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# **Earthquake Risk Decision-Making in Lifeline Organizations**

## **Phase I (Pilot Study) Report**

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March 2003

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## **Acknowledgements**

The authors would like to acknowledge and thank: FEMA, PEER and the PEER sponsors for their support and enthusiasm; the Academic Advisory Group for its participation and suggestions; and especially the many current and retired employees of PG&E, Caltrans, and the Seismic Advisory Board (SAB) who volunteered their time to be interviewed and then conscientiously reviewed, clarified, and corrected the written summaries of the interviews that formed the basis for this initial Phase I (pilot study) about earthquake risk decision-making in lifeline organizations.

## **Executive Summary**

This report describes the work conducted by Battelle Northwest during the Fall 2001 and Winter 2002 period for the Lifelines Program of the Pacific Earthquake Engineering Research (PEER) Center.

### **Background and Approach**

In areas with earthquake potential, preparing for and responding to earthquakes is a significant responsibility of lifeline organizations. The decisions made by these organizations about how to manage and mitigate the risk of earthquakes are vital to both the organizations and the communities they serve. The overall purpose of PEER Lifelines research is to improve the understanding of how lifeline organizations make decisions about earthquake risk, identify critical issues and areas for potential improvement, and transfer general recommendations about decision-making to a broad range of lifeline organizations. This report describes the initial pilot phase of the research. The purpose of the pilot effort is to test data collection and analysis methods and to provide the participating organizations, the Pacific Gas & Electric Company (PG&E) and California Department of Transportation (Caltrans), with preliminary analysis on earthquake risk decision-making in their organizations.

This pilot study is primarily descriptive. It is an attempt to better describe and characterize earthquake risk mitigation decisions. It focuses on earthquake risk mitigation decisions in the lifeline organizations that are leaders in this area, and on the methods for studying these decisions. The pilot study is intended to identify key research issues and develop and assess the research methods to provide the basis for designing and conducting subsequent phases of research not to come to final conclusions.

The methodological approach developed for the pilot study was the product of several workshops involving the project team, the participating representatives from the sponsoring organizations, and a panel of academic experts. The pilot study approach focused on specific past earthquake risk decisions in PG&E and Caltrans. These decisions were selected to cover a wide range of earthquake risk mitigation decisions. A decision analysis framework was used to identify key characteristics of these decisions that should be described and analyzed. In-depth interviews with program and project participants were conducted to obtain the information about the decisions. For each organization three decisions were studied. The PG&E decisions were: the establishment of the earthquake risk management program; the retrofit of the San Francisco Headquarters building; and the retrofit of the Lake Almanor and Butt Valley dams. The Caltrans decisions were: the establishment of the bridge seismic retrofit program; the retrofit prioritization program; and the replacement and retrofit of the Carquinez Bridge.

### **Results**

External events drove the earthquake risk decision-making programs in both organizations. In general, most decisions were made either explicitly or implicitly in regard to political considerations and influences. For both organizations, the decision-makers did not generally get involved in the details of the issues. No specific tradeoff analysis or cost-benefit approaches were deemed necessary or relevant. It was clear that general organizational objectives and goals included a strong safety culture and responsibility towards the public. Generally, a broad set of mitigation options were considered and a salience bias was clearly in evidence. Relevant criteria were generally considered. Both organizations learned and improved their prioritization decision methodologies as time went on. In general, most of the criteria were explicit. For the two organizations, tradeoffs were difficult to assess in any meaningful way and uncertainties associated with technical information were generally not directly communicated to the decision-makers.

Beyond protecting the public safety and insuring continuity of service one measure of success of the earthquake risk decision-making program for PG&E is if the costs are allowable and can be passed on in the rate base. For Caltrans, success beyond safety is achieved by pleasing the communities served and acceptance by the elected officials. Overall, by these measures, both organizations' programs are clearly successes. The major difference found in this study between the two organizations was the involvement and influence of many more organizations and stakeholders in Caltrans decisions.

## **Findings**

Earthquake risk decision challenges differ only in a matter of degree from other non-earthquake related complex business decisions. The same decision elements are present but they are usually more daunting in earthquake risk decisions. Often, too little mitigation action is taken prior to major earthquakes and then decision-makers may tend to overspend on mitigation efforts after the earthquake. Cost benefit analysis as part of a comprehensive decision analysis to maximize expected utility would be a logical approach and the preferred way to address earthquake risk mitigation decisions. However, this has not been done in the past.

Earthquake risk management actions are most successful soon after actual earthquakes. Determining and communicating additional benefits from the mitigation efforts can help justify a program/project, particularly with some stakeholders. Organizations should focus as much as possible on the lifeline "systems" rather than the individual components. Also, R&D efforts are important and significantly contribute to successful earthquake risk decisions. Since retrofitted bridges and buildings look and function the same as before mitigation efforts, it is difficult for the public to see the benefits. Thus, the public needs to be educated and frequently reminded of the value of such programs/projects. Probabilistic rather than deterministic analysis of earthquake hazards produces more complete and accurate results and is an effective part of performance-based earthquake engineering.

An organizational champion for earthquake risk management is critical as is the organizational culture to nurture that champion. Peer reviews of earthquake risk programs are essential. In addition, the lifeline organization should participate in cross-organizational technical groups to share up-to-date information and experiences. A core group of professionals within the organization should be identified as the technical lead for earthquake risk. Lifeline organizations should make full use of external organizations to support earthquake risk management programs/projects and develop close working relationships with Federal agencies heavily involved in the program/project. Communications with external parties need to be carefully managed and external advisory groups should be used to enhance credibility and technical accuracy.

