PEER METHODOLOGY TESTBEDS

1) Definition and Purpose

Beginning with the Year 5 Research Program (funding around October 2001), PEER is establishing a series of PEER Methodology Testbeds. The testbeds are real facilities, inventories of facilities, or networks to which the PEER performance-based earthquake engineering (PBEE) assessment and design methodologies will be applied. The primary purpose of the testbeds is to assess the applicability of the methodologies and foster their refinement. The testbeds will serve supplementary purposes such as further focusing and integrating the research, promoting multi-disciplinary research interactions, emphasizing systems level research, and involving interested earthquake professionals and decision-makers.

2) Testbed Descriptions

The plans involve the following four testbed types: Buildings, Bridges, Highway Network, and Building Campus.

2.1 Building Testbeds **–** Two building testbeds will be examined. One is the Van Nuys building, which is an older reinforced concrete building representative of a class of buildings constructed around the 1960s in the western US. Instrumental records and damage from past earthquakes make the Van Nuys building suitable for verifying analytical models and simulation platforms, while its seismic deficiencies make it suitable for rigorous implementation of the assessment methodology. The second is a newer laboratory building, the Life Sciences Building on the U.C. Berkeley campus, whose valuable nonstructural systems and contents are likely to dominate performance decisions. Further details on these two buildings are provided below.

Van Nuys Building - The Van Nuys building site is near the center of the San Fernando valley, approximately 4.5 miles from the epicenter of the 1994 Northridge earthquake. Designed in 1965 and built in 1966, the 65,000 square foot building functions as a hotel, with restaurants, lobby, and services on the first floor. The building has a seven-story, reinforced concrete structure with details typical of the construction era, including reinforced concrete perimeter beam-column framing and interior slab-column framing. The building is supported on a friction pile foundation driven into primarily silty fine sands and fine sandy silts. The building was instrumented and damage was documented for the 1971 San Fernando, 1987 Whittier Narrows, and 1994 Northridge earthquakes.

The following studies are contemplated for the building:

- Single-facility assessment methodology – The rigorous PBEE assessment methodology will be applied to the existing building to evaluate the performance in terms of explicit life safety, cost, and downtime metrics. Recorded response and damage from prior earthquakes will be used to help validate the assessment procedures, which will then be applied to probabilistically evaluate performance for the seismic site hazard. Performance predictions will be compared to those of current evaluation standards, including FEMA 356 and ATC 40.

- Retrofit assessment methodology – A retrofit involving the addition of structural walls will be developed using FEMA 356 and ATC 40. The rigorous assessment methodology will then be applied to the rehabilitated building to ascertain the degree of improvement. Benefit-cost methods will be applied to gage the merits of the retrofit.

- New design methodology – The building will be redesigned using a PBEE design approach with the same geometry and architectural program as the existing building. The rigorous assessment methodology will be applied to the redesigned building and the target performance will be evaluated using a benefit-cost model. An objective here is to understand the performance that can be achieved using the new design methodology.

Life Sciences Addition Building - The Life Sciences Addition building is located in the southwest quadrant of the UC Berkeley Campus, approximately 0.6 miles from the Hayward Fault. The building is a 150,000 sq. ft, six-story structure. The load-carrying system consists of a complete reinforced concrete space frame, comprising waffle slabs supported by concrete girders that in turn are supported by concrete columns. The foundation consists of a 38" deep continuous mat foundation. Unlike the Van Nuys building, the structural system in this building generally conforms to modern seismic design and detailing requirements. The building is one of the critical research facilities on the UC Campus, accounting for more than 12% of the total annual funded research. In 1997, the building equipment was valued at approximately $15 million. Funded research is approximately $50 million annually, but this does not account for the value of irreplaceable laboratory specimens, such as genetic samples. The testbed studies will apply rigorous PBEE assessment procedures with an emphasis on the performance of nonstructural systems and research equipment. Of particular interest are life-safety performance of research equipment related to containment of hazardous materials and safe occupant egress. The investigation will consider an evaluation of the cost and benefits of nonstructural mitigation that takes into account the interruption of research activities.

2.2 Bridge Testbeds – Two bridge testbeds are considered. The first is a study of the Humboldt Bay bridge that has been underway by PEER researchers for the past year or so. This is an older bridge that is vulnerable to both ground shaking and soil liquefaction and has been seismically retrofitted by Caltrans. The second bridge testbed has not yet be specifically identified and will be chosen with consultation by Caltrans according to the criteria outlined below. This testbed is currently referred to as the I-880 testbed since it is anticipated that the study will involve a portion of the I-880 system that was replaced following the 1989 Loma Prieta earthquake.

