

REVIEW OF THE PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER (PEER)

YEARS 7-9



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Alfred E. Alquist Seismic Safety Commission

Review of the Pacific Earthquake Engineering Research Center

Executive Summary

The Pacific Earthquake Engineering Research Center (PEER) is a major national and regional engineering research center established in October 1997 by the State of California and the National Science Foundation (Government Code §8876.1 *et seq.*). PEER is the primary earthquake engineering research arm of the State of California.

Under law, the California Seismic Safety Commission (Commission) is required to periodically monitor the work of PEER on the State's behalf and produce an independent evaluation of its progress (Government Code §8876.7). Three previous reports have been issued. This report is primarily concerned with years 7 to 9.

Findings

The Seismic Safety Commission finds:

1. PEER's efforts have produced cost-effective products that benefit the State of California consistent with the goals and initiatives of the *California Earthquake Loss Reduction Plan*.
2. PEER continues to meet its goals. It has been instrumental in affecting State laws and regulations. Specific PEER accomplishments include:
 - Trained students and professionals to use state-of-the art technologies to reduce earthquake vulnerability of buildings and infrastructure
 - Influenced important changes in national standards for the design of concrete structures that increase safety and reduce construction and retrofit costs
 - Produced guidelines for assessing and mitigating the effects of liquefaction and earthquake induced landslides
 - Improved retrofit techniques for bridges resulting in greater safety and lower construction costs
 - Partnered with electric utility companies in California to guide PEER's development of applied research that enhances standards for substation, transmission and distribution systems
 - Developed improved ground motion estimates for seismic conditions appropriate to large regions of California. These new estimates will soon be widely used in the design and safety evaluations of facilities of all types when they are incorporated into the next edition of the National Seismic Hazard Maps and future State regulations.

3. PEER's principal product, performance-based earthquake engineering (PBEE), shows great promise, and is now emerging as a critical tool for design and evaluation of major buildings, utilities, and lifelines.
4. The technological basis of PBEE and its application by the engineering profession must be improved by continuing research, development, and dissemination, particularly for the design of new structures.
5. PEER has formed effective partnerships with public and private organizations, including its Affiliated Institutions and Business and Industry Partners, directly benefiting earthquake safety in California.
6. PEER has leveraged over \$22 million in federal and corporate funds.

Recommendations

The Seismic Safety Commission recommends that:

1. PEER take the lead and collaborate with its Business and Industry Partners and other organizations to educate owners, regulators, and design professionals about performance-based earthquake engineering and to transfer PEER's research results into practice.
2. PEER package its research results as a tangible set of documents and web resources that can be readily used by engineers and earthquake risk managers.
3. Both the State of California and the private sector continue to fund PEER at twice the state's current financial support of PEER's core program to offset the pending loss of National Science Foundation funding.
4. Because of the large amount of the public works bonds (Propositions 1B through 1E, as well as future bonds), fiscal responsibility dictates that the State dedicate a reasonable percentage of future bonds for research in all applicable disciplines to ensure that funds are invested wisely and in the most-cost-effective manner.

Table of Contents	Page
What is PEER?	1
PEER's Mission	1
What is Performance-Based Engineering?	2
Why is the Commission Reviewing PEER?	2
PEER's Funding History	3
How PEER Efforts Have Already Benefited California	4
Challenges and Opportunities For PEER	5
Why Should California Invest in Earthquake Engineering Research?	6
Findings	8
Recommendations	8
Acknowledgements and Publication Information	9

Alfred E. Alquist Seismic Safety Commission

Review of the Pacific Earthquake Engineering Research Center

What Is PEER?

The Pacific Earthquake Engineering Research Center (PEER) is a major national and regional engineering research center established in October 1997 by the State of California and the National Science Foundation (Government Code §8876.1 et seq.). PEER is the primary earthquake engineering research arm of the State of California (PEER.Berkeley.edu).