It is important to note that key earthquake engineering champions and staffs in both organizations should be appreciated and commended for their extraordinary performance over many years and against great odds. To develop, champion and sustain the earthquake mitigation efforts in both companies was not without problems but was no small feat. PG&E and Caltrans have proven they are indeed leaders in their field with much to teach both lifeline and other organizations.

The study team identified many important questions relating to earthquake risk decision-making. These questions need deeper exploration in Phase II and include: How should earthquake risk mitigation decisions be made in lifeline organizations and how do these concepts translate to organizations confronting different environmental contexts? What is acceptable risk? What is meant by performance based decision-making? How can earthquake risk champions encourage decision-makers to seriously assess earthquake risks in the absence of a major quake? How important is it that top-level decision-makers understand risk probabilities and uncertainty issues and how can engineers better communicate

with these decision-makers? How are alternatives generated and evaluated and what can be done to position organizations to be able to more effectively respond to a salient earthquake event?

### **Recommendations**

Performance-based earthquake engineering holds great promise for improved logical earthquake risk decision-making. To gain the full benefit of PBEE, a more rigorous cost-benefit tradeoff analysis should be done. The aspects of dealing with the involuntary risk to loss of life in earthquake situations can be effectively dealt with in expected utility theory applications and should be. Besides the loss of life issue the huge economic cost consequences due to loss of service need to be more thoroughly researched and estimated and then factored into the analysis.

PEER should pursue a deductive theory driven approach to Phase II. The many significant questions that arose after examining the pilot phase interview data beg to be more fully answered. A comprehensive theoretical approach appears to offer the best method to answer the unanswered questions remaining from the descriptive/inductive pilot Phase I approach. This continued research offers significant benefits, not only to lifeline organizations but to any organizations facing low probability high consequence events such as our countries' current efforts to defend critical infrastructure against terrorist acts.

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## **1.0 Introduction**

Earthquakes can have major impacts on public safety and on the ability of communities to maintain essential services and functions. Therefore, in areas with earthquake potential, preparing for and responding to earthquakes is a significant responsibility of lifeline organizations. (Lifeline organizations are understood to include power, transportation, water and wastewater, gas and liquid fuel, and telecommunications.) The decisions made by these organizations about how to manage and mitigate the risk of earthquakes are vital to both the organizations and the communities they serve. The research described here was undertaken to better understand earthquake risk decision-making in the lifeline sector and to identify issues that might warrant further study in an effort to improve earthquake risk mitigation decision-making in these organizations.

### **1.1 Purpose**

The overall purpose of this research is:

- To improve understanding of how lifeline organizations make decisions about earthquake risk, particularly what and how information is used and how information is communicated within and outside the organization.
- To identify critical issues and areas for potential improvement in the decision-making process.
- To transfer general recommendations about decision-making to a broad range of lifeline organizations

This research is multi-phased. This report describes the initial pilot phase of the research. The purpose of the pilot project is:

- To test data collection and analysis methods for broader application in the subsequent phase.
- To provide the participating organizations, the Pacific Gas & Electric Company (PG&E) and California Department of Transportation (Caltrans), with preliminary analysis on earthquake risk decision-making in their organizations

### **1.2 Sponsor: Pacific Earthquake Engineering Research Center (PEER)**

The research is sponsored by the Lifelines Program of the Pacific Earthquake Engineering Research Center (PEER), supported with funds from the California Energy Commission, Caltrans, and PG&E. The Federal Emergency Management Agency is a sponsoring partner for the project. PEER is headquartered at the University of California, Berkeley (<http://peer.berkeley.edu>).

### **1.3 Content of the Report**

The information in this report is organized as follows. Section 2 provides background for this research by describing the performance-based earthquake engineering (PBEE) approach being developed by PEER, and the relation of PBEE to decision making. Section 3 defines the scope and limitations of the study described in this report. Section 4 describes the performance outcomes for this effort. The methods used for this study are described in Section 5. Because this is a pilot study, determining the effectiveness of the methods used is important. Section 6 summarizes the earthquake risk decisions studied to achieve the purpose defined above. Key results with respect to how lifeline organizations make decisions are found in Section 7. While this is a pilot study, these results provide an initial description of key aspects of earthquake risk decision-making. Section 8 summarizes the pilot findings from this study, both for

earthquake risk decision-making, and for the methods for studying these decisions in lifeline organizations. Section 9 then focuses on how subsequent phases of this research should be conducted.

## **2.0 Background**

This research brings together the thinking of two disciplines: performance-based earthquake engineering and theory and research on decision-making. Performance-based engineering defines engineering criteria in terms of the performance of the entity being engineered. Decision-making theory and research focuses on explaining how decisions are made and how decision-making can be improved. The foci of both of these disciplines provide an effective framework in which to investigate earthquake risk decisions.

### **2.1 Performance-based Earthquake Engineering – the PEER Approach**

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

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

Despite advances in recent years in use of performance-based earthquake engineering, existing technologies and methods for PBEE fall short on a number of grounds. Methods for seismic design or evaluation that currently are in widespread use are much less scientific and direct than the rigorous approach that is being developed by PEER. As a result of this indirect and empirical approach we have learned that seismic performance outcomes, as demonstrated in recent devastating earthquakes, are highly uncertain and variable. Furthermore, socio-economic aspects such as costs to owners or society generally are not considered directly in the design, and the resulting costs, again as demonstrated by recent earthquakes, may be debilitating.