Humboldt Bay Bridge – This Humboldt Bay site includes three bridges over waterways crossing two islands. The structures are relatively simple, founded on piles in liquefiable soft soils. The site is perceived to be vulnerable to strong ground shaking from M7.5 subduction type earthquake. Soil liquefaction, approach fill settlement, and lateral spreading are issues of interest in the PEER program, which feature prominently in this study. Detailed simulation and performance studies under consideration include:

- Examining the impacts of permanent ground deformation on response of the bridge system.

- Evaluating effectiveness of the seismic retrofit in terms of probabilistic performance parameters describing post-earthquake bridge functionality, repair costs, and repair times.

- Evaluating the propagation and significance of uncertainties in earthquake source mechanisms, site and soil parameters, and foundation and structural response on the resulting performance metrics.

I-880 Testbed – It is anticipated that the I-880 testbed will be modeled after portions of the I-880 elevated highway in Oakland that was constructed in the mid 1990s as a replacement to the Cypress Street Viaduct. These structures typically consist of post-tensioned box girder or multiple I-girder superstructures supported on tall piers. The foundations are typically deep pile or drilled shaft foundations embedded in the soft soil that predominates in this region. Structural details are likely to impart considerable ductility capacity to the system. Early in Year 5 (fall 2001) specifics of this study will be determined by the PEER testbed team in consultation with engineers from Caltrans. Aspects of interest to this case study include:

- Implementation of knowledge on bridge pier performance gained through prior PEER research, including effects of near-fault ground motions.

- Integrate structural, geotechnical, and soil-foundation-structure interaction in a comprehensive analysis.

- Provide improved bridge fragility information for use in the Bay Area Highway testbed.

2.3 Disaster-Resistant Campus Testbed –This testbed will focus on the appropriate performance levels for owners of large campuses, both institutional and private. In any case where owners of large-scale facilities must prioritize investment, between retrofitting of existing buildings and construction of new buildings, it is important to identify mechanisms for estimating potential losses based on a combination of building conditions and functional needs of the organization. To that end, the development of performance criteria is tied to the operational priorities as well as building conditions. The specific campus for this testbed has not been selected, but two possibilities are under consideration ; (1) the UC Berkeley campus and/or (2) a corporate campus in the Silicon Valley that has a combination of office, research and development, and production capacity on the campus. In the case of UCB, there are approximately 114 buildings on 77 acres, of various ages and construction types. The buildings house teaching, research, libraries and offices--a variety of functions necessary to the operation of the institution. Setting priorities in this setting is particularly critical, because no functions can be easily sent far off-site. In the corporate setting with research, office, and production functions, the need for complex priority-setting is similar, and the contrast between the needs and values in the two settings will help to define the needs of performance-based engineering. Particulars of the study might include:

- a documentation of the potential losses (already complete for UCB),
- an evaluation of ground motion inputs as part of the loss estimation and design criteria standard,
- a method for quantifying the change in potential losses based on enumerated performance standards,
- a priority system for implementing performance standards.

2.4 Highway Network Testbed - How one determines the appropriate performance level for a bridge should consider the functionality and performance of the surrounding transportation network. If critical elements in the transportation network are damaged, the transportation time for people and services increases resulting in increased costs for goods and decreased productivity for the workforce until normal operation of the system is restored. It is important for decision makers to be able to evaluate risks to a transportation network both in terms of damage to the system and additional losses resulting from those damages so that the performance of vulnerable links can be improved and redundancy can be built into critical parts of the system.

The highway system of the San Francisco Based was selected as the Highway Network Testbed on the basis of recommendations from a PEER Transportation Risk Workshop in 1998. The rationale for this selection included the importance of the regional economy, the high complexity and limited redundancy of the transportation system, and the high and near-fault seismicity of the region. The system includes over 2600 bridges, among which are several major bay crossings. The system has a wide range of bridge ages and has been subject to extensive assessment and retrofit by Caltrans. The testbed study includes:

- Evaluating potential direct and indirect economic losses following a major earthquake, including assessing the distributed seismic hazard, modeling bridge fragility, evaluating performance of the transportation network and its components, and translating system performance into economic losses.

- Evaluating the interdependence of bridge performance on the network performance, helping answer the question of the degree to which the highway system analysis should be used to decide performance criteria for individual bridges.

- Validation of the network performance model by comparisons with data from the 1989 Loma Prieta earthquake, and effectiveness assessment of the Caltrans bridge retrofit program over the past decade as a means of improving overall highway network performance.

