PEER Lifelines Advisory Panel on Electric System Seismic Safety and Reliability

Final Report
September 23, 2004

Summary

The PEER Lifelines Advisory Panel on Electric System Seismic Safety and Reliability was convened by the Joint Management Committee of the PEER Lifelines Program in the spring of 2003. The objective in the formation of the Advisory Panel was to establish a well-qualified group that would provide comprehensive review and recommendations regarding the importance and usefulness of the applied research being conducted by the PEER Lifelines Program to the electric power industry and its customers and regulators in California. The Charge to the Panel addressed four topics, and the Panel provided detailed responses to each Charge.

Charge 1: Evaluate the applicability of the research in improving the earthquake safety and reliability of electric power.

Panel Response: PEER Lifelines research is directly applicable to improving the earthquake safety and reliability of California electric utilities. The results have already improved utility practices and industry codes, have solved specific problems, have been used by other lifelines and critical infrastructure in California and elsewhere, and have informed and involved faculty at major universities to establish a long-term interest in meeting utility research needs.

Charge 2: Recommend new directions or topics for future research.

Panel Response: A next phase of research work is needed. The Panel identified seven high-priority areas of research that should be continued in the next year to two years to capture clear and immediate benefits. In parallel, an electric system network analysis using the current Program results should be performed to identify the specific research results that are still needed to improve electric system earthquake performance as measured by greater reliability and reduced financial and human losses. Tasks to obtain these results should be carried out during the latter part of the next phase of the Program.

Charge 3: Comment on sharing and distribution of research results

Panel Response: Expanded sharing and distribution of research results is urgently needed to enable California to receive the greatest benefit of the PEER Lifelines research. The Panel recommended conducting an integrated program to prepare Application Guides and

perform professional training using the Guides to transfer the research results into the practice of the electric power industry.

Charge 4: Provide recommendations on coordination and leverage with other research programs.

Panel Response: Research coordination should be enhanced with other research, educational, professional, and industrial organizations. There are many opportunities for likely cooperation that will leverage the funding resources of the PEER Lifelines Program and will increase the production of applied research results.

Introduction

This report presents the comments and recommendations of the PEER Lifelines Advisory Panel on Electric System Safety and Reliability that address the Charge to the Advisory Panel. This effort was carried out in the past 14 months through two working meetings accompanied by conference calls and e-mail reviews. The report summarizes the formation of the Advisory Panel and presents its Charge, then discusses the Panel's comments and recommendations in detail. Information about the two working meetings is provided in two appendices.

Background of the PEER Lifelines Program

The PEER Lifelines Program was established in 1997 as a multi-year, multi-discipline applied research effort to improve the safety and reliability of electric power in earthquakes. Since the inception of the Program, the conduct of the research as been managed by the Joint Management Committee, comprised of representatives from the funding agencies and the Pacific Earthquake Engineering Research Center (PEER). By requiring agreement on scope, budget, and schedule between the funders and the researchers prior to beginning every research task, the funders are assured that the research results are well aligned with the needs of the users of the research, and the researchers are satisfied that the studies they are conducting are compatible with their academic needs and interests. This mode for conducting user-driven applied research has been successful and productive.

Since 1997, three funding cycles of the Peer Lifelines Program have taken place. In Phase I, PG&E rate-payer funding initiated the Program, and 23 individual research tasks were carried out that addressed utility needs for improved earthquake hazard characterization along with better understanding of the seismic performance of utility buildings and substation equipment. In the second phase, in 1998-1999, PG&E funding was augmented by a one-year contract with the California Energy Commission (CEC) through their Public Interest Energy Research Program. The CEC funded Phase III for three years plus a one-year extension (2000-2004) to address an expanded scope of work. The CEC and PG&E participation was greatly augmented by the Phase III partnership with the California Department of Transportation (Caltrans), which co-funded tasks primarily addressing earthquake hazards characterizations.

During the entire period from 1997 to 2004, the Joint Management Committee has met frequently (every four to eight weeks) and has organized topical coordination meetings on a quarterly basis among the researchers and funding representatives in an effort to keep the research activities on scope and schedule, and to maximize the integration of results from previous tasks into the current tasks and into planning for future tasks. Thus, as Phase III comes to an end, the research results represent more than seven years of well-organized effort.

PEER Lifelines Program Advisory Panel

In the spring of 2003, the Joint Management Committee formed an Advisory Panel to perform a comprehensive review of the status of the PEER Lifelines Program research results and to provide recommendations for the future of the Program. The objective in the formation of the Advisory Panel was to establish a group that is well qualified to provide comprehensive and representative review and recommendations regarding the importance and usefulness of the applied research being conducted by the PEER Lifelines program to the electric power industry and its customers and regulators in California. The Joint Management Committee decided to ask members of the Inter-Utility Seismic Working Group (IUSWG) to serve on the Panel.

The IUSWG was formed in 1990 as an ad hoc organization of earthquake experts in the major California gas and electric utilities, and met as needed to address technical earthquake problems and issues facing the California utilities. Other utility organizations outside of California participated at times, including Bonneville Power Administration and BC Hydro. Some of the IUSWG technical issues evolved to be handled by the IEEE-693 Working Group, which continues to establish guidance for the seismic design of substation equipment. The Seismic Safety Commission involved the IUSWG several times in addressing utility aspects of the Commission's five-year plans.