To address these problems, the primary goals for PEER are:

- To develop understanding and tools related to performance-based earthquake engineering for defining the seismic hazard and representing the seismic input;
- To develop analytical models and performance databases for geotechnical, structural, and nonstructural components and systems;
- To develop an analytical platform for seismic performance simulation that will represent accurate geotechnical, structural, and nonstructural behavior and assist in visualizing performance;
- To develop an assessment and design methodology that will consider multiple performance objectives and represent results in terms of decision variables that can be used by engineers and decision-makers; and
- To provide the improved tools for loss assessment and decision-making for individual facilities and for networks of facilities, such as utility and transportation lifelines.

## **2.2 The Relation of PBEE to Decision-Making**

In order for PBEE to achieve its performance objectives, decision-making processes must be able to fully take advantage of PBEE models, tools, and resulting information. No matter how good PBEE becomes, its ultimate impact depends on the extent to which earthquake risk mitigation decision-making takes maximum advantage of what it has to offer. For this reason, current earthquake risk decision-making processes must be better understood and decision theory and research must be effectively applied to improve earthquake risk decision-making. The goal is to identify and propose earthquake risk decision-making processes that will be able to take advantage of and build on the progress being made in PBEE.

This research focuses on better understanding the current state of earthquake risk decision-making in order to identify critical issues and areas for improvement. It employs a broad theoretical orientation having to do with decision-making processes in general as well as the current state of knowledge in the key area of decision analysis. Decision analysis focuses on the decision as the unit of analysis and primarily addresses understanding the decision context, decision modeling, decision analysis methods, and solution selection. Other theoretical perspectives are often helpful to understand the dynamic nature of the actual decision-making processes and inter-relations between decision-makers and other relevant decision stakeholders.

The goal of this project is to identify key earthquake risk decision-making issues and areas that may require further study and improvement in order to advance more effective, including cost-effective, earthquake risk decision-making performance outcomes in lifeline organizations in the future. Earthquake risk decision-making presents lifeline organizations with many difficult challenges. Several characteristics of earthquake risk mitigation decisions make them different from many other critical investment decisions that lifeline organizations typically have to make. For instance,

- The desired end or benefit of the investment is not a positive gain but protection against probable losses (this is true of all decisions that are primarily risk prevention/risk mitigation decisions).
- While the benefit is avoidance of substantial but highly uncertain and temporally indeterminable losses, the costs are moderate to high, certain, and immediate.
- The degree of uncertainty that must be taken into account is high.
- Communicating loss probabilities to the relevant decision-makers and stakeholders in a comprehensible fashion is challenging.
- The legal intricacies of liability, insurance, etc., are complex.
- There is a greater need for a holistic system perspective in these decisions because lifeline system performance and loss avoidance for the community as a whole is the ultimate objective.

- The externalities of earthquake risk mitigation decisions are critical and stakeholder involvement is important.
- The complications of managing diverse stakeholder interests (internal and external) can be far greater than with most other decisions.
- Preventing loss of life as a result of earthquakes cannot be straightforwardly compared to preventing loss of life from other potential investments, such as roadway improvements. Issues such as the lack of control of the individual in preventing the loss and the magnitude of losses occurring at a single point in time affect the way people evaluate these different loss situations and attribute blame and liability. The attribution of blame is not shared between the lifeline organization and the victim as it might be if the victim had some control over the situation, rather it is likely to be placed squarely on the shoulders of the lifeline organization and, perhaps, politicians and overseers of these lifeline organizations.

Earthquake risk mitigation decisions are just beginning to be dealt with in most lifeline organizations and little research as been directed at the decision-making process per se, although a great deal of research has been done to provide better information to this decision process. The little research that does exist on earthquake risk mitigation decision-making has focused on case studies (see Taylor, Mittler, and Lund 1998). This research project is an attempt to go beyond the case study to develop lessons learned best practices, and recommendations as to how earthquake risk mitigation decision-making could be improved in lifeline organizations.

Because so little is known about earthquake risk mitigation decision-making and how to study it, this project is being conducted in multiple phases:

- Phase I, this pilot study, is primarily descriptive. It is an attempt to better describe and characterize earthquake risk mitigation decisions—the decision context, the decision goals, and the decision methodology and processes. It focuses on earthquake risk mitigation decisions in the lifeline organizations that are leaders in this area, and particularly on the methods for studying these decisions.
- Subsequent phases will be directed at improving earthquake risk mitigation decision-making in lifeline organizations in the future and putting together a set of guidelines for the engineers, staff, and decision-makers involved with earthquake risk decisions. This research can either (1) provide a better understanding of the current state of earthquake risk mitigation decision-making in lifeline organizations and a more comprehensive descriptive accounting of lessons learned and best practices that can be used to improve future earthquake risk mitigation decision-making and/or (2) go beyond this descriptive approach to provide recommendations informed by decision theory and research regarding how earthquake risk mitigation decision-making could be improved in the future. The precise goals and objectives of this research will be determined upon the completion and review of this initial pilot study, an assessment of what is feasible for the next phase, and a clarification of the sponsors and stakeholders needs and desires.

### **3.0 Scope**

As a pilot study, this study was intended to design and pilot an approach for completing the research and analysis on the earthquake risk decision-making processes in lifelines organizations. The pilot study is intended to identify key research issues and develop and assess the research methods as to provide the basis for designing and conducting subsequent phases of research not to come to final conclusions. However, the information collected goes beyond this purpose, and is useful as an initial description of how these decisions are made and where there are strengths and weaknesses in the decision processes. This information may also provide some immediately useful results for the participating organizations.

Therefore, the purpose of the pilot study was expanded, and the scope was expanded to meet the expanded purpose.