PEER identifies California's research needs in earthquake engineering and coordinates the efforts of nine institutions (Core Universities) that include: the California Institute of Technology; Stanford University; the Universities of California at Berkeley, Davis, Irvine, Los Angeles, and San Diego; the University of Southern California; and the University of Washington. Investigators from eleven other universities including six Educational Affiliate Institutions also participate in PEER. Its Business and Industry Partners Program encourages private investment to address specific engineering issues in collaboration with PEER.

PEER's Mission

PEER's mission is to develop and disseminate performance-based earthquake engineering (PBEE) technology. PEER achieves its mission through research, education, and technology transfer programs aimed at cost-effective reduction of earthquake losses. PEER's mission tasks include:

- Refine the characterization of seismic hazards used for engineering design.
- Develop engineering tools for seismic safety assessments of buildings, bridges, lifelines, and other structures
- Develop design criteria that will ensure safe and efficient performance of newly constructed facilities.
- Develop methodologies for mitigating seismic hazards in existing facilities, including engineering and public policy.
- Develop performance-based approaches for design and evaluation of facilities that help meet economic and functional objectives, particularly for services that are essential immediately after earthquakes.

What Is Performance-Based Earthquake Engineering (PBEE)?

Traditional design procedures and building codes prescribe forces that are intended to represent the effects of earthquakes on structures. In many instances, codes also prescribe specific construction detailing requirements. Engineers must make sure that structures (e.g., buildings, bridges, wharfs, utilities) are strong enough to resist these forces and that the detailing procedures are followed. The implication of prescriptive codes is that structures will perform adequately during earthquakes.

Performance-based earthquake engineering (PBEE) is a relatively new concept that goes beyond prescriptive procedures to base design decisions explicitly on the expected consequences of earthquakes in terms of life safety, protection of structures and their contents, and the ability to use facilities after earthquakes. PBEE procedures do this by predicting damage that facilities are likely to experience. From this information, an engineer can determine the expected consequences in terms of casualties, dollar losses, and disruption of functions. This information allows the designer and owner to make better decisions about the effectiveness of various alternatives in controlling those consequences. As a result, performance-based designs can be more efficient from a construction cost standpoint, perform more predictably, and be more reliable as a risk management tool than traditional, prescriptive-only designs.

In the long run, the quantitative approach of PBEE will lead to more reliable and safer structures with lower life-cycle costs.

Why is the Commission Reviewing PEER?

Existing law designates that the California Seismic Safety Commission periodically monitor the work of PEER on the State's behalf.

The Commission consulted with three State agencies—the Business, Transportation and Housing Agency; the Office of Emergency Services; and the State and Consumers Services Agency—to make this independent evaluation of the effectiveness of PEER programs and to recommend priorities for PEER's future efforts.

This report is prepared in accordance with Government Code §8876.7 and Contract No. SA5304 with the Regents of the University of California, Berkeley Campus (the host of the PEER Center). This report reviews PEER's work from October 2003 through September 2006, Years 7-9.

Three previous reports describing reviews of PEER's prior years are available at www.seismic.ca.gov/sscpub.htm .

PEER's Funding History

In Years 7 to 9, PEER received \$15 million from various finding sources. Over the past nine years, PEER received \$54 million in funding, including:

Government Support for PEER's Core Program

Federal:

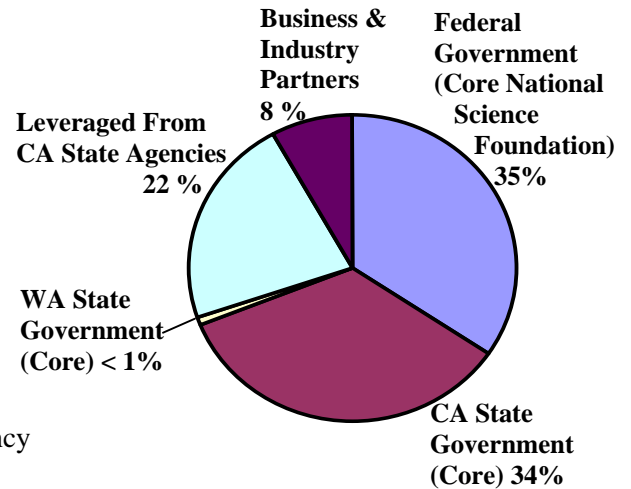
\$18.6 million National Science Foundation (NSF)