The IUSWG was also identified as a useful source of advice for the PEER Lifelines Program. Individuals involved in the Working Group have participated, both formally and informally, in providing advice on research needs and individual research projects since the inception of the Lifelines Program.

The PEER Lifelines Advisory Panel is composed of individuals who have participated in the IUSWG, along with additional individuals who are current and appropriate technical experts in electric power and earthquake engineering and science. The members are predominantly from the large California electric power utilities. The members of the Panel are listed in Table 1. The Panel chairman, Woody Savage, served as chair of the IUSWG for a number of years.

Table 1. Members of the PEER Lifelines Advisory Panel

Robert Anderson, Seismic Safety Commission
Peter Aguila, Southern California Edison
Leon Kempner, Bonneville Power Administration
Edward Matsuda, Bay Area Rapid Transit
Philip Mo, Southern California Edison
Dennis Ostrom, Consultant (resigned from the Panel in March 2004)
Craig Riker, San Diego Gas and Electric
William "Woody" Savage, US Geological Survey (Chair)
Ronald Tognazzini, Los Angeles Department of Water and Power
James Wight, San Diego Gas and Electric (resigned from the Panel in May 2004)
Don Willoughby, Pacific Gas and Electric

Charge to PEER Advisory Panel

The following four charges were provided to the Advisory Panel by the Joint Management Committee as the proposed scope of their activities to be conducted during the twelve months period until the end of the current phase of work on June 30, 2004. The Panel accepted these charges at its meeting on June 16, 2003.

1. Review current PEER Lifelines research activities and projects in order to evaluate and comment on the applicability of this research towards helping achieve the goals of improved electric component and network performance and public safety

2. Recommend new directions or topics for research for the next phase of the PEER Lifelines program, including recommendations for either increasing or decreasing emphasis on specific topic areas

3. Comment on the sharing and distribution of information and research results from the PEER Lifelines program with California electric utilities and related organizations

4. Provide comments and recommendations on the coordination and leveraging of PEER research with other research programs, either currently being conducted or planned, by California electric utilities

Advisory Panel Meetings

To carry out its Charge, the Panel had two meetings. The first meeting on June 16 and 17, 2003, was held in conjunction with a research coordination meeting for Topic 4, Substation Equipment, at the PEER Center offices in Richmond, CA. A report on the meeting results, including the agenda, is provided in Appendix 1. The second meeting was held on April 1 and 2, 2004, also at the PEER Center. The agenda for the second meeting is provided in Appendix 2, and this report incorporates the results of the meeting. Substantial discussions among the Panelists were conducted at the two meetings, and e-mail exchanges and conference calls were used to review draft reports.

Panel Comments and Recommendations

The Advisory Panel has developed extensive comments and recommendations in response to the Charge to the Panel. Many detailed comments are included in the interim report of the Panel in Appendix 1. For this final report, a more comprehensive and integrative view has been taken by the Panel. These comments and recommendations are described in four headings that correspond to the topics of the four charges.

Response to Charge 1: PEER Lifelines research is highly applicable to improving the earthquake safety and reliability of California electric utilities.

The following specific examples illustrate four types of application of the research results.

- Research results are applicable to utility practices and industry codes, and have resulted in seismic performance improvements in California.
    - Input motions for testing. A new input motion specification for shake table testing was developed by a PEER research project, and will be included in the next revision to the Institute of Electrical and Electronic Engineers (IEEE) 693 standard (Recommended Practices for the Seismic Design of Substations). This project developed empirically-based input motion time histories that meet the IEEE 693 requirements, as well as validated a set of numerically generated time histories that will be made available for download at the IEEE West Coast Committee website. Filtering recommendations, executables for implementing the new specification, and examples have also been provided for users to download. This project is expected to improve the reliability and consistency of shake table tests, and lead to improved seismic performance of electrical equipment qualified by such tests.
    - Transformer bushing response. Previous PEER projects have identified the need for changes in the qualification procedures for testing transformer bushings. The most recent PEER project on this subject made important new steps in gaining a more complete understanding of the problem through a combination of analytical and experimental investigations. In addition to quantifying the magnitude of amplifications experienced by bushings mounted on transformers, the project also highlighted the possibility of resonances that have previously not been adequately considered.
    - 230 kV disconnect switch performance. A previous PEER project investigated the seismic performance of 230 kV disconnect switches through experimental and analytical studies. These tests demonstrated the ruggedness of typical switches without special seismic enhancements, when mounted on stiff supports, allowing procurement of less costly equipment. This project identified the weakness of cast aluminum fittings at the insulator bases, which could be inexpensively replaced by stronger, more ductile materials. This allowed PG&E and other utilities to obtain seismically qualified switches at a much lower cost in future procurements. Prior to the tests, PG&E had paid 30% more to obtain seismically qualified 230 kV disconnect switches. The project also yielded valuable seismic response data that PG&E continues to use for the evaluation of switches by analytical procedures.
    - 500 kV transformer bushings. Tests on a standard porcelain 500 kV transformer bushing and a porcelain bushing modified to meet IEEE 693

criteria verified that porcelain bushings are vulnerable to earthquake damage, and 500 kV porcelain transformer bushings could probably not be built or modified to meet IEEE 693 requirements. This result helps utilities and vendors to more fully understand the vulnerabilities of porcelain 500 kV transformer bushings and to promote consideration of less vulnerable, seismically qualified, 500 kV composite transformer bushings. Composites are safer, easier to install and maintain because they are much lighter and washing is not required, more rugged seismically, and are approaching the price of porcelain.