PEER selected two organizations for the pilot study: Pacific Gas and Electric Company and California State Department of Transportation. These organizations were selected for several reasons:

- They have been strong supporters of and participants in PEER
- They were willing to perform this role
- They provided a good contrast in organizations: providing gas and electricity versus transportation public versus private organizations
- Both have been deeply involved in earthquake risk management over the past several decades

#### **4.0 Desired Performance Outcomes: Products and Audiences**

Pilot Outcomes—

- Identification of key issues and clearer direction for subsequent phases of this research
- Description and understanding of current state of earthquake risk mitigation decision-making in two leading lifeline organizations
- Interim guidance to earthquake risk mitigation champions regarding pilot findings and best practices

Phase II Outcomes

- Assessment of relevance of earthquake risk mitigation decision-making practices in the two pilot lifeline organizations to other lifeline organizations
- More in-depth investigation of select key issues and specific guidance regarding how to best address these issues in various lifeline organizations
- Unanswered questions and directions for future research

Audiences

- Champions of earthquake risk mitigation in lifeline organizations
- Earthquake risk mitigation decision-makers
- Decision-makers dealing with other risk mitigation issues (terrorism, etc.)

#### **5.0 Methods**

The methodological approach developed for the pilot study was the product of several workshops involving the project team, the participating representatives from the sponsoring organizations, and a panel of academic experts representing a diverse range of decision-making perspectives. The pilot study approach had the following characteristics:

- It focused on specific past earthquake risk decisions in PG&E and Caltrans
- These decisions were selected to cover a range of earthquake risk mitigation decisions, including
  - Programmatic decisions – decisions regarding establishment of new programs or implementation of existing programs cutting across the organization
  - Project decisions – decisions focused on a single or small number of related facility, structure, etc.
- A decision analysis framework was used to identify key characteristics of these decisions that should be described and analyzed

- The representatives from the sponsoring organizations identified and elaborated on the decision-making issues to explore
- Other decision theories and research perspectives were identified by the academic expert panel as potentially relevant to earthquake risk mitigation decision-making in lifeline organizations
- In-depth interviews were conducted to obtain the information about the decisions
- Multiple people with direct involvement in the decisions were interviewed

The decision analysis framework very generally identified the types of issues to be examined, including:

- A basic overall description of the decision,
- Decision context,
- Alternatives
- Criteria
- Uncertainties
- Implementation

This framework was general enough to address not only the issues traditionally addressed by decision analysis but also some issues identified by the representatives from the sponsoring organizations and the academic experts. A detailed set of specific questions was developed to guide the interviews. These questions are included as Appendix B.

Two interviewers conducted the interviews, each with a background in decision analysis. One interviewer functioned as the lead interviewer, the other as the primary note taker. The interviewers alternated in performing these functions. Also present at each interview, was one or two staff members of the organization. These were the staff who work closely with the PEER Lifelines Program, and were involved throughout the development of this study. They were also the liaison between the Battelle research staff and the interviewees. The role of these staff varied from silent observer to active questioner. In no case, however, was there any indication that they limited or disrupted the interviews. At the start of each interview the interviewee was provided with a two-page project summary document that included the project sponsor, purpose, approach, products, benefits, confidentiality agreement, basic information on the interviewers, and contact information (see Appendix E).

Most of the interviews were approximately one and a half hours in length. A few were as long as three hours in circumstances where one interviewee was interviewed about two decisions, or played a major role in risk management. In most cases, two or three interviews a day were conducted. Interviews were taped with the permission of the interviewees. All interviews were done in person, with the exception of two done by telephone. After the interviews, the detailed notes were written by the interviewers and provided as feedback to the interviewees.

The interviewees were selected for each decision by the organizational liaisons with advice from the project research team and from other staff within their organizations. They were selected based on their knowledge of and role in the specific decision. They were also selected to cover a range of perspectives on the decision. At PG&E, two or three people were interviewed for each decision, for a total of 8. At Caltrans, five to nine people were interviewed for each decision, for a total of 18. More people were interviewed for the Caltrans decisions because there appeared to be more perspectives on these decisions because of their very public nature. The interviewees are identified in Appendix C.

## 5.1 Caveats and Method Limitations

This study is inferential and a departure from the normal scientific approach. The study team looked at the data and information and inferred conclusions in an “ex post facto” manner. Any conclusions regarding causality must be cautiously considered in this light. The participants who were willingly interviewed provided the information and naturally impacted what was found and learned. It is important to acknowledge that these participants were generally very proud of their roles and contributions and were looking back and reflecting over many years worth of professional efforts.

## **6.0 Decisions Studied**

For each organization, we identified a total of three decisions to be studied. They included both programmatic and project decisions.

### **6.1 Pacific Gas and Electric Company Decisions**

The three decisions identified for PG&E were a programmatic decision (ongoing earthquake risk management program) and two project decisions (earthquake retrofit of the headquarters building and earthquake retrofit of the Lake Almanor and Butt Valley dams).

#### **6.1.1 Earthquake Risk Management Program**

Early seismic concerns were mostly associated with PG&E nuclear energy production. After the North Palm Springs earthquake in 1986 caused serious damage to a high-voltage sub-station in Southern California, it was determined that the same situation could happen to PG&E. This was the start of an interdisciplinary, proactive, internal effort that evolved to become the earthquake risk management program. The program grew to include hydro generation and distribution, gas pipelines and distribution, nuclear power production systems, and buildings within its scope. The emphasis of the earthquake risk management program was to bring together earth scientists, civil engineers, specialists, and operations personnel to explore and analyze seismic risks and options in a disciplined manner.

The drivers behind this program are life safety and restoration of critical services. Customer impacts are always considered. Additional factors include legal liability, environmental effects, and media/public exposure of PG&E. Also of particular significance is the corporate culture and strong sense of social responsibility that attempts to go beyond what is marginally acceptable or legally required. Where possible, seismic upgrades are combined with other programs (e.g. tenant improvements for buildings, trenching cost sharing with other utilities for pipeline replacements, etc.). If seismic safety issues are involved the projects get funded.

