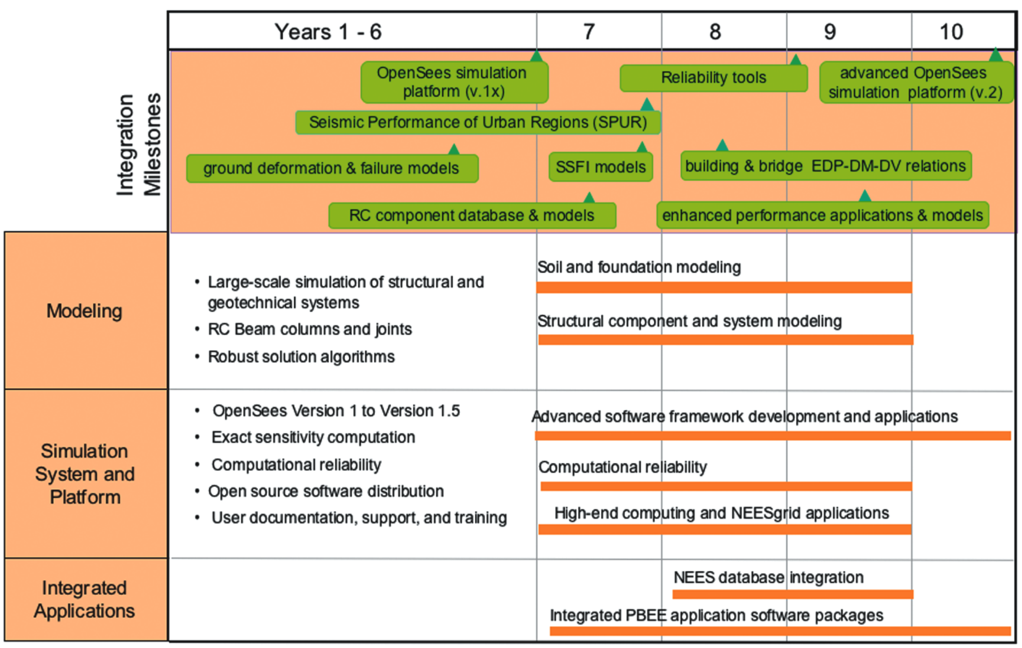

Figure 2.17 – Strategic Plan: Thrust Area IV — Simulation and Information Technologies

NEESit effort 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 2006 as version 1.7.

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.

Within the Modeling category is a thrust to complete the structural models for degrading cyclic behavior of RC components (including shear interaction in columns and joint behavior); improve models for low-cycle fatigue, bar buckling, and fracture, and understand how these behaviors are affected by loading history; model RC systems at incipient collapse; and validate 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, will 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, Year 9 will commence a new project on the development of software tools that include major elements of the PEER methodology, such as hazard definition, modeling and simulation, computation of fragility curves, sensitivity, and incremental dynamic analysis. The software packages will be applied to specific problems, such as soil site response, bridge foundations, and building frames, which are important deliverables and methods of dissemination for PBEE methods. The PBEE software tools will be designed to be modular and extensible for growth in their functionality over time.

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 modeling 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 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.

A major collaboration has been with computer scientists through a separate collaborative NSF-sponsored project on the Seismic Performance of Urban Regions (SPUR), which is allied with the PEER research program. This project integrates PEER's research on structural and geotechnical simulation with fault rupture and ground motion simulation of a region (by Bielak at Carnegie Mellon University) and system integration and visualization research by computer scientists at Mississippi State University and the University of California, Irvine. The results of regional simulation and visualization have provided important insights into how near-fault ground motions vary spatially and affect building response. Computer scientists at MSU (Haupt) have developed middle-ware for communication of massive amounts of data between databases and *OpenSees*, ground motion simulators, and visualization tools. It is notable that Haupt's work with SPUR and PEER has been adopted by NEESit as the simulation portal, and this work will continue in the future between MSU and NEESit. Computer scientists at UC Irvine (Meyer) have developed new rendering methods that can handle scalable visualizations of the subsurface, ground surface, and buildings in a region during an earthquake. Meyer has developed portable visualization for immersive systems and standard graphics boards and displays.

Over the past two 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 8 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.
- 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 the testbed and benchmarking projects and validation of the *OpenSees* models. 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.

During Years 6–7, TA IV researchers worked closely with the Humboldt Bay bridge testbed team on the models and simulations for SFSI, where the robust solution methods in *OpenSees* were particularly valuable because of the complexity of the soil models for liquefaction. This testbed highlighted the need for more robust 3D models to simulate liquefaction and ground deformations, which are the focus of Years 8–9 research by Conte and Jeremic (4132004, 4262004). The other bridge testbed on the I-880 viaduct used the nonlinear beam-column models, including a validation study, and the soil-foundation-structure interaction models developed in the previous Thrust Area 2. This testbed highlighted the need for improved models to simulate cyclic deterioration of RC components associated with rebar buckling, which is the focus of research by Kunnath and Lehman (4232004 and 2472004). The building testbed project on the Van Nuys building and UC Science Building used the nonlinear beam-column elements and RC joint models developed through prior research. Collapse assessment studies of the Van Nuys testbed highlighted the need for improved models and computational strategies to simulate shear critical strength degradation, which is the focus of projects by Filippou and Mosalam (4212004 and 4252004). The testbed exercises further demonstrated how the *OpenSees* scripting routines facilitated parameterization of modeling variables for a large number of analyses and database management of the large arrays of EDP data to evaluate structural and nonstructural performance.

