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 buildings and infrastructure to meet the diverse economic and safety needs of owners and society.

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

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

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

Despite advances in recent years in the use of performance-based earthquake engineering, existing technologies and methods for PBEE fall short on a number of grounds. Methods for seismic design or evaluation that currently are in widespread use are much less scientific and direct than the rigorous approach that we are developing. Although response of structures to strong ground motions in most cases is expected to be nonlinear, earthquake hazard today is represented by design maps through relatively simplistic single-parameter quantities such as linear spectral response. Likewise, structural evaluation and design commonly use linear analysis adjusted by factors whose values are based on tradition and limited earthquake experience rather than systematic performance considerations. Furthermore, engineering design and assessment generally focus on structural parameters and fail to quantify 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 (Figure 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.

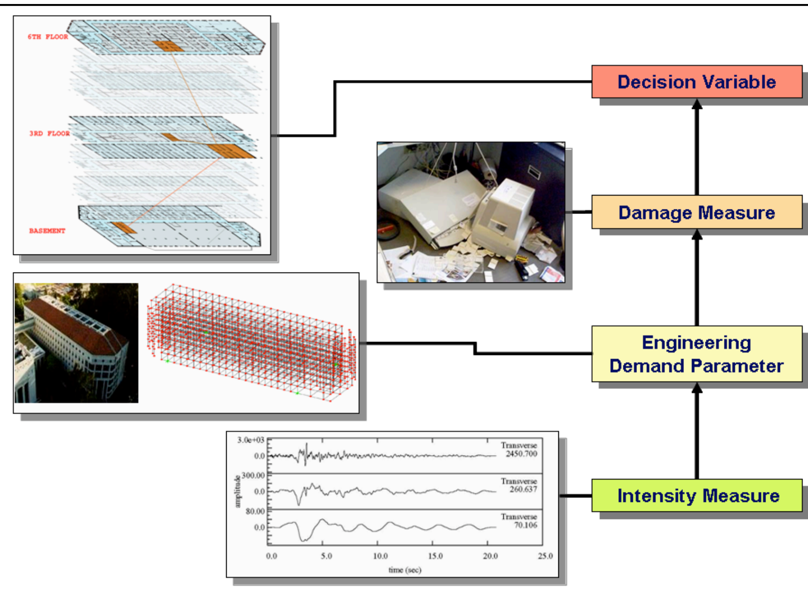

Figure 1.1 – Performance-based earthquake engineering framework. PEER is conducting research on the overall framework (right) and individual elements (left). In the example shown, the functionality of a science lab depends on damage in geographically distributed, inter-dependent laboratories.

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. 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.

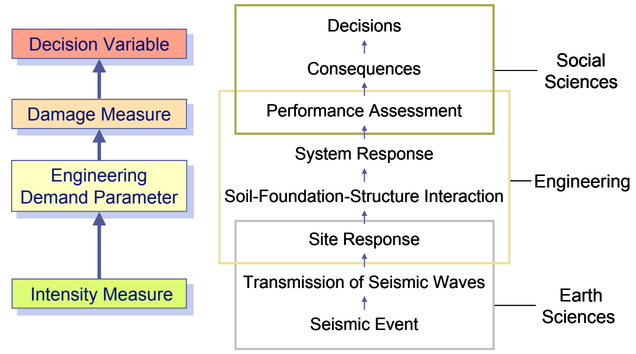

Figure 1.2 – Multi-disciplinary integration in performance-based earthquake engineering. Steps in performance-based earthquake engineering shown center, PEER's framework variables shown left and traditional disciplines shown right.

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 improvement in current methods but instead makes the major step in information and technology advancement necessary for realistic implementation of performance-based earthquake engineering. PEER is providing the focus, resources, vision, and professional and educational environment that make these things possible.

Participation in PEER has resulted in a genuine transformation in attitudes and outlook among PEER researchers and 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 through 10. They also provide a model for benchmarking studies that will be a major focus of future years.