- Improved identification of remaining performance uncertainties. Testing has identified specific areas, such as transformer bushing failure modes, response of bushings with supports, and porcelain strength determination, that require additional research to provide a better understanding of high-voltage equipment performance when subjected to strong earthquake input motions.

- Research has solved specific problems
  - Interaction of connected equipment. Several analytical and experimental PEER projects on this subject have resulted in an improved understanding of the behavior of interconnected substation equipment. The methods of analysis developed in these projects, and validated by experiments, provide better estimates of requirements for conductor slack, some of which have been implemented by IEEE 693. Although the current methods remain somewhat unwieldy, they serve as a guide for future development of tools that can more easily be implemented by utility engineers for design.
  - 500 kV disconnect switch seismic performance. A 500 kV disconnect switch was seismically tested in a collaborative project that involved three California utilities and three manufacturer partners. This project filled an important utility need by demonstrating (1) the seismic capability of the equipment after making some relatively minor design changes, and (2) the effectiveness of qualifying equipment through the collaboration of multiple users. These new switches have been procured for PG&E's Path 15 project as well as other recent projects in California (Path 15 has been found to be an extremely critical link for the transmission of power between northern and southern California during periods of electrical energy shortage in the State). In addition, tests highlighted some deficiencies in the IEEE 693 requirements for performance level testing, which will be revised in the upcoming edition of the standard. The tests also resulted in the adoption of new stronger and lighter insulators for installation in these switches by the California utilities.
  - Consistent design ground motions. The PEER Lifelines Program's Next Generation Attenuation project is resulting in more consistency in design response spectra. It is helping to resolve the problem of having greatly varying response spectra for the same site depending on the consultant

used to develop design ground motions. In the past, peak ground accelerations have varied by 50% at the same sites.

- Results have been used for other lifelines and critical infrastructure in California
    - Fault displacement hazard. There has been significant variation in how displacements at fault crossing are evaluated. The consistent approach developed by PEER Lifelines research, which has concurrence by the leading experts, will help ensure that appropriate fault displacements are used in design and analysis. The results of the research will help prevent designing for displacements that have an extremely low likelihood of being exceeded, which can be very costly. The results will also help prevent under design, which could result in safety and/or operational problems. BART is using the results of this research for retrofit decisions at a number of existing fault crossings and for design at a number of future fault crossings. Water and gas utilities and Caltrans are also using this research.
    - Consistent time histories for engineering analysis. Time history analysis has been found to control the design of a number of types of structures including bridges and tunnels. Time-history characteristics for design, including the size of a velocity pulse, can greatly vary depending on the consulting firm and individual developing them. Not only are the clients getting vastly different time histories, but also the cost for development is generally quite high. It appears developing reasonable time histories is more of an art, which takes a great deal of experience and insight, than a science. The PEER Lifelines project to develop a library of time histories for various conditions that has been peer reviewed by leading seismologists will be used by BART, Caltrans, and other lifelines and critical infrastructure. This library will result in more consistency, use of the appropriate time histories, and saving the cost to develop project-specific time histories. BART has found that some of the time histories used in the past are excessively severe and have resulted in unnecessarily expensive designs.

- Academia is more informed about and involved in meeting electric utility needs for applied research.
    - Faculty at major universities in California and other states are now aware of issues of concern to electric power and other utilities, and are addressing these issues in their research and student advisement.
    - Graduate students have been trained in engineering analyses of substation equipment, and represent an investment in future expertise that will be available to the electric utility industry.
    - The PEER Lifelines Program has engaged in inter-university communications within California and outside the State on common-interest earthquake research on electric power equipment and systems. A

well-attended workshop involving the three NSF engineering centers in 2003 was an effective initial exchange of information about each center's lifeline-related research and planned directions.

Response to Charge 2: A next phase of research work is needed.

In considering future work, the Advisory Panel stepped outside of the previous structure of the research program, which was organized into seven topics. This change in perspective allows a greater focus on the integration of research into applications within the electric power industry that make the most improvement in future earthquake performance. The Panel recommends the following three-step strategic plan for additional PEER Lifelines applied research in which the progress already made in the Program is used to carefully analyze and identify the most significant topics and tasks of more research that will lead to the greatest improvements in earthquake safety and reliability of the electric power network.

Step A: At the start of the next phase, conduct research that extends the progress of Phase 3 work to capture clear and immediate useful results. There are seven specific areas recommended for such high-priority research. These activities should be carried out in about one to one-and-a-half years, to mesh effectively with the completion of Step B and the start of Step C.