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 8 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 9, the identification of capability and software design for version 2.0 will commence, and efforts to grow and support the expanding user/developer base will continue. Most of this support is through the core development staff of research engineers at Berkeley (Fenves 4102004). Version 2.0 will include advanced capabilities using the parallel computing resources at SDSC.

Model development for RC members will continue and conclude with completion of shear-flexure-axial interaction models (Filippou 4212004), and continuation of advanced models for 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 Jeremic (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.

In Year 8 we identified a need to develop comprehensive tools for PBEE, of which simulation is an important component. The goal of the tool is to provide users a comprehensive tool for defining the hazard, selecting ground motions, building a model, conducting simulations, and computing damage measures and decision variables. The focus is on simulation models and methods for specific problems (e.g., site response, bridge pier, and building frames). It became clear through organized discussions this year that more effort was required for defining the scope and functionality of the software tools for PBEE. The recent demonstration of PBEE by Moehle (Distinguished Lecture Presentation, EERI, 2005 Annual Meeting) and simulation interface such as OpenSees Navigator have provided guidance as to what the PBEE tools should do and how they operate. Although the project was not begun in Year, 8, the deliberations were important. Our plan is to begin a new project for Years 9–10 to develop the PBEE tools. These will be important deliverables for stakeholders to have access to the PBEE methods.

3 EDUCATION PROGRAM

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 Education Program's activity. 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 to provide undergraduate and graduate students with opportunities in the Education Program. Our overall objective is to build a culture within PEER, starting at K-12 and extending through graduate school, where students become excited about earthquake engineering learning and contributing to the learning of others. Figure 3.1 illustrates the overall strategic plan with focus areas, milestones, and the range of students covered by the programs and deliverables. Detailed descriptions of programs/projects are provided in subsequent sections of this chapter.

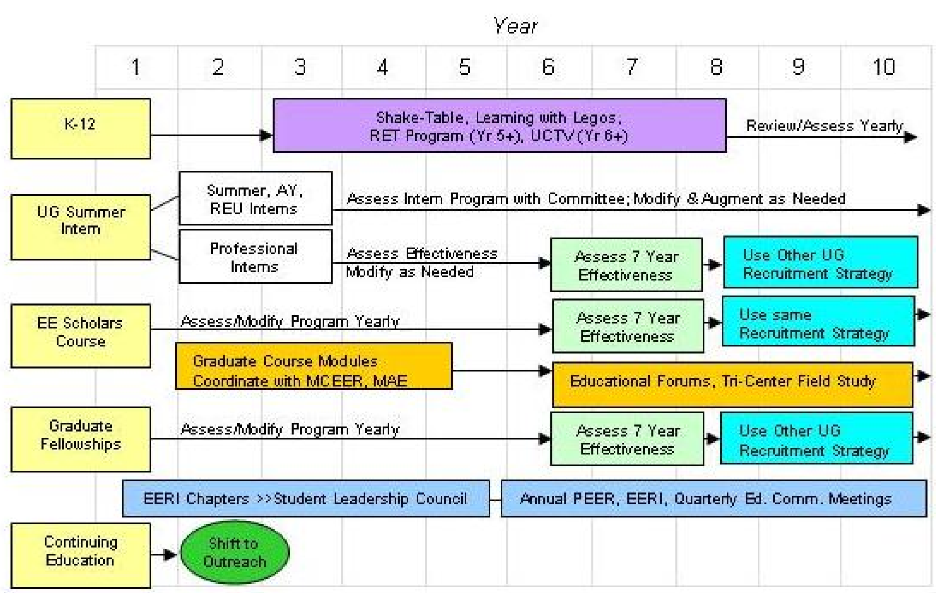

Figure 3.1 – Education Program Strategic Plan

3.2 Current Education Projects and Curriculum Innovations

3.2.1 Current Education Projects

During Year 8, the Education Program will sponsor eight ongoing projects. These are described briefly as follows.