Another area of significant growth is in collaborations with other earthquake centers in the U.S. PEER previously has collaborated on a relatively limited basis with the Southern California Earthquake Center and the other two Earthquake Engineering Research Centers – the Mid-America Earthquake Center and the Multidisciplinary Center for Earthquake Engineering Research. During Years 6 and 7 we have embarked on joint strategic planning that already has led to joint funding of several projects that provide 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*, as summarized below:

<u>PEOPLE:</u>

Multi-Disciplinary Earthquake Engineering Education for Undergraduate Scholars

The Pacific Earthquake Engineering Research Center offers the ***Earthquake Engineering Scholars' Course (EESC)*** to attract and prepare undergraduate students for graduate study in earthquake engineering. The course provides instruction to about 30 select students from PEER and its Education Affiliates during four weekend retreats at PEER campuses. The course is targeted at graduating seniors who have demonstrated an interest in earthquake engineering or an earthquake-related field, who have achieved a high level of academic scholarship, and who will increase the diversity of PEER's student population. Each of the weekend retreats focuses on a different theme of earthquake engineering, including: seismology and earthquake ground motion; geotechnical engineering; structural dynamics and earthquake-resistant design; and public policy and decision making. The course provides a unique opportunity for students to interact intellectually and socially with many faculty members, graduate students, and industry partners. Students also have the opportunity to see earthquake engineering laboratories and experience campus life at a PEER core university. The program has been very successful at recruiting new talent to the field of earthquake engineering at PEER schools.

Figure 1.3 – PEER students in the Earthquake Engineering Scholars' Course discuss earthquake engineering practice with industry partner.

International collaboration opportunities for educating future researchers

PEER has fostered international collaboration on performance-based earthquake engineering to leverage its contributions in research and education with complementary activities in other countries – particularly its Pacific Rim neighbors in Japan, Taiwan and China. PEER views such collaboration as a natural vehicle to educate the next generation of earthquake engineers with an international perspective on earthquake hazard mitigation. An example of one such collaboration is a study between PEER and the National Center for Research in Earthquake Engineering (NCREE) in Taiwan to pseudo-dynamically test a full-scale building frame for the purpose of validating technologies and criteria for seismic performance simulation and design. One of PEER's Research Fellows, Paul Cordova, who received his undergraduate degree from Cal Poly Pomona and is now a PhD candidate at Stanford University, played a leading role in the design, analysis, and follow up study of the test frame. Mr. Cordova spent the summer of 2002 at the NCREE laboratory and has maintained his collaboration through visits to NCREE, joint presentations at international workshops and conferences, and web-

Figure 1.4 – PEER graduate fellow contributes to international research collaboration.

based communication technologies. The frame study has facilitated longer range collaboration between PEER and NCREE to utilize PEER's OpenSees platform for hybrid simulation and testing as an international component of NSF's NEES initiative.

Shake Table Competitions for K-12 Students

It is critical that K-12 students understand the career opportunities available to them in Science and Engineering, and that they see higher education as the path to these opportunities. A great example of how this outreach becomes a reality is the UC Irvine "Learning with LEGOs" competition. Led by PEER faculty Tara Hutchinson and Gerry Pardoen, each year UC Irvine invites hundreds of K-12 students from the inner-city to participate in a shake table competition using LEGOs. Along with the competition, the students are taught earthquake engineering basics, and are shown that these are careers open to them through higher education. UC Irvine's program has spawned a smaller competition at UC San Diego and UC Berkeley, as well as an Undergraduate Shake Table Competition through PEER run by our Student Leadership Council. For a video segment shown on UCSD-TV on the PEER shake table competitions and their impact on K-12 education, see http://peer.ucsd.edu.

Figure 1.5 – K-12 students and their LEGO structures anxiously await the UC-rumble.