3) Methodology Application

The methodology application will vary from testbed to testbed, depending on the nature of the problem and the purpose of the testbed. Additionally, the emphasis will vary. Some testbeds will emphasize geotechnical considerations (ground deformation and soil-foundation-structure interaction), while others will focus more on structural response, including nonstructural components and contents. Further, some of the testbeds may be more comprehensive than others, and the performance may be characterized in different ways. For example, the decision variables may be described in terms of either expected losses to a scenario event, annual probability of exceeding some loss, or the confidence level that a certain loss will not be exceeded given a specified hazard level. In all cases, an important objective is to identify those parameters and uncertainties which contribute most to the expected performance.

Some typical aspects of the testbed methodology application are described in the following paragraphs.

Establish performance metrics - Each testbed will be approached by first establishing a set of performance metrics. PEER has embraced the notion that, in general, the most useful performance metrics are casualties, direct dollar losses, and loss of function (which may include some measure of percentage loss and time). One or more of these may be relevant to a particular testbed. In a performance assessment application, the metrics may be expressed in terms of the expected losses over an established period (for example, the probability that the dollar losses will exceed a certain amount in a year, or the degree of confidence that losses will not exceed a certain dollar amount over the defined life of the facility, or some other measure). In a performance design application (emphasizing design, as opposed to assessment), the performance objective may be expressed in similar terms with a target performance established, which the design aims to achieve. Once the performance metrics are established, a planning effort will be undertaken by the testbed project team to determine what is to be done in the next six steps of the methodology application, as listed below.

Define the seismic hazard – Each testbed exists in a specific location (or across a specific region). The seismic hazard of that region is defined by identifying seismic sources that may affect the site (region) and defining the time-magnitude-mechanismdistance relations. A probabilistic seismic hazard analysis is a part of this procedure. In some cases, the actual seismic hazard may be modified to elucidate certain aspects of performance that are not evident in the actual hazard for the site.

Define the seismic input – Given the seismic hazard, the seismic input is defined in terms of suites of ground motion records, response spectra, or other tools/parameters as may be appropriate. Likely, the seismic hazard will be disaggretized into bins characterizing critical intensity parameters, followed by the development of statistically representative ensembles of ground motion records. Depending on the nature of the problem, the input may be at bedrock or may be at the ground surface; the former is more typical in the case where the testbed emphasis includes simulation of the soil and soil-foundation-structure interfaces, whereas the latter may be more typical in cases where the emphasis is on structural and nonstructural response and where the interaction with the foundation can be characterized with simple models not requiring full modeling of the soil.

Create a simulation model – A simulation model of the system will be created using OpenSees. The extent of the model will depend on the nature of the problem, as described above. In some cases, a two-dimensional model will suffice, but generally the model will represent the three-dimensional problem. To the extent possible, the model will be composed of component models developed and validated through PEER research.

Conduct performance simulations to determine Engineering Demand Parameters – Performance simulations will be conducted using OpenSees. The output of the simulations will include response records, peak values, cumulative measures, and other measures as appropriate. Output values may be as general as roof drift (or story drift/ductility) and as specific as component deformations. In the PEER framework, these have been referred to as Engineering Demand Parameters (EDPs). In a probabilistic analysis, the simulations will determine distributions of response parameters as well as sensitivities of the EDPs to changes in the input, modeling, and analysis procedures.

Translate Engineering Demand Parameters to Damage Measures and Decision Variables – Engineering Demand Parameters (EDPs) calculated in the preceding step need to be translated into performance metrics such as casualties, costs, and functional loss. An example is translating interstory drift (an EDP) to nonstructural (e.g., gypsum partition) damage (a Damage Measures or DM), and then further translating that to repair costs and time (repair cost and time are Decision Variables, or DV). In many cases, such as the one just noted, the EDP can be calculated in one step, assuming that the resulting damage does not affect the EDP. Some cases are not so simple; an example is where the failure of a "nonstructural" infill wall in one story results in formation of a soft story that changes the dynamic response of the structure. In that case, the DM and the EDP cannot be simply separated.

Present results in useful formats – A central tenet of performance-based earthquake engineering is to foster the transfer of earthquake engineering results into terms that are useable by stakeholders and decision-makers, as well as to engineers. Likewise, a primary function of the PEER Methodology Testbeds is to identify useful metrics and language for that purpose. Each testbed will experiment in a coordinated and systematic way with different approaches to presenting information to stakeholders and decision-makers, and studies will identify those approaches that are more useful and those that are less useful. As noted above, one approach is to present information in terms of annual probabilities of exceeding a certain loss. An alternative approach is to define the degree of certainty that a certain loss will not be exceeded over the life of the structure. Still another is to define the degree of certainty that a certain loss will not be exceeded given an event having a specified probability of not being exceeded. Still other approaches may be identified. For example, in some cases the stakeholder may wish to know what aspects of the problem contribute most to the uncertainty in characterizing performance, so that resources can be directed in rational ways.