3.2.1.1 Research Experience for Teachers (RET)

Middle-school students from the inner city are often unaware of career opportunities in science and engineering. In an effort to improve math and science education at the middle-school level, PEER has begun working with teachers and their students through a ***Research Experience for Teachers (RET)*** supplemental grant. Our goal is to increase the knowledge and skill level of teachers from inner-city schools, while at the same time having some direct impact on their students. In Year 5, nine teachers from eight inner-city schools spent several weekends on a PEER campus learning about earthquake engineering from faculty and graduate students, as well as receiving detailed instruction on operation of the university's laboratory equipment. These teachers also participated in one session of PEER's Earthquake Engineering Scholars Course. The teachers then worked with their own students to develop science fair projects with experiments carried out by the students and teachers at the PEER university campus. Two of these projects made it to countywide science fair finals, taking second place. We believe that this program is making an impact on K-12 education in two ways: (1) by developing earthquake engineering knowledge and laboratory skills of the K-12 teachers that they can utilize in the classroom and (2) by exposing K-12 students to the university environment so that they can begin to realize it is an achievable goal.

In Year 6, the program expanded to more PEER universities. Six teachers participated in the RET program. In addition to working with a PEER faculty mentor for four weeks during the summer, the participants attended a one-day Communication Skills Workshop, a collaborative effort between the Southern California Earthquake Center (SCEC) and the PEER Research Experience for Undergraduates (REU) Summer Internship Program, as well as a workshop on how to translate their research experience into hands-on classroom practice and experiences for their students. An example of the impact we can have is RET participant Tami Church, a science teacher at Lapwai High School, on the Lapwai Reservation in Idaho. Through doing research, she "feels better prepared to help [her] students follow their dreams and pursue their goals." She also participated in the Native American Engineering Camp at Washington State University, and has set a personal goal of seeing at least four of her former students graduate with engineering degrees.

Figure 3.2 – Middle- school students and teachers gain experiences in science and earthquake engineering through PEER's Research Experience for Teachers program

For Year 7, our efforts at UCSD were focused on inner-city teachers. Three teachers from inner-city middle schools worked together to develop a simple shake table competition that could be used in the classroom. The teachers attended presentations by the EERI Student Chapter on various aspects of earthquake engineering and participated in ongoing large-scale testing programs in UCSD's laboratories. As part of the RET program, these teachers were able to take back to the schools the necessary materials to carry out the simple testing programs in their classrooms. Also in Year 7, two teachers from the Year 6 RET program were invited to participate in the Tri-Center Field Mission in Japan. This Year 7's RET program seemed to be the most effective we've organized so far at PEER, and we plan to follow the same format for the Year 8 RET.

3.2.1.2 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. Over a period of ten weeks during the summer months, students work under the direction of a PEER faculty mentor on a PEER-funded research project and submit a report detailing their research experience during the fall term. We endeavor to restrict interns to working on projects that are current or recent-past PEER projects, although in exceptional cases students are allowed to work on non–PEER-related projects. During the past six years, PEER has sponsored participating students to attend the EERI Annual Meetings held variously in St. Louis, Monterey, Long Beach, Portland, Los Angeles, and in Ixtapa, Mexico. Prior to the Friday evening reception, students presented posters about their summer research experience in an informal setting, while interacting with renowned specialists 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 2004 submitted their final research reports on November 1, 2004. The Education Program is currently recruiting 15 students to participate in the PEER Summer Internship Program during summer 2005.

Figure 3.3 – PEER Summer Interns at the 2005 EERI Annual Meeting in Ixtapa, Mexico

3.2.1.3 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 (in an activity conducted jointly with SCEC) offers a one-day Communication Skills Workshop for the interns to assist faculty with oral and written reporting skills. The Workshop affords the interns 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.

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 2004, REU students from MAE, MCEER, and PEER met in Charleston, South Carolina, for a lively discussion of ethics in engineering, as well as an opportunity to hone their presentation skills in PowerPoint presentations relating their summer research experience to the group.

The PEER Education Program is currently recruiting seven students, focusing on those from groups historically under-represented in the field, for the summer 2005 REU Program. The 2005 REU Symposium will be held August 4–6 in Reno, Nevada.

3.2.1.4 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 introduce high-ranked undergraduate students to four topics in the field of earthquake engineering including seismology, geotechnical engineering, structural dynamics, and public policy. The fall 2004 version of the EESC was a multi-campus program that provided instruction to 32 students from 11 PEER universities during four weekend retreats at PEER core-university campuses [UC San Diego (Geotechnical Earthquake Engineering), California Institute of Technology (Seismology), UC Irvine (Structural Dynamics), and UC Los Angeles (Public Policy)]. Although these individual topics were the primary focus of each of the four weekends, the students commented on the faculty's success in developing a connection between the four topics that united the course overall and provided the students with 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 make a presentation during each of the retreats. For example, at UC Berkeley, several young BIP engineers gave the PEER Scholars tours of seismic retrofit projects on the Berkeley campus, described engineering drawings and engineering practices, and shared experiences ranging from school to professional practice. The schools also utilized 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 go on to pursue graduate study, often at a PEER institution.