The program began with a five-year effort to replace vulnerable circuit breakers. The 1989 Loma Prieta earthquake vindicated the program since all old circuit breakers identified as needing high seismic performance were destroyed. This quake also caused pipeline failures in the Marina District of San Francisco. PG&E then developed a seismic prioritization process to be used to guide the replacement of vulnerable pipeline segments. The buildings portion of the program also included a screening process to prioritize needed seismic retrofits. The program is now transitioning from a mitigation to a maintenance focus.

The organizational graphic in figure 1 shows the formal organizational and reporting relationships (solid black lines) and also the informal relationships utilized for decisions for this project (blue dotted lines). The three seismic risk management committees and their composition and relationships are also included. The organizational graphic clearly shows that the Geosciences Department had significant informal relationships with virtually the entire PG&E organization through the seismic risk management program.

### **6.1.2 Headquarters Building Earthquake Retrofit**

The PG&E corporate headquarters buildings located at 215 and 245 Market Street in downtown San Francisco were severely damaged by the 1989 Loma Prieta earthquake. Initially PG&E HQ got a yellow tag. Although it was quickly changed to a green tag, the damage was found to be much worse/severe than originally determined. The safety rating was poor/very poor.

The corporate power control and telecommunication functions were located in this building as well as the large engineering staff and several corporate officers. Functionality as well as life safety were the big issues. Recovery also was a factor. The functionality was very significant since services must be restored very soon after a quake. Life safety requirements were addressed through existing codes, but the functionality requirements were somewhat unprecedented and not addressed by codes.

Cost, employee morale and safety, public safety, timing, and technological/legal feasibility were the major factors in evaluating the alternatives. Alternatives consisted of demolition, sale, and temporary move out and then move back either to the 215/245 Market Street site (if retrofitted) or to move some employees to some other, perhaps not in San Francisco, site. (See Summary Findings table for more decision related information.)

Management's main concerns were: the cost, legal liability since they now "knew" the significance of the problem, and possible panic from the employees. In particular, management wanted assured building performance—both safety and functionality and no cost over runs. Maintaining functionality, life safety, and the historic nature of the building were the significant factors to management. The decision was made to take maximum advantage of the historic nature of the building and make a problem into an opportunity and get a 20% federal tax credit. A practical problem associated with this retrofit was how to design and complete the retrofit without removing the terra cotta exterior cladding. Another key decision was to minimize PG&E staff involvement in the actual retrofit process once the decision was made to bring in outside experts and companies.

The organizational graphic in figure 2 shows the formal organizational and reporting relationships (solid black lines) and also the informal relationships utilized for decisions for this project (blue dotted lines). The extent and the relationships of the non PG&E participants are quite evident and were intentional.

### **6.1.3 Lake Almanor and Butt Valley Dam Earthquake Retrofit**

PG&E made a major corporate decision to undertake a systematic regional evaluation of seismic hazards for all dams and hydro projects in the Sierra Nevada Mountains and foothills. PG&E decided to address any problems identified in a proactive manner. It is notable that this major decision was made internally and was not driven by outside Federal regulators. During this evaluation a major potential problem was identified. The old Northern California Butt Valley and Lake Almanor dams were constructed to less stringent seismic standards than other newer dams. These dams were subject to liquefaction in the case of an earthquake because their construction used hydraulic fill. Several new near-by faults were identified by the Geosciences Department that could trigger liquefaction. Further studies were performed and the risk of dam failure was estimated to be approximately one in 500 years. This is a very high risk and was deemed unacceptable. Besides the danger to public safety and the environment, a loss of these dams would result in the loss of hydropower generating capacity from PG&E's most productive downstream hydro-power generating system.

PG&E had to consider if there was justification for continuing operations (JCO) in light of the risk posed by the dams. PG&E knew it had a major problem. The lower San Fernando dam had failed in 1971 as a



result of the San Fernando earthquake. The strength of the Butt Valley dam was less than that of the failed dam, and the potential magnitude for earthquakes near the Butt Valley and Lake Almanor dams was larger.

For the near-term, justification for continuing operations was given with lower lake levels and modified operating conditions along with stockpiled materials and equipment at the dam so any damage could be quickly fixed. For a long-term solution PG&E considered options from draining and restoring the natural habitat to relocation to numerous rebuild options. Complicating issues included the local stakeholders who depended on the lakes for recreation and tourism. The upgrade was also not popular with the irrigation districts, the State Fisheries organization, and agricultural interests.

The determination was made to rebuild the Butt Valley dam and retrofit, with a buttress, the Lake Almanor dam. Because this was considered emergency work, FERC waived the National Environmental Protection Act (NEPA) requirements and the State waived the California Environmental Quality Act (CEQA) requirements. The project was quickly funded and the construction work was completed in about 18 months. (See table 1 for a summary of other project related information)

The organizational graphic in figure 3 shows the formal organizational and reporting relationships (solid black lines) and also the informal relationships utilized for decisions for this project (dotted lines). The informal relationships with the high-level management committee demonstrate the importance of this decision