Iterate as necessary – Application of the methodology to the testbeds is expected to be a learning experience. We will discover gaps in knowledge, necessary modeling refinements, and missing pieces or ideas we just plain failed to think of. We expect that the team working on the PEER Methodology Testbeds will record the missing links and communicate them to PEER management and PEER researchers so that the gaps can be bridged.

4) Topical Issues

In conjunction with the testbed investigations, a number of topical issues have been identified regarding the PEER PBEE methodology that span across one or multiple testbeds. These issues should be discussed within the testbeds and, in certain cases, task groups will be created to address these topics early in Year 5. The following issues have been identified:

- *Hazard Intensity Measures* – Current structural engineering practice generally describes ground motion intensity in terms of elastic spectral acceleration at the fundamental structural period (Sa_{T1}), whereas geotechnical practice generally uses peak ground acceleration (PGA). The appropriate intensity index (or vector of multiple indices) should reflect aspects of the ground motion that most influence the seismic performance metrics. Over the past few years, efforts have been underway both within and outside PEER to identify improved measures to quantify ground motion intensities. So as to move forward with the testbeds in a coherent fashion, a select number of ground motion intensities should be agreed upon to report and evaluate in the testbed studies.

- *Articulation of Performance Metrics* – The goal of the PEER PBEE methodology is to define performance in terms that the project stakeholders can relate to. Three so-called "Decision Variables" have been identified for this purpose, i.e., (1) casualties or life safety hazards, (2) direct dollar losses to the building and its contents, and (3) loss of functionality or downtime. However, there is not yet agreement on how these decision variables should be quantified and reported to the stakeholders.

- *Description of Repair Levels and Costs* – Much of the work to date both within PEER and by other groups has focused on calculating what are termed within the PBEE framework as "Engineering Demand Parameters", such as intestory drifts, floor accelerations, hinge rotations, etc. Considerable work remains in relating these parameters to damage measures that can ultimately be translated into repair costs. Therefore, collaborative efforts are needed to define appropriate "Damage Measures" that relate the Engineering Demand Parameters to damage and repair limit states in geotechnical, structural, and non-structural components and systems.

- *Propagation of Uncertainties* – The essence of the PEER PBEE methodology lies in characterizing performance through a probabilistic basis that explicitly considers those uncertainties which dominate the final outcome. While the uncertainties in some parameters, such as the ground motion hazard, are known to play a significant role in the final outcome, the significance of other uncertainties are less clear. Evaluation of the significant uncertainties will first require consistent tracking and propagating of uncertainties from one PBEE realm to another (e.g., from IM to EDP to DM to DV).

- *Design and Decision Making* – Initially, the testbed studies will exercise the PBEE methodology in an assessment mode to quantify the expected performance of an existing (or hypothetical) structure. The full power of the methodology will be in design applications to develop either retrofit schemes for either existing facilities or new solutions to future (planned) facilities. Similar in a sense to how existing prescriptive building codes specify minimum strength, stiffness and ductility (toughness) requirements, new approaches need to be developed that more explicitly relate to specified performance targets. Like the PBEE assessment methodology, the design methods should span the range of considerations from reflecting the seismic hazard through to the desired performance of the decision variables.

5) Testbed Operations and Management

Participation in a testbed is viewed as a collaborative activity that will require a commitment on the part of participating PEER researchers to define and deliver milestones, share results with other testbed participants, and participate in meetings. At each meeting, progress will be described and new directions will be discussed as driven by the testbed needs.

The testbed teams and management structure are shown in Fig. 1. The testbeds will be managed through the PEER Research Executive Committee, which is comprised of the PEER Thrust Area Leaders, the PEER Deputy Director, and the PEER Director. To help manage and facilitate interaction between testbeds, the management structure includes a full time Testbed Coordinator position filled by a post-doctoral researcher. Testbeds are collected in two groups, one dealing with buildings/campuses and the other with transportation (buildings and highway network). PEER Research Executive Committee members associated with each testbed (or grouping of testbeds) are designated in parenthesis under the testbed (grouping) title.

Each specific testbed will be managed by a team consisting of a PEER Research Executive Committee member, the Testbed Coordinator, key assigned representatives of the PEER Business and Industry Partner Program, and PEER researchers who have dedicated projects to coordinate the testbeds. In addition to the testbed coordinator, the testbeds have designated projects to develop an OpenSees model and conduct simulations for the performance evaluation. Beyond the role of the simulator and the coordinator, participation in the testbed is expected as part of each investigators individual research project.