California:

\$9.0 million Business Transportation and Housing Agency
 \$4.5 million State's General Fund,
 \$2.3 million UC Office of the President's General Fund
 \$2.4 million UC Berkeley's College of Engineering
 \$0.2 million UC San Diego and UC Irvine

Washington:

\$0.4 million University of Washington and the Washington Department of Transportation



PEER Funds for Years 1 to 9

Business and Industry Partners and Leveraged Support for Targeted Research Projects

- \$ 6.7 million Caltrans Leveraged Support
- \$ 5.4 million California Energy Commission through PG&E
- \$ 3.4 million Pacific Gas & Electric Company (PG&E)
- \$ 0.3 million Bay Area Rapid Transit District (BART)
- \$ 0.3 million California Earthquake Authority
- \$ 0.3 million Business and Industry Membership
- \$ 0.2 million Federal Emergency Management Agency (FEMA)

In the past, 56 percent of PEER's funds have come from the State of California and 35 percent have come from the National Science Foundation. However, PEER's funding from the 10-year National Science Foundation contract will end September 2007.

PEER has leveraged over \$22 million from federal and corporate funds that includes \$4 million from PG&E, BART, and other business and industry members.

How PEER Efforts Have Already Benefited California

Several PEER products and activities have already made significant impacts on seismic safety in California. PEER has:

1. Trained students and professionals to use state-of-the art technologies to reduce earthquake vulnerability of buildings and infrastructure
2. Influenced important changes in national standards for the design of concrete structures that increase safety and reduce construction and retrofit costs
3. Produced guidelines for assessing and mitigating the effects of liquefaction and earthquake induced landslides
4. Improved retrofit techniques for bridges resulting in greater safety and lower construction costs
5. Partnered with electric utility companies in California to guide PEER’s development of applied research that enhances standards for substation, transmission and distribution systems
6. Developed improved ground motion estimates for seismic conditions appropriate to large regions of California. These new estimates will soon be widely used in the design and safety evaluations of facilities of all types when they are incorporated into the next edition of the National Seismic Hazard Maps and future State regulations.

Table 1 shows how PEER research projects focus on all elements of the *California Earthquake Loss Reduction Plan*.