3.2.1.5 Tri-Center Earthquake Field Study Program for Students

The ***Tri-Center Earthquake Field Study Program for Students*** is an effort that started in May 2002 to focus on earthquake reconnaissance experience for PEER students. Each summer this project brings together graduate students 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" gained not only broaden the students' experiences but also train them 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.

Figure 3.3 – PEER participants in the 2004 Tri-Center Field Study at the Hanshin Expressway Earthquake Museum in Kobe, Japan

In July 2004, five PEER students and 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-Defense 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 comparing U.S. and Japanese 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.

MAE will be responsible for coordinating a trip to Greece in July 2005, where they will visit Aristotle University of Thessaloniki, National Technical University of Athens, and the University of Patras. A select group of middle-and high-school teachers from PEER's RET program will also participate.

3.2.1.6 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, which are 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 concerning the programs offered by the PEER Education Program. 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 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.

In 2002, the SLC had decreased in size to where only half of the core schools were represented, and three of the primary officers were on the verge of graduating. This had the potential to adversely affect their ongoing programs, while also making it difficult to get information out to the PEER Student Association. In Year 6, one of our goals was to grow in size and depth, so that each core school is represented by at least one, if not more students. We now have an average of two SLC representatives per school, some just beginning their graduate work. We are currently maintaining strong participation in the SLC, and with more people to share the volunteer work, the information flow to students has improved significantly.

In order to increase the visibility of PEER among undergraduates during the past year, the SLC planned a new form of outreach to undergraduates studying civil/structural engineering through an **Undergraduate Seismic Design Competition**. Held in conjunction with the Year 7 Renewal Review and NSF Site Visit at PEER Headquarters in May 2004, five teams from PEER associated universities designed and built earthquake-resistant structures within specified constraints. The 15-story scale models were tested on the Educational Shake Tables. The event was a huge success, and plans are under way for the 2005 competition to be held April 30, during the PEER Annual Meeting. In addition to teams from PEER schools, MAE and MCEER are also sending teams to participate in the competition.

3.2.1.7 Tri-Center Ph.D. Candidate Exchange

The ***Tri-Center Doctoral Candidate Exchange*** in Year 6 was a new program that sent two PEER graduate students nearing completion of their doctorates to give lectures at MAE and MCEER, while PEER reciprocated by welcoming two students for lectures from each of these centers. 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 on April 16, and Bryant Nielson (Georgia Tech) gave his talk on April 23 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 would not otherwise occur. We are currently arranging for the Year 8 exchanges which typically take place in the spring.

3.2.1.8 PEER Professional Fellowship Program

The ***PEER Professional Fellowship Program*** is aimed at increasing contacts between our students and practicing professionals. Although started on an informal basis, our first formal PEER Professional Fellow was Maury Power of Geomatrix Consultants in 2002. Another of our Professional Fellows for Year 6 was William Holmes of Rutherford & Chekene, who gave a lecture on "Staying Active in the Profession after Graduation." In addition to the lecture, Mr. Holmes had lunch with members of the EERI Student Chapter and met with graduate students to discuss their research. As a leading practitioner who is very involved in PEER, EERC, and code committee development, Mr. Holmes continues to be a superb role model for our PEER students. In March 2004, Norm Abrahamson visited UC Davis for a one-day meeting with students and made a presentation on Probabilistic Seismic Hazard Analysis. Year 8 visits, which typically occur in the spring, are currently being planned.

3.2.2 Curriculum Innovations and Tools

PEER has encouraged and coordinated several curriculum development activities, including the following.

3.2.2.1 Teaching Modules for Graduate Students

Initiated as a Tri-Center activity, this project has created a series of graduate-level, self-contained, web-based, teaching modules. The modules include materials on various subjects and may be shared by a variety of academic institutions without 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 the ***"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 developed 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. Some classes directly utilize the Graduate Course Modules developed in previous years, while many others are incorporating PEER research results into lectures and assignments in a less formal way. 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 course-related notes, the module contains a number of Java applets that allow students to rapidly assess the characteristics of ground motions they would expect 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. Using 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. Lastly, 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 carry out 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 will be the basis for a guide to the seismic retrofit program on the Berkeley campus, in anticipation of the 100-year anniversary of the 1906 earthquake.

3.3 Progress on Future Plans

In Year 8 and beyond, the PEER Education program intends to continue those programs that have served the students well, including *PEER Summer Internship Programs*, *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 Series on UCTV:*** PEER is continuing work with UCTV on developing an Earthquake Education Series 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 series would consist of up to six short documentaries on PEER Interns and Graduate Students working on earthquake engineering research, as well as short video clips of PEER faculty explaining key issues and concepts in earthquake engineering. It is anticipated that funding for this effort would take the form of an NSF Informal Science Education Supplement. 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 involved in earthquake engineering, and we are making progress. For the second year, we have added "Overcoming Adversity" in addition to Academic Preparation as criteria for our PEER Summer and REU Internships. We have also stepped up our efforts to increase awareness about PEER Programs to traditionally under-represented groups and to 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 under-represented 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 application as previous years, as well as a diverse applicant pool. We plan to continue these efforts with the Year 8 Earthquake Engineering Scholars Course, including overcoming adversity as a selection criteria, as well as making more space available to students outside the PEER core universities, including students from our new Education Affiliates.