IDEAS:

Post-Earthquake Functionality and Building Tagging

Even a building that may have successfully protected all its occupants during a major earthquake is no longer useful if the damage it has suffered causes it to be closed to further occupancy. Whether a damaged building poses a safety risk depends on the amount of damage and the likelihood of strong aftershocks following the main earthquake shock. The current practice is to "tag" a building with a red, yellow, or green rating depending on the damage level, assuming that the building may be subjected to a strong aftershock. It is well known, however, that the risk of aftershocks decreases with increasing time following the mainshock. The question has been how to take this into consideration

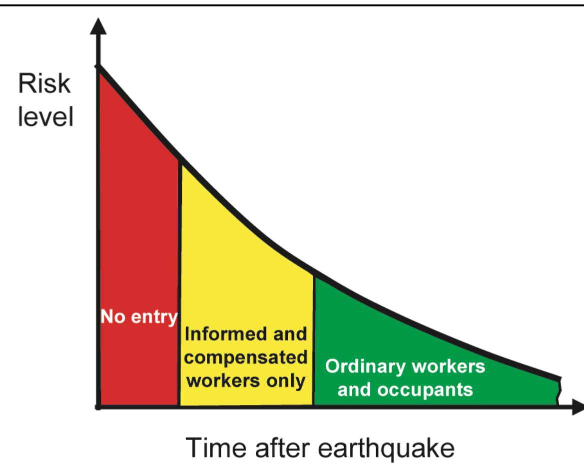

Figure 1.6 – The probability of strong aftershocks decreases with time after an earthquake, so a damaged building becomes safer to enter.

when determining the occupancy of a damaged building. Professors Cornell, Bazzurro, and Menun have used the PEER performance-based earthquake engineering framework to devise a procedure just for this purpose. The procedure couples an analysis of the collapse probability of a damaged building with an evaluation of aftershock probabilities to devise a relation between allowable occupancy and time after the mainshock. The methodology has been expanded to a step-by-step procedure that is being implemented by PEER's Business and Industry Partners to establish, *prior* to the next damaging earthquake, relations between building damage and post-earthquake occupancy allowances. These assessments will help our industry partners get critical facilities back in operation more rapidly following the next damaging earthquake.

Building Testbed Demonstrates the Primary Sources of Earthquake Losses

In close collaboration with its Business and Industry Partners, PEER researchers applied their new performance-based earthquake engineering methodology to two existing buildings in California. One of these structures is a seven-story building that is representative of older reinforced concrete construction. The testbed provided an opportunity to calculate expected earthquake losses, including economic losses due to damage of structural and nonstructural components, economic losses due to downtime, and casualties due to building collapse. Results indicate that nonstructural components are a major contributor to economic losses. They also demonstrate that moderate-level, frequent earthquakes are larger contributors to economic losses than larger but less frequent earthquakes. The study included comparisons with current practice to demonstrate the advantages of the PEER performance-based approach over the current best practices. The multidisciplinary, collaborative exchange of ideas and results that this study created have produced unique accomplishments that could not be reached by individual investigators or disciplines working in isolation.

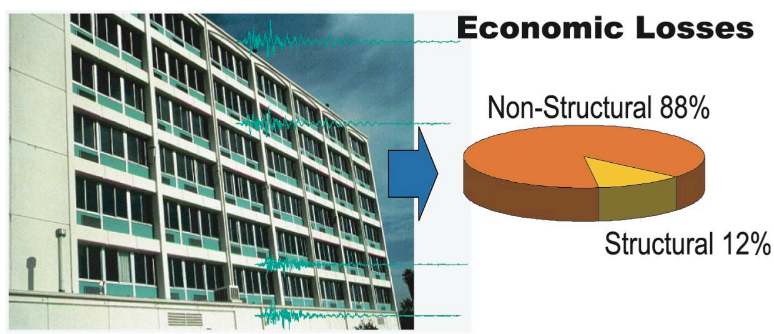

Figure 1.7 – PEER's performance-based methodology enabled researchers and industry partners to explore the nature of expected losses during future earthquakes.

PEER has contributed to broader policy-related discussions of performance-based regulation.