1. Continue the Next Generation Attenuation project to include vertical motions and numerical modeling of near-fault, large-earthquake motions that lack extensive empirical recordings. Extend these results into practice through the consistent development of ground-motion time histories to be included in the Design Ground-motion Library, which is an important and practical product.
2. Continue efforts to implement the Virtual Geotechnical Data Center with the current and new partners. This is a highly leveraged activity that has large, long-term economic benefits to California utilities and many others.
3. Continue to develop the regional-scale liquefaction and landslide deformation hazard maps. This development directly addresses a significant gap in design practice for lifeline systems.
4. Continue to carry out equipment testing and analysis to improve fragility (vulnerability) models and IEEE-693 performance specifications. These activities in past phases of the Program have produced dramatic savings in the cost of improved seismic performance of new equipment.
5. Continue efforts to create user-friendly design procedures and practices related to seismic qualification and evaluation. Specific needs are for interaction of equipment and component qualification procedures.
6. Continue to improve performance assessment procedures for the typical stock of common utility buildings.
7. Continue to improve electric utility procedures and practices to collect rapid post-earthquake damage information and perform rapid damage assessment.

In each of these seven areas, there are important opportunities to continue to develop working relationships with industry and with other universities interested in research regarding the seismic performance of electric power facilities.

Step B: Use a network-model-based sensitivity analysis to identify the primary causes of power network damage and operational disruption, given the current level of information regarding ground-motion and ground-failure hazards to the system and vulnerabilities in the system. From this analysis, research tasks can be identified that provide the greatest benefit to improving earthquake performance as measured by greater reliability and reduced financial and human losses. This effort should be carried out in parallel with the continuing work of Step A, so that during the second year of the next phase, when the results of this sensitivity analysis are available, the further research efforts can be focused on the most beneficial tasks for risk reduction.

Step C: Carry out the specific tasks and sets of tasks identified in Step B for the remaining term of the next phase. This procedure will allow a robust research task plan that is assured to be the most essential to achieving improved earthquake performance of electric power systems in California.

Response to Charge 3. Expanded sharing and distribution of research results is urgently needed to enable California to receive the greatest benefit of the PEER Lifelines research.

The Advisory Panel, along with many individuals and groups in California and nation-wide, is profoundly impressed with the high quality, great breadth of scope, and focus on practical needs that have been achieved in the research results obtained by the PEER Lifelines Program. The full transfer of these research results into widespread applications by the electric utilities of the State and by other utility and transportation organizations in the State and the Nation, however, needs more attention. To that end, the Panel recommends two specific activities that augment the research efforts themselves and that will assure effective utilization of the results.

A. Prepare Application Guides based on research results

The research results as they are documented and compiled in the Program are not practically available to users within the electric power industry. At best, the results can be digested and used by industry consultants and a few specialists within the industry. The Panel recommends that a series of Application Guides be prepared under the direction of the PEER Lifelines Program to lay out the clear application within the utility industry of new ground-motion and ground-failure hazards characterizations, improvements in design inputs, equipment performance tests, and other research products. These Application Guides would likely need to be written by well-qualified individuals from consulting engineering organizations, with input from the academic researchers. An industry advisory group could work with the Joint Management Committee to identify the scope and content of each Application Guide, and then review the draft Guides at

several stages of development. The Guides should be written in a fashion that allows for periodic updates as additional research is done or as users have experience in practical applications of the Guides. Optimally, such Application Guides could be adopted by Standards Development Organizations (such as IEEE and ASCE) to be maintained and distributed. The American Lifelines Alliance is a project of FEMA that could assist in this conversion of industry practices to national guidance.

B. Plan and conduct professional training.

Effective means of training to use the Application Guides can take several forms:

- Topical seminars for utility personnel, utility consultants and other professionals would create a fast track to interaction and application in California. Once such training is established, other utilities may be more interested in supporting the PEER Lifelines research itself. Modest charges could help offset the out-of-pocket costs of the training.
- Publication of derivative professional papers on the use of Application Guides in peer-reviewed journals and professional conference proceedings would promote long-term education of students and professionals nationally and internationally.
- Web sites with dynamic links could create "one-stop shopping" for current research results, Application Guides, seminar offerings, and other information of interest to the broad community. Likely long-term hosts for such web sites would be professional societies.

The professional training element of promoting the application of the research results likely should be established through partnerships and cooperative agreements, since this activity, although very important, is not the primary focus of the PEER organization.

Response to Charge 4: Research coordination should be enhanced with other research, educational, professional, and industrial organizations.

The Advisory Panel concurred with the concept of the fourth Charge that there are good opportunities to leverage the PEER Lifelines Program with other research, both fundamental research and highly applied research, to the benefit of interests in the State of California. Some research is actively being carried out that could be productively coordinated with the Program, while in other cases the opportunities for others to participate in the Program need to developed and persuasively articulated to prospective partners. Three areas of likely coordination are discussed below.

- Refresh and expand coordination and cooperative agreements with the Electric Power Research Institute, US Geological Survey, California Geological Survey, BC Hydro, Bonneville Power Administration, Department of Energy, other California utilities, and others.

