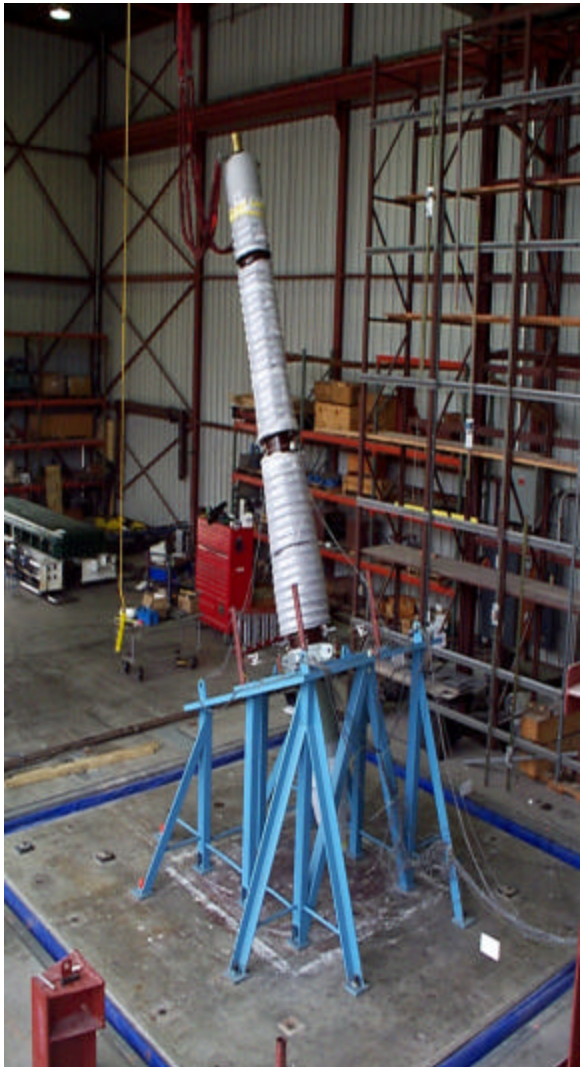


# Meeting California's Earthquake Engineering Research Needs: A Review of the Pacific Earthquake Engineering Research Center

## California Seismic Safety Commission

CSSC Publication No. 01-05  
December 10, 2001



**Figures 1 and 2**  
Electrical bushing (left) and bridge column (right) being prepared for testing

**Publication Information**

Report No. SSC 01-05  
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**Meeting California's Earthquake  
Engineering Research Needs:  
A Review of the Pacific Earthquake  
Engineering Research Center**

**California Seismic Safety Commission  
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**Executive Summary**

In 1996 the California Legislature passed Senate Bill (SB) 1864 authorizing the establishment of a center for earthquake loss reduction which was to be managed by the University of California. The implementation of the bill resulted in the establishment of the Pacific Earthquake Engineering Research (PEER) Center through the National Science Foundation (NSF) and the University of California (UC).

In accordance with SB 1864 the University of California and the California Seismic Safety Commission (Commission) entered into a contract whereby the Commission is charged with the task of periodically reviewing the progress of the PEER Center. In conformance with this charge the Commission has recently completed its review and the Commission's principal findings from the review of the Center's fourth year are:

- PEER has developed into a world-class earthquake engineering research center and is cooperating with similar centers throughout the world.
- The PEER Center is the State of California's principal earthquake engineering research arm available to the State.
- Some of the results of the early research performed at PEER have been imple-

mented by several of its principal partners, including the California Department of Transportation (CalTrans), the Pacific Gas and Electric Company (PG&E), Southern California (SoCal) Edison, and a range of private professional engineering firms in California.

- PEER showcased current and completed research projects so public and private sectors are aware of and can participate in PEER activities.
- The mission, vision, and activities of PEER are in alignment with both the *California Earthquake Loss Reduction Plan* and the *Research and Implementation Plan for Earthquake Risk Reduction in California*.
- The NSF has approved federal PEER funding for another five years.
- Engineers developed through the PEER program have graduated with advanced degrees and several are now on the faculties of universities or contributing to professional engineering practice throughout the western United States.
- PEER research is directly applicable to ten of eleven elements of the *California Earthquake Loss Reduction Plan*.
- As of December 2001, 159 research projects are underway. The projects are directly applicable to meeting the goals and objectives set for in the States' strategic plan to reduce earthquake risk and speed recovery.

**Funding for Year Four**

The total funding for the PEER Center for the fiscal year ending September 30, 2001 (Year Four) was \$5,849,346. The total base funding by the State under SB 1864 for the PEER Center

was \$1,500,000. Total project expenditures for Year Four were \$4,578,059. The balance of the funds was used to operate the Center and to maintain a reserve to fund the mobilization of PEER earthquake reconnaissance teams. In Year Four the PEER Center sent a team to assess earthquake damage as well as building and facilities performance after the Nisqually earthquake in Washington State.

After a thorough review of PEER, the Commission provides the following observations and recommendations:

**There is a need to grow the Center**

PEER Center research is producing results whose benefits are many times the dollars invested.