**Figure 1. Pacific Gas & Electric Seismic Risk Management Program PG&E Co.**

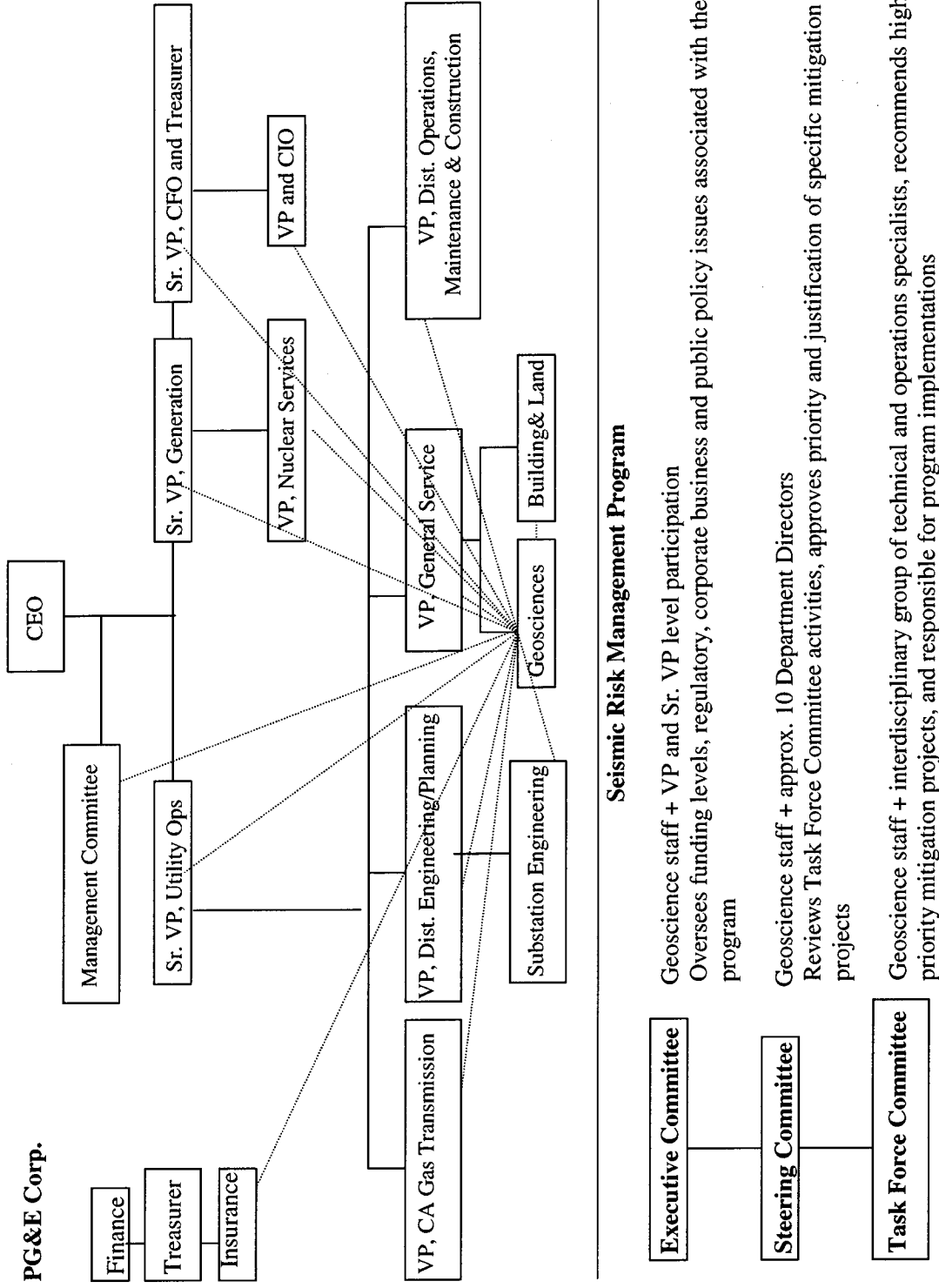