In marketing terms, this is the "warm market." These organizations all have active research and development interests, and have been involved with the PEER Lifelines Program in the past, to at least some extent. Effort directed to renewing contacts and holding informational meetings to look for opportunities for collaboration and co-funding would likely be productive.

The California utilities offer a particularly beneficial opportunity, due to their many common interests associated with the shared political and seismic hazards settings. Two possible actions are suggested: (1) The PEER Lifelines Program could host annual meetings involving California electric utilities as well as consulting engineers, institutes and other non-profits, and governmental agencies to discuss technical topics of common interest, such as the performance of transmission substations in scenario earthquakes around the State; and (2) following the next significant earthquake in the State, the Program could hold a post-earthquake conference to share information among industry partners and the research community on findings from that event in a public forum, prior to publication, when interest in electric utility performance is highest. Other utilities connected through the Pacific Coast Intertie would also be interested.

- Attract cooperative funding and in-kind support from other utilities, transportation systems, and such critical infrastructure as financial and medical networks.

  Support for the development of Applications Guides, and for the research that underlies the Guides, could be sought from other critical infrastructure elements (e. g. other utilities) that depend on reliable electricity and face the same earthquake hazards. Other utilities that could be partners for funding and in-kind support include water, communications, and natural gas. Water utilities have a dependence on electric utilities for pump storage systems. Communication utilities depend on electric utilities to perform their lifeline function. Electric utilities are very dependent upon gas utilities as an energy source. One common area of mutual interest is large-scale soil-structure interaction, which can affect pipelines and buried cables, as well as closely interconnected surface facilities such as large substations.

- Expand exchanges with the MCEER and MAE NSF Centers

  Each of the three NSF centers is more comfortable working alone without involvement from their regional counterparts, but the most productive research will likely come when they work together in an integrated fashion. PEER in particular is strong in ground motion and geotechnical areas and can contribute to both MCEER and MAE in hazard analysis. PEER is also strong in development of substation component vulnerability analysis, which is needed by MCEER for their models on electric system resilience. MAE, on the other hand, has developed models for emergency management in the transportation sector that MCEER could adapt for the electric sector. The MAE model would also be improved with hazard and vulnerability research from PEER. These comments illustrate how the three Centers can integrate. PEER is well positioned to contribute significantly to infill research results needed by the other two centers,

and to advance all three Centers' goals to improve seismic reliability. The PEER Lifelines Program could provide the mechanism and motivation to expand the Tri-Centers' exchanges and collaboration.

Conclusions

The PEER Lifelines Program has accomplished major progress in improving the scientific and engineering knowledge of both the earthquake hazards that threaten the electric power infrastructure and the seismic vulnerability of that infrastructure. Because of this progress, the Advisory Committee finds that the PEER Lifelines Program is highly valuable to the power industry in California, and outside of the State.

For the future, the Panel recommends continuing seven high-benefit research tasks from the end of Phase III. At the same time, it is recommended to conduct a sensitivity analysis to identify, for subsequent focused research, the major remaining risk factors. The Program should expand sharing and distribution of research results to assure more rapid and effective application of the research results. Expanded cooperation among researchers and among funding agencies and in-kind supporters will increase the productivity and application of the program.

The members of the PEER Lifelines Program Advisory Panel appreciate the insight they have gained into the Program. They hope that the recommendations and comments that are contained in this report can be well applied to encourage ongoing funding for the Program, and to encourage broadened industry involvement.

Appendix 1

PEER Lifelines Advisory Panel on Electric System Seismic Safety and Reliability

Report on Meeting of June 16-17, 2003
PEER Center Offices, Richmond, CA
June 25, 2003

Roster of Attendees

Present: Robert Anderson, Seismic Safety Commission
Edward Matsuda, Bay Area Rapid Transit
Philip Mo, Southern California Edison
Dennis Ostrom, Consultant
Craig Riker, San Diego Gas and Electric
William Savage, US Geological Survey (Chair)
Ronald Tognazzini, Los Angeles Department of Water and Power
Don Willoughby, Pacific Gas and Electric

Absent: Peter Aguila, Southern California Edison
Leon Kempner, Bonneville Power Administration
James Wight, San Diego Gas and Electric

Agenda

A copy of the agenda for the meeting is provided as Attachment 1.

Review of Advisory Panel Charge and Election of Advisory Panel Chair

Stu Nishenko opened the discussion of the formation and the role of the Advisory Panel. The background of the Inter-Utility Seismic Working Group (IUSWG) and the formation of the Advisory Panel was discussed by Stu Nishenko, David Chambers, Lloyd Cluff, Woody Savage, and others. The IUSWG was started in 1990 as an ad hoc organization of earthquake experts in California gas and electric utilities, and met as needed to address technical problems and issues facing the California utilities. Other utility organizations outside of California participated at times, including Bonneville Power Authority and BC Hydro. Some of the IUSWG technical issues evolved to be handled by the IEEE-693 Working Group, which continues to establish seismic guidance for substation equipment. The Seismic Safety Commission encouraged the involvement of the IUSWG at several points in addressing utility aspects of the Commission's five-year plans. The IUSWG was also identified as a useful source of advice for the PEER Lifelines Program, and individuals who have been involved in the Working Group have participated, either formally or informally, in providing advice on research needs and individual research projects since the inception of the Lifelines Program. The PEER Lifelines Advisory

Panel is formed from the individuals who have participated in the IUSWG, along with additional individuals who are current and appropriate technical experts within the California electric power utilities. The objective in the formation of the Advisory Panel was to establish a group that is well qualified to provide comprehensive and representative review and recommendations regarding the importance and usefulness of the applied research being conducted by the PEER Lifelines program to the electric power industry and its customers and regulators in California. The IUSWG was selected as a suitable source of members for the Advisory Committee.