- CalTrans, an active partner with the PEER Center, provides one specific example. The benefits-to-cost ratio CalTrans is achieving ranges from ten to twenty times their investment in PEER-based research. This translates to a \$15 to \$30 million dollar per year reduction in costs to design, build, and maintain CalTrans bridge inventory.
- There are three major areas of earthquake research that are currently not funded or are under-funded by the State that PEER is positioned to take on. These areas are: 1) seismic hazards assessment and mitigation for schools; 2) seismic hazards assessment and mitigation for hospitals (hospitals are facing a multi-billion dollar requirement to conduct seismic retrofit) and long term health care facilities; 3) and seismic hazards assessment and mitigation for lifelines, such as electric and natural gas utilities, telecommunication infrastructure, potable water, waste water, and water for fire

fighting. PEER would be in position to take a lead role in earthquake mitigation research for the subject areas if funded.

**The Commission recommends the following:**

- The Commission recommends that PEER funding from the State be increased from the current level of \$1.5 million per year to a new level of \$5 million per year if matching funds can be established.
- The Commission also recommends that PEER be considered the focal point of all earthquake engineering research and testing activities at the State level.
- PEER co-fund the National Information Service for Earthquake Engineering (NISEE) Library located at the Richmond Field Station as part of the PEER Center's Core activities, using additional funds provided by the State, should they become available. This unique library contains archived and state-of-the-art earthquake engineering research and related information. The library is accessible worldwide.

## **Introduction**

### **What is the purpose of this report?**

The following report on the PEER Center is prepared and presented in accordance with Contract #SA2090JB between the Regents of the University of California, Berkeley (the host of the PEER), and the Commission.

The Commission monitors the work of PEER on the state's behalf, produces an independent evaluation, and recommends priorities for PEER to contribute to the reduction of earthquake losses.

The Commission consulted with the Business, Transportation, and Housing Agency, the Consumer Services Agency, and the Governor's Office of Emergency Services to prepare this report pursuant to Government Code §8876.7.

In accordance with SB 1864 and the contract between the Regents of the University of California and the Commission this report provides the following:

1. A brief overview of the PEER Center.
2. Interpretation of the results of the research to indicate how the research may affect State law and policy.
3. Recommendation of ways to promote the application of research.
4. Recommendation of priorities contributing to achieving the center's objectives, provide direct benefits to California residents and businesses, and lead to the completion of specific recommendations in the State's earthquake risk reduction program.

## **Background**

### **What is PEER?**



**Figure 3** Entrance to the PEER Center

The PEER Center is an (NSF) Earthquake Engineering Research Center located at the University of California, Berkeley Campus, Richmond Field Station. PEER is a part of NSF's program to reduce losses due to earthquakes through the National Earthquake Hazard Reduction Program (NEHRP).

Investigators from over twenty universities and several consulting companies conduct research in earthquake-related geohazard assessment, engineering seismology, risk reduction, and geotechnical and structural engineering.

PEER organizes its research around the performance-based earthquake engineering approach. Owners and other decision makers define performance targets in terms of safety, cost, and functionality needs according to that approach. The approach translates these performance targets into engineering criteria aiming to produce facilities performing to expectations within the greater economy (FEMA 1996).

In addition to conducting research to develop performance-based earthquake engineering technology, PEER's mission is to disseminate technology to earthquake professionals who ensure the results are useful, useable, and used.

PEER has nine Core Institutions and nine Affiliated Institutions in seven western states:

**Core Institutions:**

- California Institute of Technology
- Stanford University
- University of California, Berkeley
- University of California, Davis
- University of California, Irvine
- University of California, Los Angeles
- University of California, San Diego
- University of Southern California
- University of Washington

**Affiliated Institutions:**

- California Polytechnic University
- San Jose State University
- Universities of Alaska in Fairbanks
- University of Hawaii
- University of Utah
- University of Nevada in Las Vegas
- University of Nevada in Reno
- Oregon State University
- Washington State University

**What are PEER's Goals?**

PEER's goals include the development of a fully integrated approach for more reliable earthquake engineering to meet the needs of the public. These goals also include:

- Proceeding with the establishment of liaisons with business and industry leading to continuous and mutually beneficial interactions
- Fostering the transfer of knowledge and technology into design and construction practice
- Providing university students with a broad understanding of the requirements for

bringing sophisticated products all the way from the laboratory to the market.

- Developing next-generation earthquake engineering technology to meet the needs of the construction industry
- Pursuing crosscutting interdisciplinary research and education
- Improving training for practicing engineers.

Currently PEER is in Year Five of its ten-year research plan. There are 159 research projects being carried out by PEER researchers.