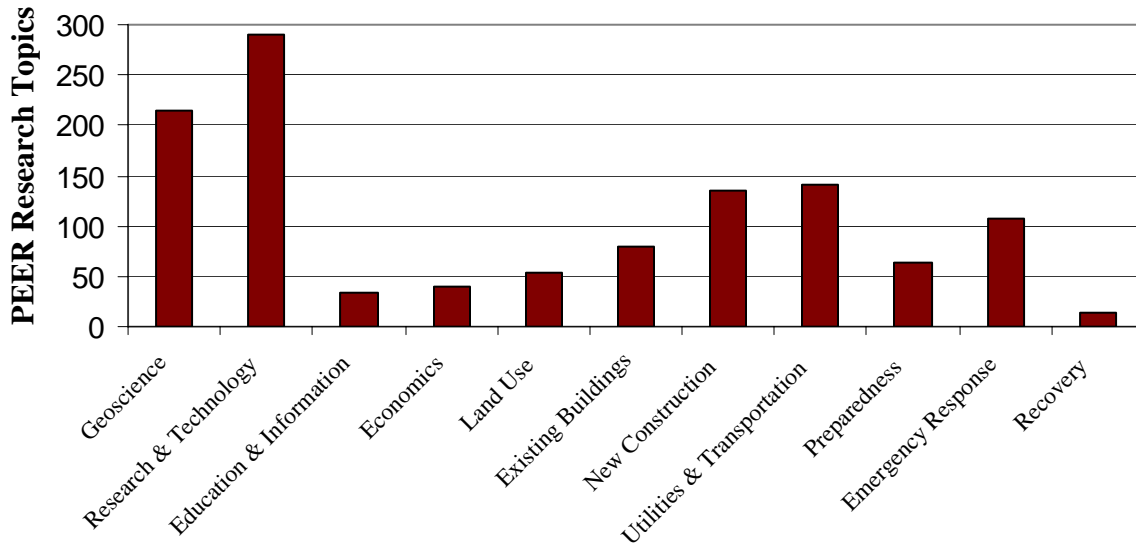


Table 1 - Years 7-9—PEER Research Topics Consistent with the Elements of the *California Earthquake Loss Reduction Plan*
 (Note that PEER also addressed other topics in the *Plan* during Years 1 to 6.)

PEER has applied its research resources to many practical projects in California:

Example #1: The Bay Area Rapid Transit (BART) system was constructed in the 1960s and 1970s. Built to seismic standards considered high for the time, recent research indicates that the system has both life safety and post-earthquake operability deficiencies. PEER helped develop a cost-effective program using performance-based procedures to meet life safety objectives and shorten times for restoration of train service after earthquakes.



Example #2: The earthquake safety and sustainability of California's institutions of higher learning have also benefited tremendously from the use of performance-based earthquake engineering and PEER's research results. In 1997, the University of California at Berkeley (UC) embarked on an aggressive program to upgrade seismically deficient buildings using PBEE. Costs for these improvements were substantially less than bringing UC's buildings into compliance with older, prescriptive, force-based codes for new buildings. UC was able to be more flexible in its allocation of funds, meet its budget, tailor its building performance objectives, and spend its retrofit funds more efficiently with PEER's help.

Example #3: PEER created significant improvements in the way structures are evaluated and designed in California. PEER has identified vulnerable characteristics of buildings that can lead to collapse in severe earthquakes; this has helped create better methods for evaluating and retrofitting older concrete buildings. These improved techniques will be included in the 2007 California Building Code, potentially saving hundreds of millions of dollars both before and after future earthquakes.

Example #4: PEER has also developed the OpenSees computer program for simulating the complex performance of structural systems in earthquakes. OpenSees has become a widely-accepted, web-based application for analyzing structures under various loading conditions.

Challenges and Opportunities for PEER

PEER has clearly demonstrated its ability to be opportunistic and seek out funding for future projects. It is approaching the end of its 10-year agreement with the National Science Foundation, which ends September 30, 2007. For the past several years, every NSF dollar has attracted about twice that in dollars from state agencies and from industry. Future funding from NSF may become available, but it will likely be on a much-reduced and less-coordinated level.

PEER expects to receive \$3.6 million from the federal Network for Earthquake Engineering Simulation (NEES) over the next five years to address older concrete buildings that are at risk of collapse.

In addition, PEER is responding to requests from local governments to assess the earthquake risk posed by high-rise buildings. Regulators, developers and owners of new high-rises urgently need answers to questions about their vulnerability. PEER is negotiating contracts with the cities of Los Angeles and San Francisco and other stakeholders to support its tall buildings research program and leverage Federal funds from FEMA, NSF, and the US Geological Survey.

However, PEER has yet to clarify the potentially adverse effects of next year's reduction of financial support for its core research and education programs, and describe how future individual projects will fit into its overall mission.

Other challenges and opportunities for PEER include:

- Obtain much-needed funding from the State of California and from private industry during a time of general economic slowdown.
- Balance the needs of the National Science Foundation with those of other major funding partners.
- Recruit, retain, and increase members in its Business and Industry Partners (BIP) program.
- Educate, promote, and demonstrate—to the general public, elected officials, building owners, building department officials, and other key stakeholders—the value and benefits of PEER research and seismic hazard mitigation efforts.
- Lead, educate and train students and practicing engineers how to use PBEE and other PEER-developed products in their daily practice.
- Promote PBEE to the California Building Standards Commission, International Code Council, and other organizations so that it can be adopted into building codes expeditiously.