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 because 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

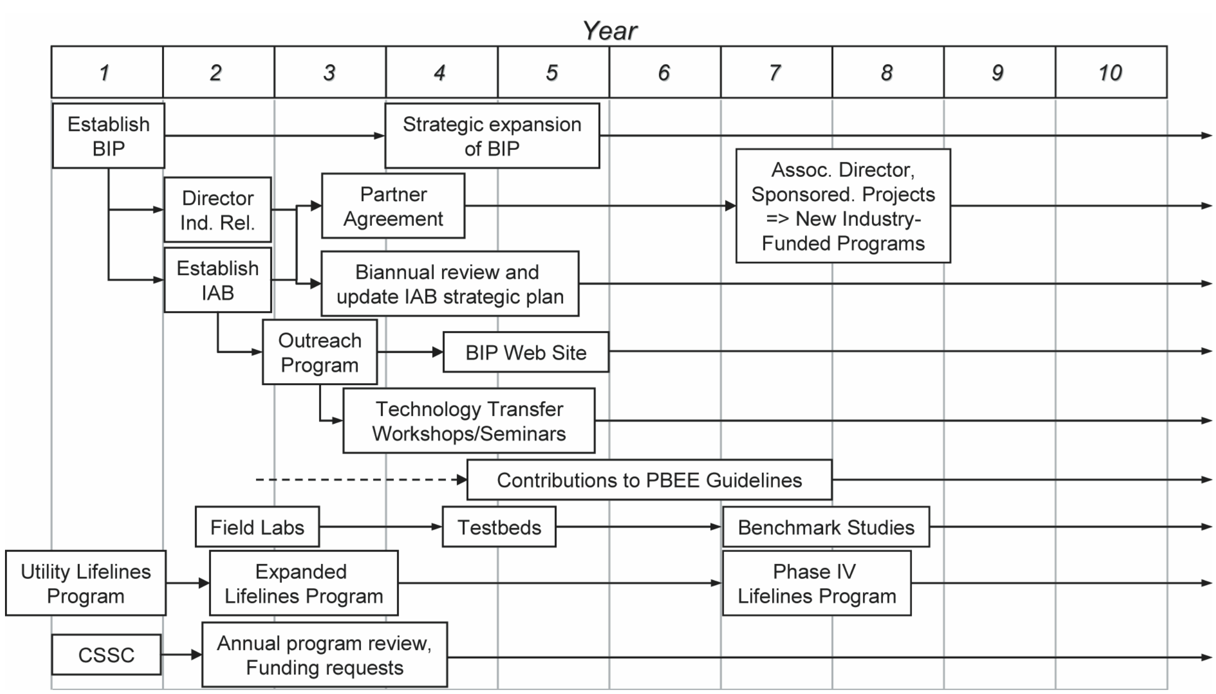

Figure 4.1 – Strategic plan for industrial/practitioner/government collaboration and technology transfer

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 (now at NEES, Inc.) had the responsibility of managing public relations and outreach until late March 2005. PEER is currently in the process of recruiting a new manager for this position. The 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, 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. Outcomes of these meetings have been directed to the California Energy Commission to guide their continued funding of the Lifelines Program.

PEER began negotiations 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 been communicating with the Bay Area Rapid Transit (BART) to formulate applied research projects. The initial contacts have been successful, and we are in the process of negotiations for the budget and schedule.

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 also were 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 are:

- A 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.

The Business and Industry Program membership consists of Member, Affiliate, and Contributing members. A Member is an organization that has signed the membership agreement; an Affiliate is an organization that provides cash to the program under the PEER strategic plan but which has not signed the membership agreement. A Contributing organization provides other non-project-specific support to the Center. It is noteworthy that the organizations providing the primary funding to the Lifelines Program qualify as Affiliate Members; the contracts were executed prior to formalization of the BIP Program in 2001 and contracting complications prevented signing the formal BIP agreement at this time, even though these partners in all other practical measures are fully engaged in our BIP program.

Recently, we have been successful in attracting new BIP members, including 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.

Note that the formal membership agreement was not executed until 2001. Membership prior to 2001 is based on the less formal partnership agreement.

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: 38 people attended the December 2003 workshop; 43 people attended the March 2004 workshop; and 75 participants attended the most recent workshop in December 2004. 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.