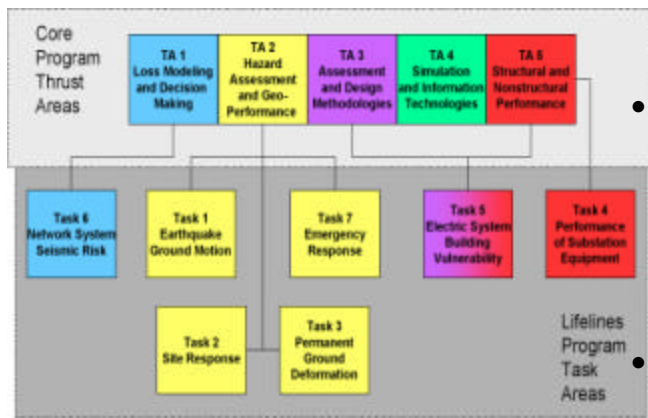
**What are the benefits to the State of California?**

California has the greatest seismic risk exposure of any state in the country. The seismic risk per year to the building stock alone is estimated by the Federal Emergency Management Agency (FEMA) at approximately \$3.3 billion dollars in California or approximately 75% of all the known seismic risk of the country. This is due to the combination of geology and the fact that most of the population and associated businesses and industries are concentrated in areas of high seismicity. PEER research and technology transfer activities benefit the State by helping systematically reduce seismic risk through the development of performance-based earthquake engineering technologies and products, the transfer of the results of the Center's research to the public and private sectors, and in the training of future students, engineers, and researchers.

PEER has two heavily interrelated major components: the Core Program and the Lifelines Program. Under the Core Program the PEER Center is developing performance-based earthquake engineering technologies in order to further satisfy the economic and safety needs of property owners and society. Applied research for utilities and transportation systems is conducted under the Lifelines Program. Figure



4 shows the relationship of the Core Program thrust areas and the Lifelines Program task areas.



**Figure 4** Core and Lifelines Research Relationship Graphic (courtesy of the PEER Center).

Senate Bill 1864 (Chapter 966, Statute of 1996 Government Code §8876.1, et seq.) states that the PEER Center shall conduct research on topics of relevant earthquake engineering research such as:

- Performance-based earthquake engineering for individual buildings, utility, or transportation components.
- Identification of key sources of future earthquake losses, quantification of the sources of risk, and development of strategies for reliably controlling losses.
- Development of cost-effective techniques for the analysis and design of retrofit measures for existing construction.
- Improving techniques for determining the suitability of sites and for understanding critical design relationships among soil conditions, foundations and structures, and for predicting response to earthquake ground motions and earthquake-caused ground failures.

- Experimentation to verify the seismic behavior of bridges, critical communications facilities, utility and transportation system elements, and nonstructural and structural components of buildings.
- Expansion of the database of performance observations from actual earthquakes to ensure the unfortunate occurrence of earthquakes will also serve the potential societal and scientific purpose of systematically advancing knowledge.
- Encourage and develop emerging technologies, design practices, and analytical capabilities offering the potential for breakthroughs in earthquake risk reduction.
- Dissemination of findings to the academic community, design professionals, government officials, building regulatory personnel, and the public.

### **What were the recommendations and findings from the 1999 committee review?**

In 1999 the Commission asked its Research Implementation Committee to review and assess the adequacy of PEER's efforts during its first two years. The Committee identified the need for PEER to:

- Expand PEER's industry partnerships to both support and benefit from earthquake technology improvements.
- Develop a better understanding of societal impacts and how public policy decisions are made.
- Inform the public about new developments.
- Train professionals to implement PEER's findings.

The Committee recommended in 1999 that the State of California:

- Increase the state government's investment in PEER from \$1.5 million to \$5 million annually.
- Leverage state government funds with support from other government agencies and the private sector.
- Consolidate and encourage better coordination of the State's management of its earthquake research to reduce piecemeal requests for research and eliminate the variety of overhead rates and special interest-driven research.

Since 1999 both PEER and California have made progress on these recommendations. State government funds have reduced slightly since 1999. Nevertheless, PEER has been able to broaden and solidify its support from industries benefiting from its efforts including the California Energy Commission, CalTrans, and the Pacific Gas and Electric Company. PEER has also begun investing an appropriate portion of its efforts in social science and public policy research as it relates to earthquake risk. PEER recently improved its public visibility by hiring an outreach director and holding its first annual conference. As more research is completed PEER plans to expand public awareness and educate key professionals in earthquake safety disciplines.

### **Do we know enough to manage earthquake risk effectively?**

No. Each major earthquake exposes unsettling surprises. For example, the 1994 Northridge earthquake exposed serious problems in modern steel frame buildings and parking structures.

The surprises relating to the performance of wood buildings has been equally disconcerting but less known to the public. Metal connections called "holddowns" in wood buildings were found to be too flexible to reliably protect owners' investments. Yet these holddowns are currently installed in many buildings.

Building officials increased the requirements for new concrete columns after the collapse of parking structures in 1994, yet there is relatively little focus on all other older concrete buildings considered at risk of collapse.

The 1989 Loma Prieta earthquake alerted CalTrans it needed to make changes in bridge design and construction practices to ensure safe and reliable transportation. Bridge research and education are helping make these major changes but similar investments in other sectors of the construction industry have not been made.