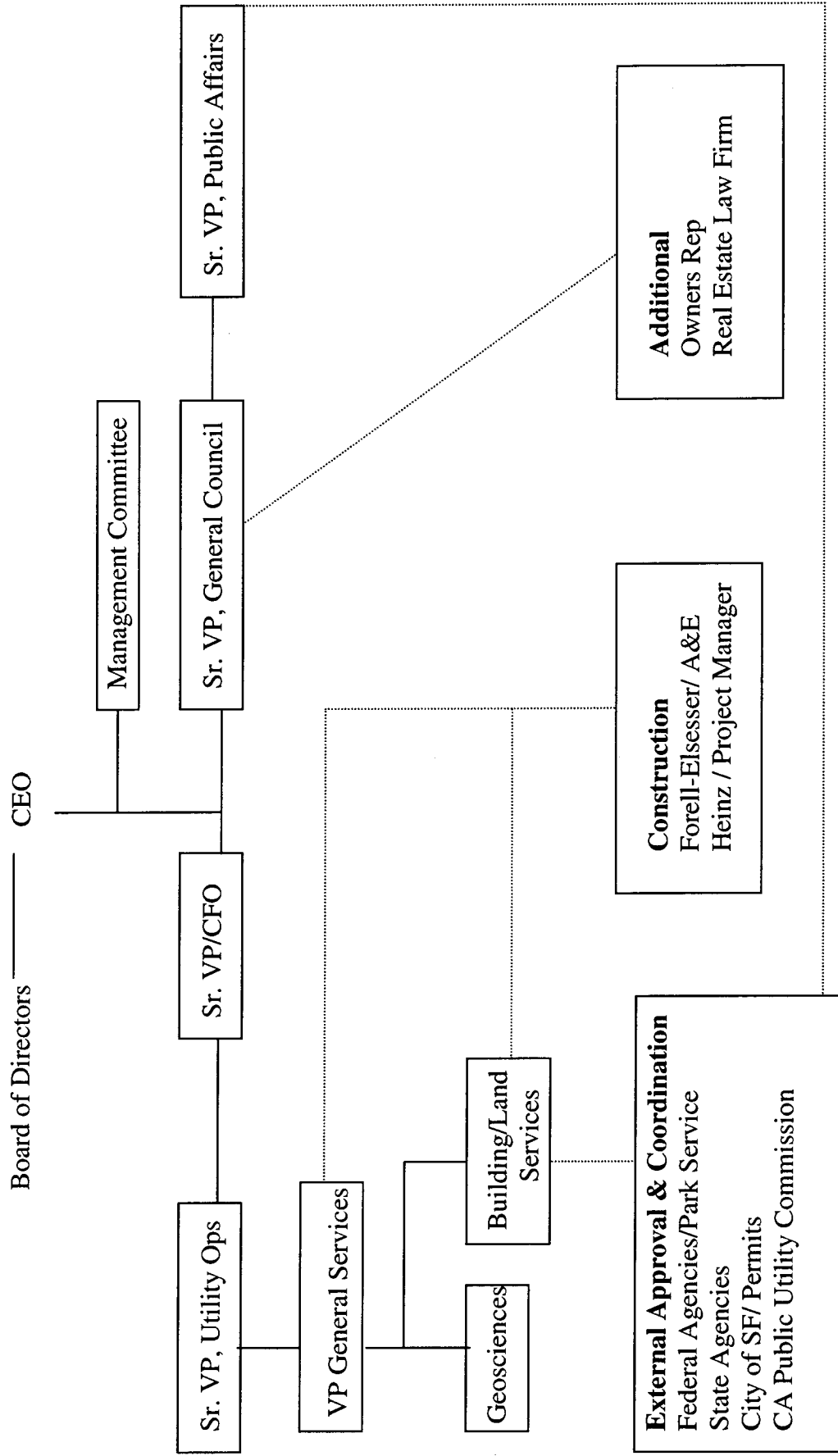
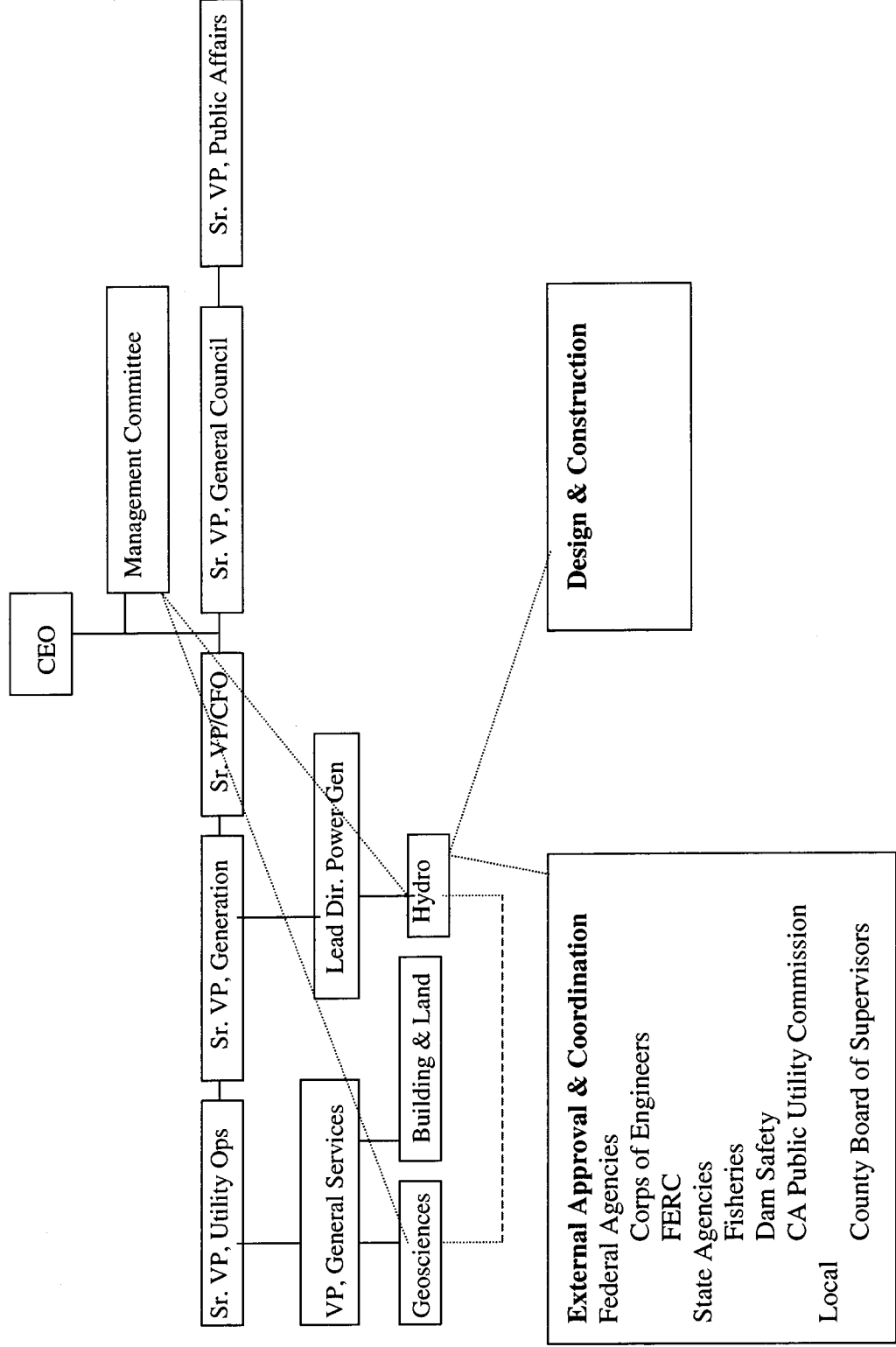