Each testbed team is expected to meet twice per quarter. Once each quarter the entire testbed team should assemble in a formal face-to-face meeting that may be held in conjunction with other PEER events (e.g., the coordinated kickoff meetings in November 2001 and the PEER annual meeting in January 2002). The second meeting each quarter may involve subsets of the testbed team(s) to focus on specific aspects of a testbed or issues which cut across multiple testbeds. These meetings may be held in person, via video or phone conference, or combinations of these. These meetings will take the place of quarterly thrust area meetings, although thrust leaders may hold occasional coordination meetings on specific topics that make sense to address through a thrust area rather than testbed emphasis.

6) Testbed Scope, Milestones and Timeline

Beginning with the testbed kickoff meeting in November 2001, each testbed team should develop a detailed scope, workplan and timeline, including plans for milestones and a final testbed report. It is anticipated that the building and bridge testbeds will remain active projects and mechanisms for organizing the research program over Years 5 and 6 (October 2001 though September 2003) of the PEER research program, and a rough timeline for these is shown in Fig. 2. All research participants are expected to contribute to each testbed, but the bulk of direct responsibility will be borne by the organizing committee and researchers on the testbed simulation and coordination projects.

Research Executive Committee

Buildings/Campus
(Testbed Managers: Comerio, Krawinkler, May)

Testbed Coordinator (Keith Porter)

Van Nuys (Krawinkler)	**UC- LSB (Comerio)**	**Campus (Comerio)**
BIP: TBA	**BIP:** Holmes, Comartin	**BIP:** TBA
Simulation: Lowes	**Simulation:** Mosalam	Scoping effort in Year 5.
Impact: May Meszaros & Ufuk	**Impact:** Ellwood MacCoun Zerbe & Chang	
Methodology: Cornell, Kramer	**Methodology:**	
Structural: Moehle Lehman, Stanton, & Lowes Deierlein	**Structural:** Fillippou	
Geotechnical: Martin, Kutter, Sitar	**Geotechnical:**	
Loss Modeling: Miranda	**Contents Modeling:** Makris Hutchinson & Pardoen	

Transportation
(Testbed Managers: Elgamal, Mahin, Fenves)

Testbed Coordinator (Keith Porter)

Humboldt Bay (Elgamal)	**I-880 (Fenves, Mahin)**	**Highway (Deierlein)**
BIP: Caltrans	**BIP:** Caltrans	**BIP:** Roblee **Coordinator:** Kiremidjian
Simulation: Elgamal & Conte	**Simulation:** Kunnath & Jeremic	**Simulation:** Kiremidjian & Moore
Impact: Caltrans	**Impact:** Caltrans	**Impact:** Moore & Gordon
Methodology: Bray Conte	**Methodology:** Stojadinovic Der Kiureghian	**Methodology:** Kiremidjian
Structural: Conte, Wallace	**Structural:** Eberhardt	**Structural:** Stojadinovic
Geotechnical: Elgamal, Boulanger	**Geotechnical:** Jeremic, Pestana	**Geotechnical:** Stewart

Supporting Data and Technologies:
Ground Motions - Sommerville
Simulation – Fenves
Data Management/Archival – Law
Data Visualization - Bailey

Figure 1 – Testbed Teams and Management

Nov. 2001	Kickoff meeting • Articulate detailed objectives and scope • Establish timeline and milestones • Identify critical path issues and unresolved questions • Develop preliminary working plan and near-term organizational goals • Establish expectations for BIP involvement • Set plans and date for next meeting(s)
January 2002	PEER 2002 Annual Meeting • Testbed meetings and feedback from BIP members
April 2002	Coordinated Testbed Meeting • Preparations for reporting at Yr 5 site visit • Identification of Research Gaps and Needs for YR 6
July 2002	Individual Testbed Working Meeting
October 2002	Coordinated Testbed Meeting • Reaffirm objectives, scope, timeline, and milestones • Review YR 5 progress and Yr 6 plans
January 2003	PEER 2003 Annual Meeting • Progress Reports On Testbeds
April 2003	Coordinated Testbed Meeting • Preparations for reporting at Yr 6 site visit • Identification of Research Gaps and Needs for YR 7
October 2004	Wrapup meeting • Present preliminary Testbed Reports
January 2005	PEER 2003 Annual Meeting • Testbed Final Reports at Annual Meeting

Fig. 2 – General Timeline for Building and Bridge Testbeds