### **Are earthquake research and education priorities compatible with the public's needs and priorities?**

Yes, in many cases. Threats from newer, simpler risks occasionally get much more attention and resources than threats from older, more complex risks. PEER's initial focus is the threat of collapse in older concrete construction; a well-established, complex problem identified in the 1971 Sylmar Earthquake. Funding for research and education comes from a variety of sources from the public and private sectors. If these sources worked more closely together to identify their needs and set priorities, the public and construction industry would benefit from more broadly applicable, cost-effective research. PEER is California's catalyst for this needed coordination and priority setting.



## What can coordinated research and education do for California?

First, when the State collaborates with other government, business, and industry sources on research and education, it helps ensure limited funds are allocated on higher-priority needs.

Second, savings in management and overhead costs will accrue. Consolidation results in smoother operations.

Third, the State can leverage its funds with other sources to create more comprehensive solutions to our needs. This is why the State helped create PEER.

## Is PEER's work consistent with the state's plans and priorities?

Yes. The state has two plans directly relevant to PEER's objectives: *Research and Implementation Plan for Earthquake Risk Reduction in California* and *California Earthquake Loss Reduction Plan* (SSC 97-02), the State's official earthquake mitigation plan. This plan is recognized by the Federal Emergency Management Agency and calls for:

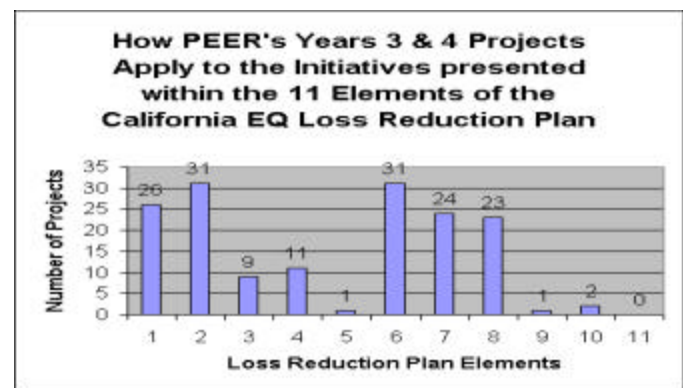
- Public oversight and priority setting
- Researchers collaborating with end-users
- Active participation in research by design professionals
- Easing new knowledge into practice
- Placing priority on problem-focused research
- Promoting education and outreach

PEER is working to put these priorities in place. To date there have been 222 research awards issued and 108 research projects completed. Project research awards underway in years three and four cover ten of the eleven elements contained in the

1997-2001 edition of *the California Earthquake Loss Reduction Plan* (see figure 5). PEER has undertaken no research as yet regarding the initiatives in the Recovery Element of the California Earthquake Loss Reduction Plan.

California's *Research and Implementation Plan for Earthquake Risk Reduction, 1995 to 2000* (SSC 94-10) recognizes that earthquake engineering is one of three broad areas needing research and education. The geosciences, societal impacts, and public policy also greatly need support.

California's *Research and Implementation Plan* calls for users of research to set priorities for applied, practical results. PEER has created advisory committees and outreach efforts to ensure its research is useful. It has already demonstrated it can work closely with end-users like PG&E and CalTrans in achieving rapid, practical results.



**Figure 5** Chart of Loss Reduction Elements And PEER Projects Years 3 & 4

1. Geosciences
2. Research and Technology
3. Education and Information
4. Economics
5. Land Use
6. Existing Buildings
7. New Construction
8. Utilities and Transportation
9. Preparedness
10. Emergency Response
11. Recovery

## How is PEER currently funded?

The State of California, the NSF, Pacific Gas and Electric Company, and FEMA provide major funding for the PEER Center. Additional funding is provided by subscriptions to the PEER Center's Business and Industry Partnership (BIP) program. The State of California provided for funding of PEER beginning in 1996. Additional State funds became available through CalTrans Research and Technology (cost sharing of existing PEER Center funding) and Public Interest Energy Research (PIER) funding provided by PG&E via a pass-through oversight contract on behalf of the California Energy Commission (CEC). Funding from other than NSF has allowed PEER activities to increase the number and scope of projects performed. The total funding for the Center for Year Four (from October 1, 2000 through September 30, 2001) was \$5,849,346.

The following table depicts a distribution of funds for the Center for Year Four.