The concept of performance-based approaches to regulation is not unique to earthquake engineering. Variants of performance-based regulation have been adopted in a number of countries for regulation of aspects of air and water quality, building and fire safety, consumer product safety, energy efficiency, food safety, forest practices, nuclear power plants, pipeline safety, and worker safety. Most of these efforts are still in their infancy, without rigorous means for assessing performance, and are presented as alternatives to existing prescriptive regulation. Regardless of the status of these efforts, performance-based regulation cannot be considered as separate from the broader regulatory system.

PEER researchers have made noteworthy contributions in a variety of important policy forums to discussion of the implications for the broader regulatory system. Especially noteworthy are the PEER contributions to the "Global Policy Summit on Performance-based Building Regulations" convened in 2003 by the Inter-jurisdictional Regulatory Collaboration Committee and the National Research Council. This forum brought together key policymakers and regulatory officials from a dozen countries with performance-based building regulatory components. PEER researchers also contributed to a workshop of U.S. regulatory authorities addressing "Performance-Based Regulation: Prospects and Limitations in Health, Safety, and Environmental Protection" convened by Harvard's Regulatory Program in 2002. The broader implications for regulatory systems have also been important aspects of PEER's contributions to the FEMA-funded, Applied Technology Council longer-term program for development of performance-based seismic design guidelines.

Figure 1.8 - PEER researchers have made noteworthy contributions in a variety of important policy forums to discussion of the implications for the broader regulatory system.

TOOLS:

On-Line Column Performance Database Provides Worldwide Access to Column Test Results

Damage to reinforced concrete building and bridge columns can result in large repair costs, downtime, and, in severe cases, structural collapse. To predict likely performance states in columns subjected to earthquakes, researchers need access to high-quality data. To assist in this effort, PEER has developed the Structural Performance Database. This

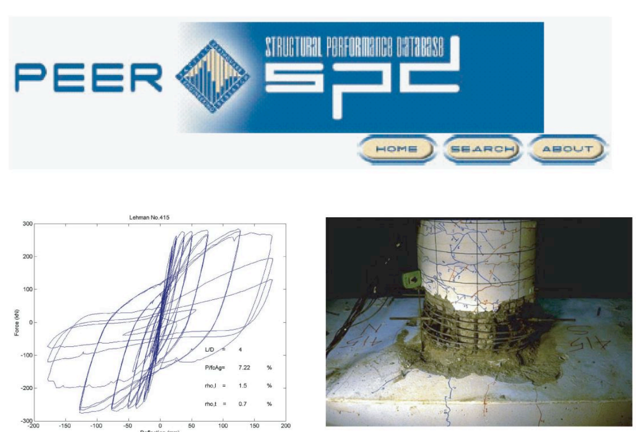

Figure 1.9 - Structural Performance Database documents force-deflection response and damage development in reinforced concrete columns.

database provides web access and search capabilities to data from over 400 tests of reinforced concrete columns *(http://nisee.berkeley.edu/spd)*. For each test, the database provides a test description, the digital force-displacement response, and the level of column deformation at each damage observation. Researchers throughout the world are using the database to develop new analytical models, to evaluate existing and proposed code provisions, and to plan new tests. Teachers and students now have access to information, including illustrative photographs. The database serves as a model for the NEES (Network for Earthquake Engineering Simulation) data repository. An XML capability facilitates interaction between the column database, the NEES data repository, and OpenSees.

OpenSees Simulation Component for NEESgrid

PEER's investment in the development of the Open System for Earthquake Engineering Simulation—OpenSees—has paid off in Year 7 with more applications of the simulation software and a growing base of users worldwide. OpenSees is an object-oriented software framework for creating simulation applications. Its modular design allows new simulation applications to take advantage of modern high-end computing, Grid communications, access to databases, and scientific visualizations for improving the ability to model and simulate structural and geotechnical systems. Recognizing the broad applications of this approach, the NEES System Integration team has selected OpenSees as the simulation component for NEESgrid. Another major effort has been a number of researchers in the U.S. and internationally have been developing hybrid physical-computational simulation methods using OpenSees as the simulation engine. Researchers at NCREE in Taiwan have embraced OpenSees as an engine for hybrid testing and have run a number of benchmark studies and have cooperated with PEER to validate OpenSees using two full-scale frames that were tested pseudo-dynamically. Researchers using NEES facilities and others at Kyoto University have demonstrated distributed hybrid simulation with OpenSees connected to experimental equipment controllers over the network.