Why Should California Invest in Earthquake Engineering Research?

California has by far the greatest earthquake risk of any state in the country. There is over a 95 percent probability that a major earthquake will strike California in the next 30 years (*California Multi-Hazard Mitigation Plan*, OES, 2004). Directly underneath a major urban center, a large earthquake could cause over \$250 billion in damage—higher than September 11, 2001 and Hurricane Katrina combined. Investment in earthquake research has the potential to save billions of dollars and thousands of lives.

In November 2006, California voters authorized over \$30 billion in bond measures (Propositions 1B through 1E) for new construction and for repair of the State's infrastructure. Since a significant portion of that investment is directed toward earthquake risk reduction, the State must invest in research to ensure that bond funds are spent effectively and that the State benefits directly from the latest developments in research.

Recent, moderate earthquakes are not indicative of California's seismic future. The state has never experienced a catastrophic earthquake striking directly under one or more major urban centers during school or business hours. Table 2 shows casualties and economic losses from past earthquakes and predicted losses for expected earthquakes.

Table 2 Casualties and Losses from Specific Earthquakes and Earthquake Scenarios

	<u>Earthquakes</u>	<u>Deaths</u>	<u>Injuries</u>	<u>Property Damage & Economic Loss</u>
Previous	1971 Sylmar, CA Earthquake	65	2,400	\$0.5 billion
	1989 Loma Prieta, CA Earthquake	62	3,757	\$10 billion
	1994 Northridge, CA Earthquake	57	9,000	\$20 billion
	1995 Kobe, Japan Earthquake	>5,500	>26,000	\$250 billion
Projected	Scenario 7.0 Hayward fault, CA	>4,000	>25,000	\$100 billion
	Scenario 7.4 event on the Puente Hills fault, Los Angeles, CA	3,000-18,000	56,000-268,000	\$80-250 billion
	Repeat of the 1906 San Francisco, CA earthquake	800-3,400	23,000-62,000	\$90-120 billion
	Scenario 7.0 Newport-Inglewood fault, Long Beach, Los Angeles, and Orange Counties, CA	2,000-6,000	20,000	\$200 billion

PEER research recently concluded that a modern building is 10 to 30 times less likely to collapse than a comparable 40-year-old building. This reduction in risk is a direct product of investments in earthquake engineering research and the resulting improvements in codes and regulations. However, chronic under-investment in research has contributed to the poor performance of some modern and retrofitted structures in recent earthquakes. Additional research, development, and application are clearly needed.

If California chooses not to continue its financial support of PEER, the greatest adverse effect will be the loss of coordinated research that has tapped the expertise from 20 western universities to address California's greatest earthquake priorities. Granted, earthquake research would continue, but without PEER's synergism, it will be piecemeal. The transfer of current and future research results into practice will be slower and less effective.

Findings

The Seismic Safety Commission finds:

1. PEER's efforts have produced cost-effective products that benefit the State of California consistent with goals and initiatives of the *California Earthquake Loss Reduction Plan*.
2. PEER continues to meet its goals. It has been instrumental in affecting State laws and regulations.
3. Performance-based earthquake engineering (PBEE) shows great promise and is now emerging as a critical tool for design and evaluation of major buildings, utilities, and lifelines.
4. The technological basis of PBEE and its application by the engineering profession must be improved by continuing research, development, and dissemination, particularly for the design of new structures.
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Recommendations

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Acknowledgements

This report was prepared by the California Seismic Safety Commission's PEER Center Review Committee consisting of Chairperson Dr. Arul Arulmoli, Co-Chairperson Mr. Linden T. Nishinaga, Dr. Dennis Mileti, Mr. Daniel Shapiro, and Mr. Craig Comartin and by Commission staff Mr. Robert Anderson, Mr. Richard McCarthy, Mr. Larry Rillera, Mr. Fred Turner, and Ms. Sue Celli. Ms. Gail Hynes Shea provided technical editing.

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Information about the PEER Center may be found at the website: <http://Peer.Berkeley.edu/>

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