### Base/Matching Funds Year 4

National Science Foundation	\$2,000,000
California State-Business, Trans. & Housing...	\$1,000,000
California State-General Fund	\$500,000
University of Calif. Office of the President	\$250,000
University of Calif. Berkeley Engineering	\$20,000

### Leverage Funds

Pacific Gas and Electric Company	\$165,000
California Transportation	\$750,000
California Energy Commission	\$750,000
Federal Emergency Management Agency	\$175,000

### Additional Funds

Research Experience for Undergraduates Supplement – National Science Foundation  
\$56,884

### Non-Expendable Funds - Cost-Share

University of California Berkeley	\$163,462
University of Washington	\$19,000
<b>Total:</b>	<b>\$5,849,346</b>

## Where does PEER plan to spend its funds?

A general breakdown of Year Four research expenditures is presented as follows:

Geosciences:	\$609,935
Research and Technology:	\$397,500
Education and Information:	\$293,230
Economics:	\$315,000
Existing Buildings:	\$1,360,778
New Construction:	\$973,343
Utilities and Transportation:	\$805,712
Preparedness:	\$64,996
<b>Total:</b>	<b>\$4,578,059</b>

The difference in funds received and funds expended are accounted for in the operation of the PEER Center and a small reserve to fund the deployment, field operations, and report preparation of a PEER funded earthquake reconnaissance team should a significant earthquake occur holding potential lessons for California. During Year Four PEER sent a team to study the Nisqually (Washington State) earthquake of February 28, 2001.

## What is the commitment by the National Science Foundation for continued funding?

On July 30, 2001, PEER announced NSF had completed a review of the PEER Center and funded PEER for a second five-year funding cycle. Funds provided by NSF for operating PEER must be matched by the State of California.

## What threats are there to the future of the PEER Center?

The most significant threat to the future of the Center is the inconsistent funding base by State and Federal government beyond a five-year funding cycle. A second threat to the Center and the earthquake engineering community in California has been the lack of state funding support for the NISEE Library. UC Berkeley

has operated this service since 1971. It provides earthquake engineering information from a variety of fields to engineers, geologists, planners, social scientists, regulators, the insurance industry, and the public. In the past funding was provided by NSF. However, NSF has indicated it may discontinue funding. The loss of the NISEE Library would seriously hinder access to state-of-the-art information regarding earthquake engineering for Californians.

### **What has PEER accomplished in education and outreach so far?**

Progress has been made in the introduction of earthquake engineering problem-solving activities for elementary school students. The development and implementation of lesson plans for elementary school teachers and the use of portable shake tables allow students to build small structures and see if they can withstand scaled-down shaking from an imaginary earthquake. A more sophisticated program has been used to interest undergraduate students in earthquake engineering and related fields for graduate school recruitment. Graduate students working on research projects through PEER participate with their advisors on state-of-the-art projects leading the way to future research and industry applications. The graduate students showcase their projects each year at the PEER annual meeting. Several students have received their PhDs and are now either working as consultants or have joined the faculties at universities within the United States where they are educating the next generation of urgently needed engineers and scientists.

Starting in the fall of 1998 PEER began offering a new Earthquake Engineering Scholars Course (EESC) which is a multi-campus program providing instruction to

undergraduate students during weekend retreats at PEER campuses. EESC is for seniors in engineering who demonstrate a sincere interest in earthquakes and achieve high academic levels. Each PEER Core institution has a specified number of Scholars depending on their program size. Scholars from PEER's Affiliate Institutions also participated in the course covering four topics in earthquake engineering:

1. Seismology
2. Geotechnical Earthquake Engineering
3. Structural Dynamics in Engineering, and
4. Public Policy



**Figure 5** Elementary school students participating in a shaking table experiment of buildings made of Lego toys.

PEER works with the California Academy of Sciences Natural History Museum in San Francisco to enhance its earthquake exhibit, thereby better educating the public on reducing earthquake losses and identifying earthquake-related career paths for young Californians.

PEER opened its annual meeting to the public for the first time in January 2001 attracting over 300 attendees. The meeting is to continue as an annual event.

## **Are other earthquake research efforts addressing California's needs?**

Yes. In addition to PEER several other centers and entities help serve the earthquake risk assessment and/or risk reduction needs of California:

- Southern California Earthquake Center (SCEC): *Geosciences*
- California Integrated Seismic Network (CISN): *Geosciences and Emergency Response*
- Consortium of Universities for Research in Earthquake Engineering (CUREE): *Private Non-profit Center*
- Applied Technology Council (ATC): *Private, Non-Profit Engineering Resources*
- Strong Motion Instrumentation Program (SMIP), California Division of Mines and Geology: *Records and disseminates ground motion records of value to practicing engineers and others.*
- Earthquake Engineering Research Institute (EERI): *Private, Non-profit National Organization*
- Structural Engineers Association of California (SEAOC): *Nonprofit Professional Organization*

The Commission as the principal earthquake engineering research arm has identified PEER for the State. As such, PEER maintains ties to all of these organizations in carrying out this mission.

## **How does the PEER Center collaborate with other centers?**

PEER is involved in cooperative efforts with the Southern California Earthquake Center (SCEC), the Mid-America Earthquake Center at the University of Illinois (MAE), and the Multi-Disciplinary Center for

Earthquake Engineering Research at the State University of New York (MCEER).

PEER coordinates research with SCEC to fill gaps between geosciences research and engineering research. PEER collaborates with MAE and MCEER to coordinate and develop Engineering Education Modules for students of all age groups. The modules incorporate interactive multi-media educational activities (CD-ROMs and hands-on kits) that students can use in high school and undergraduate classes.