Stu Nishenko initiated the selection of a chairman for the Advisory Panel, and suggested consideration of Woody Savage, who had been the Chairman of the IUSWG. No other names were proposed, and the selection was unanimous.

It was noted that the Advisory Panel did not have a member who represented the electric power operations of PG&E, while the other major utilities did have such representatives. The Advisory Panel members and the PEER Lifelines Joint Management Committee members who were present agreed that adding such a person would strengthen the Panel, and Don Willoughby, Manager of Substation Civil Engineering, was thereby added to the Advisory Panel.

PEER Advisory Panel Scope

The following four charges were provided to the Advisory Panel as the proposed scope of their activities to be conducted during the next twelve months, until the end of the current phase of work on June 30, 2004.

1. Review current PEER Lifelines research activities and projects in order to evaluate and comment on the applicability of this research towards helping achieve the goals of improved electric component and network performance and public safety

2. Recommend new directions or topics for research for the next phase of the PEER Lifelines program, including recommendations for either increasing or decreasing emphasis on specific topic areas

3. Comment on the sharing and distribution of information and research results from the PEER Lifelines program with California electric utilities and related organizations

4. Provide comments and recommendations on the coordination and leveraging of PEER research with other research programs, either currently being conducted or planned, by California electric utilities

The Panel agreed to accept the four charges as the scope of its advisory activities. The Panel recognizes the significance of the PEER Lifelines Program to improving the safety

and reliability of electric power, and appreciates the opportunity to assist the Program in reaching its goals.

Advisory Panel Observations and Recommendations

During the course of the two-day meeting, the Panel observed presentations of the purpose, content, and current status of the research topics that constitute the PEER Lifelines Research Program, and participated in the Coordination Meeting for Topic 4, Seismic Performance of Substation Equipment. These presentations and discussions provided the Panel with a broad overview of the research plan and progress, and an in-depth look at the recent results from eight research tasks in Topic 4.

The following comments, observations, and recommendations are compiled under the four charges of the Panel. These results of the Panel's meeting are interim in that they represent the initial thinking of the panel based on the presentations and discussions at the meeting and on the Panelists' previous knowledge of the PEER Lifelines Program and their expertise in matters relevant to the Program. These views will be refined after the Panel receives more information and has additional meetings during the coming 12 months.

1. ***Observations on the Applicability of the Lifelines Program***
    - Overall, the Peer Lifelines Program has a lot of important work underway that can lead to increased understanding of the earthquake performance of existing electric power systems and to improved seismic design and performance of those systems in the future.
    - The Program research has a good chance of achieving a satisfactory balance between academic rigor and utility need. A focus should be maintained on the objective of providing knowledge and procedures that can improve utility practices and decision-making.
    - The results from Topics 1 and 2 are clearly necessary to complete the development of ground motions for simulator testing (Task 408), and can improve the ability of utilities to estimate ground motions for site-specific design criteria. The results of Task 408 are important to the IEEE-693 Working Group.
    - The ground response and ground deformation information from Topics 2 and 3 is valuable for analyzing underground facilities like buried electric lines and gas pipelines.
    - The Program needs to facilitate more dialog between the hazard characterization (Topics 1, 2, and 3) and the engineering tasks (Topics 4, 5, 6 and 7) to develop earthquake hazard parameters that can be used for fragility models that are specific to electric utilities, which can then be used for risk analysis and emergency response. Hazard characterization by others that do develop this dialog are not likely to consider the unique requirements of the electric utility industry in the State of California. There is a strong need to exchange specific information on the seismic loads that have caused or can cause various existing models of equipment to fail, and hazard parameters observed in earthquake shaking and ground deformation. For example, shake-table tests of equipment

fragility use modified recordings of real earthquakes for input; what are the damage-causing parameters for that input that can be related to parameters measured for other earthquakes?