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*

**In production as of 4/05; publication year runs from 6/04 – 5/05*

An exciting outreach opportunity is currently under way: the Earthquake Engineering Research Institute (EERI) has selected Director Moehle as the EERI Distinguished Lecturer for 2005, speaking on the subject of Performance-Based Earthquake Engineering with an emphasis on progress made by PEER. This prestigious award includes a featured lecture at the EERI Annual Meeting, a paper in *EERI Spectra*, and multiple presentations of the Distinguished Lecture at EERI regional and student chapters during the year. Professor Moehle has given his Distinguished Lecture at the 2005 EERI Annual Meeting in Ixtapa Mexico, as well as at the University of California, Berkeley; Purdue University; University of Illinois at Urbana-Champaign; University of Michigan, Ann Arbor; University of Texas, Austin; University of Puerto Rico; and at the St. Louis Chapter of EERI.

During the past year, 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 *13th World Conference in Earthquake Engineering* in Vancouver, Canada; the *National Earthquake Conference* in St. Louis, Missouri; the *EERI Annual Meeting* in Ixtapa, Mexico; and the *SEAOC Annual Convention* in Monterey, California.
- Participation in the California Office of Emergency Services California Earthquake Clearinghouse initiative. This program is a joint committee of representatives of seismic hazard and engineering-related organizations from both government and academia. PEER was represented on this group by the Public Relations and Outreach director.
- A major redesign to the PEER website layout, which was rolled out in winter 2004.
- 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	# of Atten-dees
4/05	7th Next Generation Ground Motion Attenuation Workshop	Richmond, CA	Workshop	The NGA is a unique opportunity for the community of earthquake engineers to make a significant step forward in predicting strong ground motions for WUS earthquakes.	75
3/05	Simulation and seismic performance of pile foundations in liquefied and laterally spreading ground	Davis, CA	Workshop	PEER co-sponsored workshop on advances in the fundamental understanding, simulation, and performance-based design of pile foundations in areas subject to liquefaction hazards during earthquakes.	46
2/05	EERI Distinguished Lecture at U.C. 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
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.	

Date of Event	Title of Event	Location	Type of Event	Description	# of Atten-dees
6/04	International Symposium on Confined Concrete	Changsha, China	Workshop	PEER co-sponsored this workshop which 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 which 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
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 past 20 years. The last conference was held in Philadelphia in the USA in 2001. The international community organizing the conference consists of academia and practicing engineers in Singapore, USA, 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

Date of Event	Title of Event	Location	Type of Event	Description	# of Atten-dees
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 non-structural 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
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

Date of Event	Title of Event	Location	Type of Event	Description	# of Atten-dees
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
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 towards users who have little or no experience using OpenSees. The latter days were aimed at OpenSees code writers.	51

Date of Event	Title of Event	Location	Type of Event	Description	# of Atten-dees
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
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 who 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 new to PEER last year. 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. The growing number of institutions involved with PEER is a major change from the original PEER structure, and reflects the growing funding base and influence of PEER.

5.2 Leadership Team; Faculty and Student Team; and Diversity

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

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

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.

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 affiliated institutions. 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*. 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.

The *Director of Public Relations and Outreach* 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. This position is currently vacant and being recruited.

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
Kurt McMullin	San Jose State
Charles Menun	Stanford
Jack Moehle, *Ex Officio*	UC Berkeley
Ian Robertson	U Hawaii
Jonathan Stewart	UC Los Angeles
Bozidar Stojadinovic	UC Berkeley
Mark Tufenkjian	CSU Los Angeles
Solomon Yim	Oregon State

Table 5.3 – Joint Management Committee for the Lifelines Program

PEER	California Energy Commission
Jack Moehle (Chair)	David Chambers
Yousef Bozorgnia	Merwin Brown
	Laurie TenHope
California Dept. of Transportation	**Pacific Gas & Electric Co.**
Brian Chiou	Norman 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.

5.2.3 Diversity

PEER initiated a strategic plan to increase diversity beginning in Year 2. The Graduates Fellowship program Year 2, targeted Hispanic, African American, and Native American students by 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 under-represented groups, and collaborated with the UC Berkeley SUPERB program. Despite these efforts, the number 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 under-represented 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. 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 under-represented groups and to base selection on diversity considerations. Revised materials can be found at http://peer.ucsd.edu/internshipmenu.htm.
- PEER's RET program is 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 last summer, and joined us for the Tri-Center Field Study in Japan in 2004.
- PEER has successfully reached K-12 students from under-represented 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).

PEER's diversity strategy has a relatively short history, so its effectiveness cannot be well gaged at this time. Table 5.4 summarizes diversity indices for PEER at the time of this writing.