PEER's strength is derived from the breadth of the researchers participating in PEER activities and the support of the earthquake engineering community in North America, Turkey, Taiwan, and Japan. PEER has become a conduit by which several funding partners (CalTrans, CEC, and PG&E) coordinate all or part of their seismic hazard assessment and mitigation research activities. The engineering community reflects another strength in the strategic plan for the Center and its goal for the development of performance-based earthquake-engineering practices useable.

Examples of strengths sought out in SB 1864 successfully implemented by PEER include:

1. Data exchange with foreign research groups such as the Central Research Institute for Electric Power Industry in Japan and the National Center for Research in Earthquake Engineering in Taiwan;
2. Leveraging of funds from federal, state, private, and international funding sources; and,
3. Co-funding to take advantage of fieldwork, testing, or data analysis by investigators working on projects similar to PEER projects or goals that may not receive funds solely from PEER.

Opportunities capitalized on by the PEER Center include:

1. Collaboration with other centers and agencies on the study of secondary earthquake related effects on buildings, bridges, piers, pipelines, and electric transmission and distribution equipment.
2. Expanding its interaction with social scientists, economists, planners, the insurance industry, and public policy makers.

### **What are the PEER Center's accomplishments to Date?**

The PEER Center, along with the CEC, PG&E, CalTrans, and the United States Geological Survey have successfully conducted a broad collaboration focused on “applied research” projects with near-term payoffs for design practice, earthquake hazard reduction via the collection or development of high quality data, advanced models and methods regarding strong ground motion, and the performance of the structural components of buildings.

### **What makes PEER effective?**

PEER is effective primarily because of its ability to coordinate applied earthquake engineering research activities of a broad range of researchers operating out of organizations in the State. By coordinating research, PEER is able to tackle problems in a broad way that results in technological solutions that can be fully implemented for effective earthquake risk mitigation.

The “user-driven” management model employed by the PEER Lifelines Program is a unique and effective approach to span the “implementation gap” often observed between the research community and practi-

tioners. In this program a Joint Management Committee (JMC) composed of technical representatives from each sponsor and the PEER Center approves projects on a consensus basis. This full empowerment of the end-user in program decision-making has assured responsiveness of the researchers to the immediate needs of practitioners, has sensitized the research community to a variety of practical issues affecting Lifelines, and has assured the implementation of research results.

### **Other accomplishments include:**

#### Research in Performance-Based Earthquake Engineering and Geosciences

In conformance with the mission of the PEER Center a framework has been developed to assess the earthquake performance of buildings, bridges, and other facilities more uniformly. This framework provides a road map toward a common goal of research projects in all related disciplines with the flexibility necessary for exploration of various avenues to arrive at the common goal.

#### Software Framework for Earthquake Engineering Simulation

A software framework called OpenSees (Open System for Earthquake Engineering Simulation) has been developed and made available to researchers and practitioners to rapidly improve the quality of simulations and increase collaboration among disciplines.

#### Performance and Simulation Databases

Several on-line databases for storing, managing, and disseminating information in order to achieve the full potential of computing and information technologies are being developed. The databases are being developed with a standardized format based on the contents of the database.

### Site Response

A number of projects have been completed to aid in the crucial topic of evaluating and predicting the likely effect of soil and geologic conditions on earthquake ground motions. One of the major areas being improved is the quality of geologic information in earthquake loss estimation for use in FEMA's Hazards-US (HAZUS) model.

### Education: Earthquake Engineering Scholars' Course

The best undergraduate students have instituted an annual retreat to showcase the graduate earthquake engineering programs at PEER institutions and to encourage advanced study in earthquake engineering. Fields of study include seismology, geology, geotechnical engineering, structural engineering, and public policy.

### Student Leadership Council

In cooperation with the MAE Center and the MCEER, summer symposiums have been offered to undergraduate students to provide an opportunity to visit earthquake-engineering sites of interest and to interact with one another particularly on the subject of engineering ethics.

### University Consortium for Instructional Shake Tables

Another tri-center cooperative effort provides for the acquisition of instructional shake tables. Access to these shake tables in experiments fosters a greater understanding by engineering and non-engineering students of structural dynamics and earthquake response.

### Graduate Course Modules

A tri-center effort has developed courses with references for further study to formalize the transfer of information developed at the Centers.

### Utilities and Transportation

The Center continues to aggressively pursue reduction of the cost of seismic retrofitting practices by methodically testing and analyzing various columns and piers for supporting bridges. Modeling of the performance of a regional ground transportation network after a major earthquake has also begun.

The Center has also been involved with the development of techniques to increase the reliability of electric power equipment during earthquakes. CalTrans and electric utilities in their seismic retrofit programs have already used some of the results of the bridge and electric equipment testing.