- The research in Topic 4 is developing a lot of useful information that has already been implemented
    - Testing of connectors is valuable and leading to better connector designs and standard configurations to mitigate interconnection problems. The tasks on equipment interconnection are producing valuable results. In particular, the development of improved analytical models for interconnections between pieces of equipment is notable. These analytical models need to be advanced to a state that they can be formed into an engineering standard or a practice that can by used by utility engineers. .
    - 500 kV transformer bushing testing has revealed difficulties in meeting the IEEE-693 criteria with ceramics, and has focused vendors toward developing composite bushings that do meet the criteria.
    - The field measurements associated with substation equipment performance (Task 404) are interesting, and should provide a way to assess the dynamic response of the existing inventory of installed bushings. Some of the measurement activities seem to lack clear purpose, and might be better achieved by using measurements of natural frequencies and other properties derived from previous tests. The result from this task will build on Task 406 by gathering response data for other configurations of transformer tanks and bushing supports for validation of finite-element models. This information could contribute to definition of transformer tank design parameters to ensure consistency between bushing qualification test and tank design. Tasks 404 and 406 should be closely coordinated. This project may not reach its intended goals due to difficulties in acquiring the tank specimen, but is a topic of great interest among the utilities facing the threat of strong earthquake shaking, and the current results are promising.
    - The 500 KV disconnect switch tests, even with the porcelain overstress, have satisfied PG&E's needs for a standard structure/insulator/switch configuration.
- The Topic 5 research should focus more on smaller buildings like those used for control buildings rather than high-rise buildings. The goal should be a tool for streamlined assessment of all types (typically mill-type and simple one-story) of utility buildings that house equipment that is critical to the operational requirements of the utility. The industry needs to not be content with generic FEMA procedures, but to focus on procedures that meet utility-specific performance specifications, particularly the need for specific functionality of individual structures and their contents during and after severe earthquakes.
- The general areas of network analysis and validations of hazard codes (in Topics 6 and 1, respectively) are important and needed for current industry work. Advancement of research in this area is critical to the development of seismic mitigation programs and the damage assessment and situation analysis required in the initial phases of emergency response.

- The substation and system model being developed in Topic 6 (using data formatted and compiled in Task 413) wisely focuses on the most important components for system operation and restoration. Site-specific component fragilities should be included, particularly those of relatively vulnerable components. It would be useful to be able to identify the locations of all at-risk components in a system, such as vulnerable control buildings or older series capacitor banks. The use of this tool for network analysis enables utilities to prioritize resource allocation to improve system seismic reliability and recovery.

2. New Directions and Topic Emphasis

- The engineering research (Topics 4 and 5) and network analysis studies (Topic 6) in the Program need accurate and comprehensive hazard information that is specific to the electric utility (Topics 1, 2, and 3) for their inputs. If the type of hazard inputs needed by electric utilities cannot be obtained from other agencies, then continued funding of research in these topics is needed.
- Applied research is needed in improved fragilities across a range of functional states and classes of equipment, and in developing and testing methods for establishing equipment acceptance criteria.
- As long as PEER is producing results that are useful to the electric utility industry and that are not being provided by others, the research program should continue.
- Suggestions for future projects:
    - Evaluate energy absorption devices, including base isolation that has been researched by others such as MCEER.
    - Test additional interconnected equipment sets until test results better approximate analytical solutions.
    - Develop disconnect switch test protocols with emphasis on streamlining the procedures without loss of accuracy in predicting their behavior during seismic shaking (e.g., use equivalent supports, test only one pole of a switch).
    - Develop composite insulator acceptance criteria, following up on observations made during CCVT tests funded through EPRI by the Utility Consortium. This is needed by the IEEE-693 Working Group.
    - Continue transformer body/bushing performance investigations to achieve the planned goal of validation or change in the IEEE-693 criteria. This will likely result in guidance to transformer vendors for mitigating high bushing amplifications. The current project (task 406) may be unable to come to a reliable, generalized conclusion without more work.
    - Investigate existing transformer radiators to identify parameters that are critical to their function during and after strong ground motion.
    - For underground high-voltage electrical conduits, develop deformation capacities, and develop design features to mitigate deformation and lateral soil pressures due to interactions with adjacent structures, liquefaction and lateral spreading.
    - Study ground-motion effects at ridge-tops that may be responsible for transmission line tower failures.

- Investigate and develop vertical ground-motion attenuation relationships that can be used for electric system components.
- Investigate ground deformations in earthquakes as a function of soil depth and characteristics.
- Develop appropriate ground-motion and ground-deformation parameters for fragility studies.
- Improve NEHRP site classification scheme for electric utilities: finer scale classification, use of shear-wave profiles, include soil depths greater than 30 meters.
- Develop improved system performance metrics (coordinate with the American Lifelines Alliance electric power reliability guideline project)
- Establish specific and systematic procedures to document damage to substations and other facilities that will capture valuable performance data needed to improve both component fragility and system reliability models.

3. Sharing and Distributing Research Results

- The results of the research need to be packaged into practical recommendations and tools that can be used by the utility engineering community.
- Other organizations to involve in distribution of research results include Sacramento Municipal Utility District, Western Area Power Administration, California Independent System Operator, US Bureau of Reclamation, and the larger irrigation districts that produce and/or transmit power.
- Work with the IEEE-693 Working Group and the ASCE Technical Council on Lifeline Earthquake Engineering to receive and apply the results.
- Encourage researchers to publish their results in ASCE and IEEE journals. Articles in trade journals such as *T&D World* can raise awareness among utility engineers, equipment manufacturers, and utility customers.
- Regular presentation of the Program research results on hazards and engineering is needed to reach the intended user groups and to generate more interest in (and possible new funding for) the Program.
- Workshops are a useful means to reach specific target audiences, and are needed to distribute results in such areas as network performance and emergency response for the entire energy arena.
- Workshops with consultants to the utilities would be effective in communicating the research results in hazards, substation equipment performance, and building performance.
- A handy reference and useful compendium of PEER Lifelines results would be a single volume that included examples of the application of the results and an overview of complementary results from research done at the other NSF engineering research centers, Electric Power Research Institute, and others.