Table 5.4 – Center Diversity, by Institution

	UCB		Caltech		Stanford		UCD		UCI		UCLA	
	#	%	#	%	#	%	#	%	#	%	#	%
Females	13	32%	3	60%	3	23%	5	28%	3	60%	3	38%
Underrepresented Races	2	7%	0	0%	0	0%	2	18%	0	0%	0	0%
Hispanics/Latinos	5	12%	2	40%	3	23%	1	6%	0	0%	1	13%
Total # of responses for calculating % of Females and Hispanics*	41		5		13		18		5		8	
Total # of responses for calculating % of Under-Rep Races**	27		3		9		11		4		5	

	UCSD		USC		UW		Outreach Orgs		TOTAL	
	#	%	#	%	#	%	#	%	#	%
Females	7	33%	1	33%	2	17%	2	17%	42	30%
Underrepresented Races	1	7%	0	0%	0	0%	0	0%	5	5%
Hispanics/Latinos	0	0%	0	0%	0	0%	0	0%	12	9%
Total # of responses for calculating % of Females and Hispanics*	21		3		12		12		138	
Total # of responses for calculating % of Under-Rep Races**	15		2		12		12		100	

* Total number of participants minus those who did not provide gender or ethnicity data

** Total number of UC Citizens/Permanent Residents with race reported

Underrepresented Races = The total of US Citizens and permanent residents who are: African Americans, Native Americans, Hawaiian and Pacific Islanders, or any combination of races that includes at least one of these races.

5.3 Equipment and Space

The PEER headquarters is at the Richmond Field Station of the University of California, Berkeley. All activities are centrally administered at this location. One administrative support office at UC San Diego assists in the day-to-day administration and management of the education activities of the Center. Satellite office space on the UC Berkeley campus was set aside during Year 6; however, that space is not currently available as a result of programmed seismic rehabilitation work. Architectural/construction plans are under review.

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 for convening the Education Committee and for developing an education program, program announcements and requests for proposals, and for making 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 shake table, the largest tsunami wave tank, and the largest strong-wall/test floor facilities currently operating in the U.S. 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.

Each of the participating universities features many state-of-the-art networked computer facilities. In addition, the Center has direct access to the NSF-established super computer center at UCSD. The Center has established an electronic network, including video-conferencing capabilities, among the participating institutions to facilitate communications and to extend involvement in all facets of the education and research programs.

Information systems for earthquake engineering are available at UC Berkeley through the National Information Service for Earthquake Engineering as well as the CUBE/REDI programs for real-time earthquake information, and at USC as part of the SCEC Outreach Program. The Center works with and through these and other established information systems to introduce an enhanced vision of earthquake engineering research dissemination.

5.4 Organization and Management Systems

The PEER programs are organized and managed to ensure strategic planning and program coordination, project and PEER personnel communications, outreach communications, and for 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,* and *Director of Public Relations and Outreach* are described in Section 5.2.1.

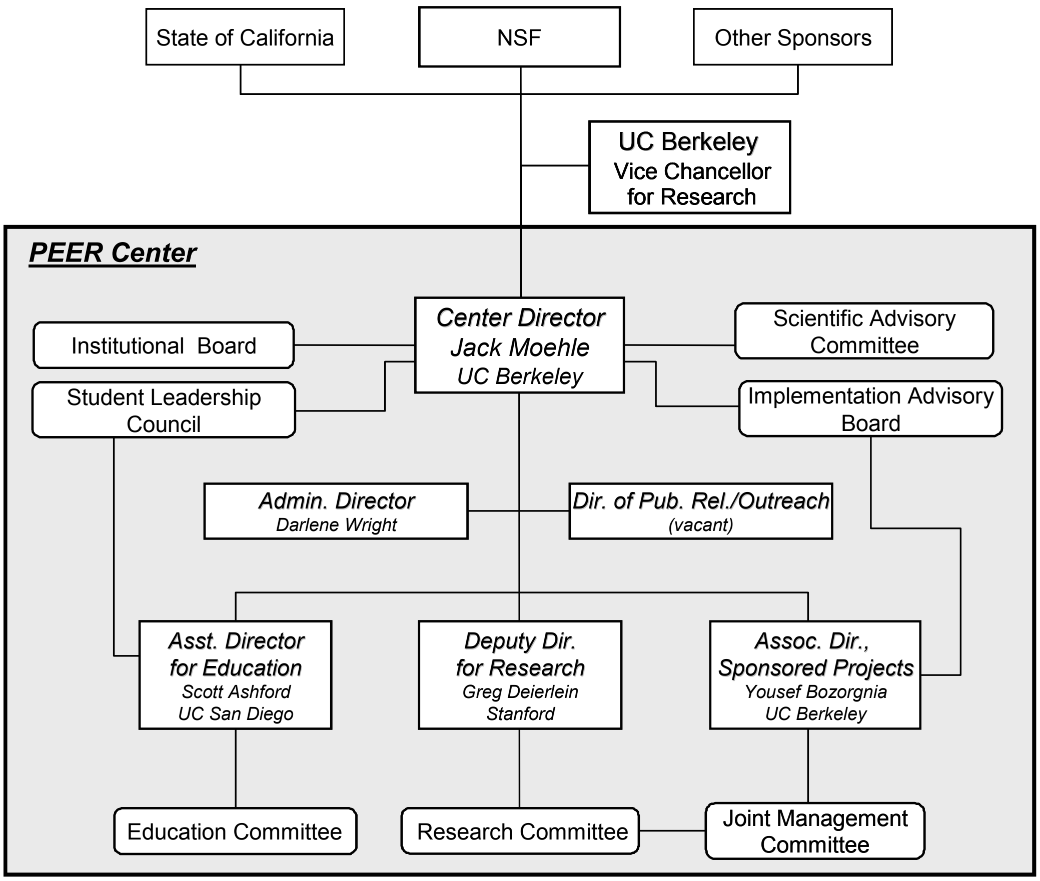

Figure 5.1 – Organization Chart

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.