### Technology Transfer

With the establishment of a public relations office and hiring of an Outreach Director, the PEER Center has demonstrated its commitment to increasing awareness of its activities. At its first annual open house meeting in January 2001 over 300 persons attended, many of whom had not been previously involved with PEER. The meeting helped the earthquake community, state, and local governments become familiar with the Center. PEER has helped to organize and participated in several national and international workshops. The loss of PEER's BIP liaison person affected growth of the BIP that has remained about the same size as in 2000. The acquisition of a new BIP liaison person should help the BIP group grow. The PEER Center has also sponsored several workshops such as the US-Japan Workshop on the Effects of Near-Field Earthquake Shaking, the First, Second, and Third US-Japan Workshops on



Performance Based Design Methodology for Reinforced Concrete Building Structures, and a workshop on Planning, Policy Analysis, and Economics in Earthquake Research.

### Immediately useful products

Some of the immediately useful products developed through the Center include:

- new seismic attenuation relationships for near source (within 20 kilometers) ground motions;
- liquefaction assessment curves based in part on common field testing methods such as the standard penetration test or the cone penetration test;
- electric utility equipment fragility data;
- improved engineering criteria for assessing vulnerability of older existing concrete buildings; and,
- improved engineering criteria for bridges based on performances matrices.

Other useful tools included the performance of simulation databases. The data contained within the databases has led to development of improved engineering criteria in use. An example is the improved acceptance criteria for non-ductile buildings that were incorporated in FEMA 356.

### **What are the observations from funding source contacts?**

PEER's strategic plan calls for the establishment of research priorities whose products are useful, useable, and used. The Center has created and uses advisory committees and a joint management committee to direct the focus of the Center in achieving the

earthquake risk reduction goals of the State and other partners. The Center also works closely with its funding partners as well as its product users.

The following observations regarding the PEER Center are presented by funding source personnel who work closely with the PEER Center:

### Observations from the California Energy Commission

The CEC is funding user-driven seismic safety and reliability research projects at PEER applicable to the electric power system for the State through its contract with PG&E. The research is supporting the development, rapid application methods, technologies for reducing earthquake hazards, vulnerability, and improving electric system reliability and safety of electric transmission and distribution systems. The research covers several areas such as: seismic performance of electric substation equipment, electric system seismic risk, electric system building vulnerability assessment and mitigation, strong ground motion and site response, permanent ground deformation, and emergency response. The research results so far are promising and will be useful in increasing seismic safety of the electric system and reliability of California's electrical infrastructure.

### Observations from the Pacific Gas and Electric Company

In 1996 PG&E formed a public/private partnership with California Universities Consortium that eventually became the PEER Center. The partnership agreement was focused on research efforts to support user-driven lifeline systems needs to improve safety and reliability during future earthquakes. The fact that this important Lifelines research component had been formed as a part of the proposed PEER research

program significantly influenced NSF in its funding decision to support the PEER Center.

The PEER Lifelines Program has been expanded by the addition of CalTrans and the leveraging of their earthquake research funding with matching funding. Other partners have joined as well in order to benefit from this unique approach (such as the State of Washington's Department of Transportation, SoCal Edison, Fluor Daniel, FEMA, and a large number of consulting companies) to have qualified researchers address the research needs of the Lifelines and Core Program partners.

Many lessons for California derive from research on earthquakes occurring in other countries. The PEER Center and various Lifeline and Core partners have benefited from participating in joint efforts with researchers in Turkey, Taiwan, and Japan. Their research has included an assessment of liquefaction and small-scale ground deformation in Adapazari, Turkey; data collection, reduction, and analysis of strong ground motion from recent large earthquakes in Turkey and Taiwan; and a lateral spreading and liquefaction research project on Hokkaido Island, Japan.

#### Observations from the California Department of Transportation

CalTrans builds approximately \$1 billion in new bridge infrastructure per year. Properly addressing seismic issues is critical to assuring the safety and reliability of California's transportation network. Therefore CalTrans has taken an international leadership role in sponsoring approximately \$6.5 million per year in earthquake research under two distinct but complimentary programs. Approximately \$5 million per year is focused on structural research to develop and proof-test

new innovative design details that increase the capacity of bridges to withstand earth-quake motions. Though this "Seismic Detail Development Program" is not directly under the auspices of PEER most of the research is performed by PEER-affiliated universities in California. The remaining \$1.5 million per year funds CalTrans' contribution to the PEER Lifelines Program. This unique partnership provides a cost-effective means to execute applied research on common-interest topics such as improved ground motion estimation procedures, network reliability analysis, and emergency response technologies. The PEER Lifelines Program provides CalTrans with a unique opportunity to leverage funding, knowledge, and experience of other research sponsors and provides unique access to seismic design leaders from industry, academia, and government organizations worldwide. Active participation in the PEER Lifelines Program along with new fundamental developments coming from the PEER Core Program are anticipated to advance CalTrans' implementation of improved design and operations procedures by 5 to 10 years and yield benefits estimated at \$15 to \$30 million per year. The benefit-to-cost ratio CalTrans is achieving is ten to twenty times their investment in PEER-based research.