4. Coordination and Collaboration Opportunities

- There are opportunities for collaborative research with the state Office of Emergency Services (OES) and the California Utilities Emergency Association (CUEA) in addressing Topics 6 and 7.

- Network analysis (Topic 6) results can be used to identify and prioritize mitigations and to support benefit/cost, time of recovery, customer outage or cash flow analysis.
- A practical and ongoing process is needed to coordinate the PEER Lifelines Program with other relevant academic (NSF Centers, etc.) and industry (the Utility Consortium project at EPRI, with Anshel Schiff as the Principal Investigator) research efforts so that the electric utility industry and their consultants can be informed of research results and how they can be applied.
- Coordination with Bonneville Power Administration (BPA), who funds its own seismic research, should be pursued; one co-funded project with PEER was carried out in Phase 2.
- Coordination among utilities, power generators, and the CEC licensing staff regarding the need for reliable performance of transformers and other critical equipment is needed. The CEC staff should be made aware of the advancements being made in the PEER Lifelines Program so that they can determine whether those advancements should be reflected in the generator licensing requirements.

PEER Lifelines Advisory Panel on
Electric System Seismic Safety and Reliability

June 16-17, 2003
Bldg. 451, Richmond Field Station

Preliminary Agenda

June 16 ***PEER Lifelines Research Program***

10:00	Welcome/Introductions		
		Stu Nishenko	(PG&E)
		David Chambers	(CEC)
		Michael Riemer	(PEER)
10:15	Review of Meeting Agenda		
10:30	Review of Advisory Panel Charge/Election of Advisory Panel Chair		
10:45	Review of PEER Lifelines Research, by Topic Areas		
	Topic 1	Earthquake Ground Motions	Norm Abrahamson (PG&E)
	Topic 2/3	Response and Deformations	Cliff Roblee (Caltrans)
	Topic 4	Substation Equipment	Eric Fujisaki (PG&E)
	Topic 5	Electric system buildings	Kent Ferré (PG&E)
	Topic 6/7	Network Analysis / Response	Norm Abrahamson (PG&E)
12:30	Lunch		
1:30	Advisory Panel Executive Session		
	General Discussion		
	Draft Advisory Panel Report / Observations & Recommendations		
4:30	Adjourn		
6:00	Group Dinner (Details TBD)		

June 17 **PEER Topic 4 Coordination Meeting**

9:30	Welcome/Introductions Eric Fujisaki (PG&E)
9:40	Task 401/403 – Rigid / Flexible Bus Interactions - Analyses (Der Kiureghian)
10:00	Task 402/403 – Rigid / Flexible Bus Interactions - Experimental (Filiatrault)
10:20	Task 404 – Improvements to Modeling (Pardoen)
10:40	Task 406 – Seismic Qualification Requirements for Transformer Bushings (Filiatrault)
11:00	Task 408 – Ground Motions for Simulator Testing (Fenves)
11:20	Task 411 – Seismic Qualification and Testing of 500 kV Disconnect Switch (Fenves)
11:40	Task 413 – Substation Equipment Database Development (Ostrom)
12:00	General Discussion

12:30	Lunch
1:15	Advisory Panel Executive Session
	General Discussion
	Draft Advisory Panel Report / Observations & Recommendations
3:45	Next Working Group Meeting
4:00	Adjourn

Appendix 2

PEER Lifelines Advisory Panel on
Electric System Seismic Safety and Reliability

April 1-2, 2004
PEER Center Offices, Bldg. 451,
Richmond Field Station, Richmond, CA

Agenda

April 1 ***Open Session***

10:00	Welcome/Introductions	
	Woody Savage	(Panel Chairman)
	Stu Nishenko	(PG&E)
	David Chambers	(CEC)
	Jack Moehle	(PEER)
10:20	Review of Meeting Agenda	
10:30	Review of Advisory Panel Charge, June 2003 Minutes and Recommendations	
11:00	Review of PEER Lifelines Research,	
	Topic 1 Earthquake Ground Motions Norm Abrahamson (PG&E)	
12:30	Lunch	
1:30	Review of PEER Lifelines Research (continued),	
	Topic 2/3 Site Response and Permanent Ground Deformation	
	Cliff Roblee (Caltrans)	
3:00	Update on PEER Activities in Topics 4, 5, and 6 Stu Nishenko (PG&E)	
4:00	Review of EPRI Lifelines Research Anshel Schiff (EPRI)	
4:30	Review of NSF Tri-Center Activities in Lifeline Engineering Jack Moehle (PEER)	
5:00	Adjourn	
6:00	Group Dinner (Details TBD)	

April 2 **Closed Session**

8:30	Welcome
8:45	Draft Advisory Panel Report / Observations & Recommendations
12:00	Lunch

Open Session

1:00	General Discussion Brief (10-15 min) presentations by Advisory Panel members on the benefits of the PEER Lifelines program to their utility and how this information has been implemented
2:00	Summary of Advisory Panel Observations and Recommendations to JMC
3:00	Adjourn