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

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.

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

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 5.7 – Implementation Advisory Board

Member	Affiliation
James Malley, Chair	Degenkolb Engineers
Fadel Alameddine	California Dept. of Transportation
Robert Bachman	Private Sector
Merwin Brown	California Energy Commission/UC Office of the President
David Chambers	California Energy Commission
Lloyd Cluff	Pacific Gas and Electric Company
John Hooper	Magnusson Klemencic Associates
Karl Kirker	Washington Dept. of Transportation
Chris Rojahn	Applied Technology Council
Tom Shantz	California Department 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 established bylaws, with general oversight from the Assistant Director for Education. The SLC reports jointly to the Center Director and the Assistant Director for Education.

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, Assistant Director for Education, and Director of Public Relations/Outreach) 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 EERCs.

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 including faculty from under-represented 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.

Table 5.8 – Student Leadership Council

Member	Affiliation
Sarah Paulsen, President	Univ. of Washington
Jack Baker	Stanford
Case Bradford	Caltech
Scott Brandenberg	UC Davis
Barbara Chang	UC Irvine
Dong Dong Chang	UC Davis
Lijuan Cheng	UC San Diego
Pendo Duku	UC Los Angeles
Andres Espinoza	UC Berkeley
Michael Gebman	UC San Diego
Curt Haselton	Stanford
On Lei (Annie) Kwok	UC Los Angeles
Won Lee	Stanford
Leonardo Massone	UC Los Angeles
Judith Mitrani-Reiser	Caltech
Griffin Thornock	Univ. of Washington
Martin Walker	UC Davis

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 under-represented 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. This office and its representative 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 by telephone. 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 website, in the quarterly PEER newsletter, and by regular email communications. Video-conferencing units have been installed at six campuses.

6 REFERENCES CITED

Hamburger, R.O. 2004. Development of Next-Generation Performance-Based Seismic Design Guidelines. In *Performance-Based Seismic Design Concepts and Implementation, Proceedings of an International Workshop,* eds. Peter Fajfar and Helmut Krawinkler, 89–100. Report PEER 2004/05. Berkeley, Calif.: Pacific Earthquake Engineering Research Center, University of California.

APPENDIX I

GLOSSARY

Term	**Definition**
ATC	Applied Technology Council
BART	Bay Area Rapid Transit
BIP	Business and Industry Partners
CalTrans	California Department of Transportation
CEA	California Earthquake Authority
CEC	California Energy Commission
CHUM	Consortium of High Schools/Undergraduate & Medical Schools
CSSC	California Seismic Safety Commission
CUBE	Caltech-USGS Broadcast Earthquakes
DGML	Design Ground Motion Library
EERC	Earthquake Engineering Research Center
EERI	Earthquake Engineering Research Institute
EESC	Earthquake Engineering Scholars' Course
ERC	Engineering Research Centers
FEMA	Federal Emergecy Management Agency
FHWA	Federal Highway Administration
HAZUS	Regional Earthquake Hazard Analysis Program, FEMA
IAB	Implementation Advisory Board
IBC	International Building Code
IUSWG	Inter-Utility Seismic Working Group
LADWP	Los Angeles Department of Water and Power
Lifelines Program	Program of Applied Earthquake Engineering Research for Lifeline Systems
MAE	Mid America Earthquake Center
MCEER	Multidisciplinary Center for Earthquake Engineering Research
NCREE	National Center for Research in Earthquake Engineering
NEES	Network for Earthquake Engineering Simulation
NGA	Next Generation Attentuation
NSF	National Science Foundation
OpenSees	Open System for Earthquake Engineering Simulation
PBEE	Performance-Based Earthquake Engineering
PEER	Pacific Earthquake Engineering Research Center
PG&E	Pacific Gas & Electric
PSA	PEER Student Association
REDARS	Risks from Earthquake Damage to Roadway System (FHWA)
REDI	Rapid Earthquake Data Integration
RET	Research Experience for Teachers
REU	Research Experience for Undergraduates
SCE	Southern California Edison
SCEC	Southern California Earthquake Center
SLC	Student Leadership Council
SPUR	Seismic Performance of Urban Regions
SSFI (SFSI)	Soil Foundation Structure Interaction
TA	Thrust Area
TRI-CENTER	PEER, MCEER, and MAE coordinated programs
UCIST	University Consortium for Instructional Shake Tables
USGS	United States Geological Survey
USGS	US Geological Survey