#### **How will PEER's efforts affect state laws and policies?**

PEER will influence the State's laws and policies, seismic hazard assessment practices, and seismic risk assessment and design by continuing to develop and accumulate high quality data and databases useful to the earthquake engineering community. PEER will also continue to conduct model development for seismic hazard assessment and risk assessment through testing, computer simulation, and observations of the performance of structures, buildings, and facilities during and after earthquakes. PEER will also participate in the development of methods to implement validated models into engineering

practice. The change in practice will positively affect building codes and siting practices. The reduction of seismic hazard risk will allow the State to formulate effective future legislation for the continued protection of life and property as well as seismic hazard reduction in California.

## **Conclusions and Recommendations**

The Commission concludes that:

- The PEER Center research is in alignment with both the *California Earthquake Loss Reduction Plan* and with the *Research and Implementation Plan for Earthquake Risk Reduction in California*. PEER's work is reflected in several of the *California Earthquake Loss Reduction Plan* initiatives in geosciences, research and technology, education and information, existing buildings, new buildings, utilities, and transportation. PEER is also meeting most of the goals under SB 1864. The principal reason why all PEER goals have not yet been met stems mainly from a lack of funding or resources in the areas yet to be addressed.
- To date there have been 222 research awards issued and 108 research projects completed. The research awards cover ten of the eleven elements contained in the 1997-2001 edition of *The California Earthquake Loss Reduction Plan*.
- Products developed by the PEER Center are making their way into use by practitioners.
- The PEER Center is developing a more collaborative connection with other NSF earthquake engineering research centers.

- The PEER Center is seeking sponsors other than State or Federal government.
- The PEER Center's Lifelines and Core Programs are developing scientific and engineering underpinnings needed to improve the specification of earthquake ground motions for engineering design.
- The PEER Center has been highly successful in using ground motion data and field observations from major earthquakes in Turkey and Taiwan (in expanding the database of near field ground motion) and in preparing robust attenuation relations for use in future seismic hazard assessments and design of complex or critical facilities. This success demonstrates the value in collecting highly perishable data by experienced personnel and reviewing the data and developing models and methods to better understand strong ground motion and seismic hazards.

The Commission recommends the following actions in order to promote the application of PEER sponsored research:

- The PEER Center should seek opportunities to collaborate with associations representing all the disciplines that play a role in earthquake loss reduction to provide their constituents with the latest findings from research to apply in professional practice, design, and public policy.
- The BIP liaison should work with the existing BIP and with local government to recruit new partners to gain new insights on earthquake engineering research and seismic hazard assessment and risk analysis.

- Work more closely with the MAE Center and the MCEER Center on common issues in earthquake engineering, seismic hazard assessment and risk analysis, and mitigation methods.
- Invite a limited number of practitioners each year to work on PEER projects.

The Commission recommends the following priorities in order to help PEER achieve its' objectives:

- The State should increase its funding level for PEER from \$1.5 million per year to \$5 million per year.
- Increase the level of non-State and non-Federal funding.
- PEER should hold or co-sponsor more frequent workshops related to research underway at the affiliated and Core PEER institutions on earthquake hazards assessment, earthquake risk analysis and mitigation decision making, and performance-based earthquake engineering.
- The State should co-sponsor the NISEE Library at UC Berkeley, Richmond Field Station, as a part of the augmentation of PEER's State funding level increase.
- PEER should work more closely with secondary school students and teachers as well as elementary school students and teachers.
- The Legislature should encourage the use of PEER research assessments in the development of post disaster assessment technologies for urban areas.

## **Report Preparation and Acknowledgements**

This report was prepared by Messrs Robert Anderson, Richard McCarthy, Fred Turner, Henry Sepulveda, and Ms. Sue Celli of the California Seismic Safety Commission staff; California Seismic Safety Commission Commissioners Mr. Linden Nishinaga, Mr. Daniel Shapiro, Mr. Stan Moy, Dr. Ashok Patwardhan, Mr. Andrew A. Adleman, Mr. Bill Gates, Mr. Douglas E. Mochizuki, Mr. Mark Church, Mr. Chris Modrezejewski, Mr. Lawrence Klein, and Dr. Bruce R. Clark; and Ms. Susan Tubbesing of the Earthquake Engineering Research Institute. For further information regarding this report please contact Mr. Anderson at (916) 263-5505 or e-mail at: [banderson@quiknet.com](mailto:banderson@quiknet.com). Further information on the PEER Center may be found at the website: <http://peer.berkeley.edu/>.

The Commission acknowledges and thanks Mr. James Roberts (retired) and Dr. Clifford Roblee from the California Department of Transportation, Dr. William Savage from the United States Geological Survey, formerly of the Pacific Gas and Electric Company, Mr. Lloyd Cluff of the Pacific Gas and Electric Company, Mr. David Chambers of the California Energy Commission, Mr. Edward Bortugno from the Governor's Office of Emergency Services, Mr. Stan Nishimura of the Building Standards Commission, within the State Consumer Services Agency, and Dr. Jack Moehle and his staff from the PEER Center for their part in assisting the Commission in the preparation of this report.