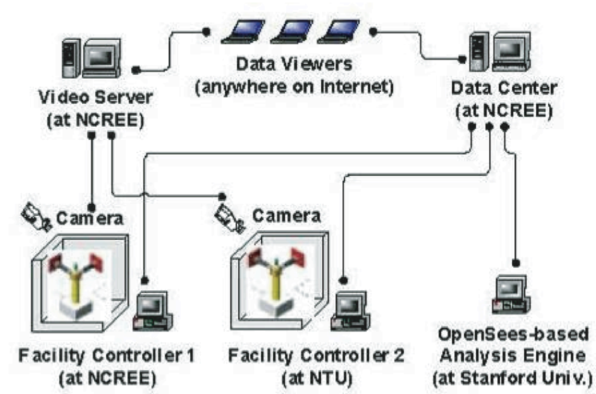

Figure 1.10 – Database structure using OpenSees as adopted by researchers at NCREE (Taiwan) for their Internet-based Simulation for Earthquake Engineering.

Filling the Gap in Strong Ground Motion Data Using Computational Simulation

In collaboration with seismologists from the Southern California Earthquake Center and Business and Industry partners, PEER is developing a new generation of simulation models to predict the characteristics of future ground motions at a site. The traditional approach is to use attenuation models, which estimate how the ground motion intensity diminishes with distance from the fault. Such attenuation models are developed using empirical data from recordings of past earthquakes. But large earthquakes are rare, and *measurements* of large earthquakes close to the fault are even rarer. Rather than wait thousands of years to record large-magnitude events close to the fault, PEER is predicting ground shaking in large-magnitude earthquakes using computer models that simulate fault rupture, propagation of ground waves, and local site amplification effects. Before conducting its predictions, PEER ran an exhaustive validation study to be certain the models were predicting the ground shaking correctly. Once the validation study was done, PEER was able to run the earthquake simulations to fill in the gap of missing data without having to wait for the devastating consequences of the next "big one."

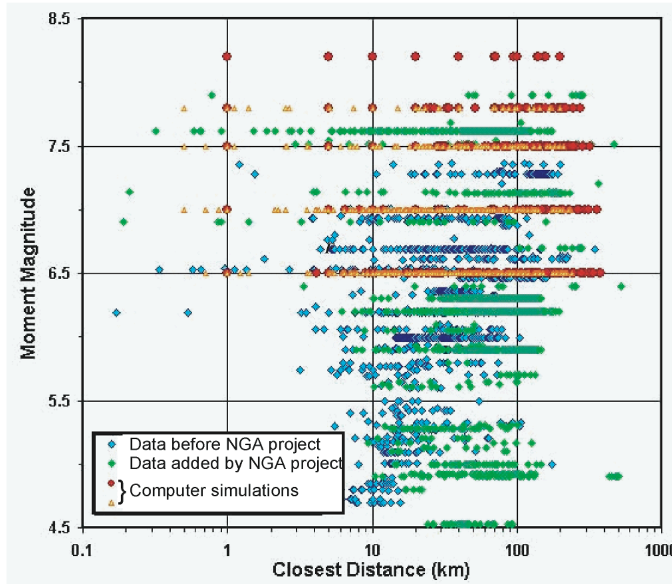

Figure 1.11 – PEER is gathering new earthquake recordings and, where recordings are missing, is filling the gap with computer simulations so better earthquake shaking predictions can be made.

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. These are summarized in Table 1. 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.