Figure 2. PG&E 215 -245 Market Street Retrofit



**Figure 3. PG&E Butt Valley/Lake Almanor Dam Retrofit**



## **6.2 Caltrans Decisions**

Caltrans decisions consisted of the programmatic decision to establish the bridge retrofit program (really to substantially increase an existing small program) and subsequent major modifications to the program, the prioritization of bridges within the retrofit program, and the decision on the type of retrofit or new bridge for the Carquinez Bridge. In addition, aspects of other projects, e.g., the new Cypress Freeway and the Bay Bridge, were discussed in the interviews. This freedom brought in useful information.

### **6.2.1 Bridge Seismic Retrofit Program**

Prior to the Loma Prieta earthquake in 1989, Caltrans had a small bridge retrofit-strengthening program in place since 1973 with a budget of about \$4 million annually. Our study of this decision focused primarily on the substantial increase in the bridge retrofit program following the Loma Prieta earthquake, and other major changes in the program to date, including another increase in emphasis following the Northridge earthquake in 1994.

Shortly prior the Loma Prieta earthquake, Jim Roberts sent a letter to Caltrans management indicating that current funding (\$4 million annually) was inadequate for single column retrofits, which was the top bridge retrofit priority at that time. Then the earthquake occurred. The Cypress Freeway collapse caused 46 deaths. The Governor convened a Board of Inquiry and the Legislature initiated new retrofit requirements. In response to the Board of Inquiry recommendations, the Governor issued an Executive Order that required Caltrans to screen all public bridges and to retrofit or replace them to meet current earthquake requirements. Caltrans was to provide a cost estimate and schedule by January 1991. Caltrans was also to establish a Seismic Advisory Board to provide it with seismic policy advice and to provide technical review of design guidelines and standards and of potential earthquake engineering improvements as needed.

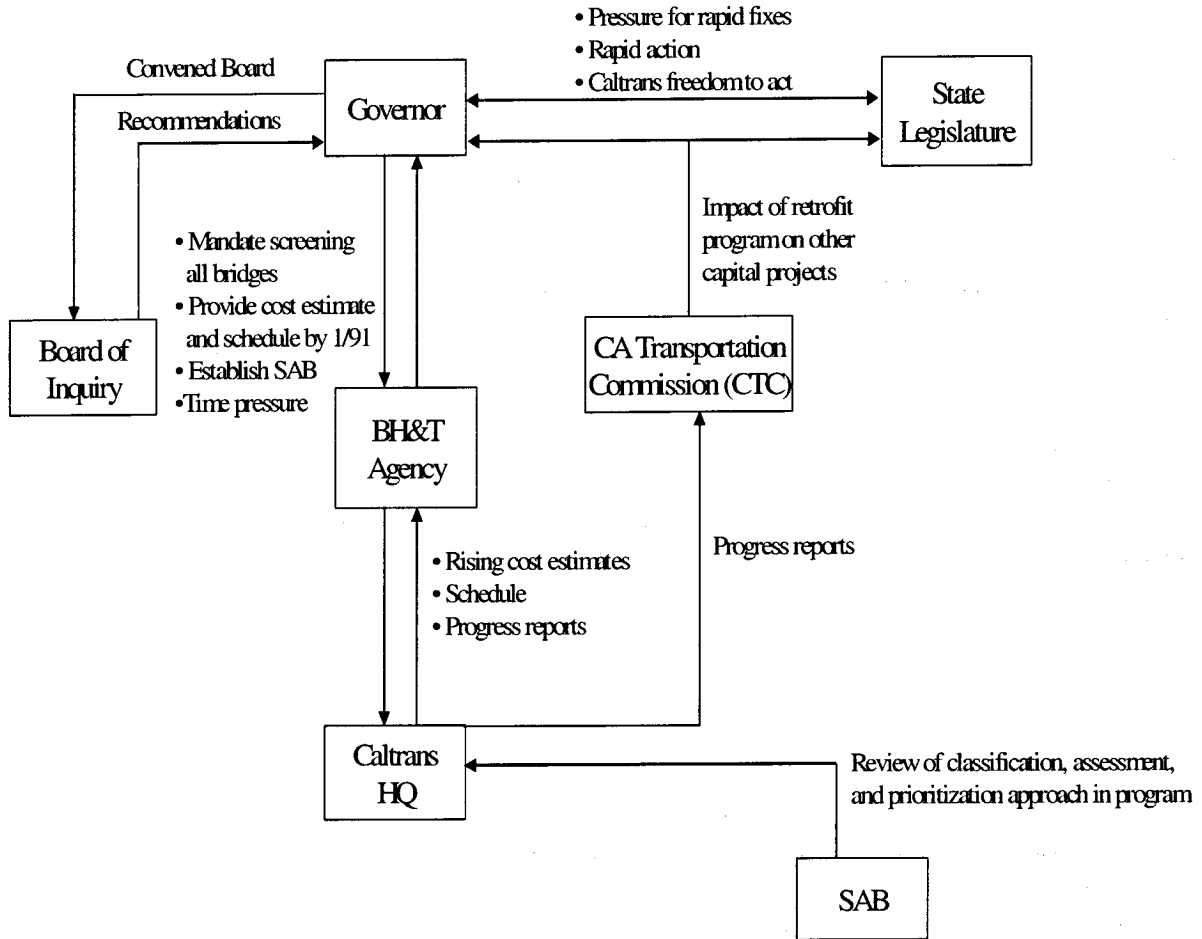
Caltrans provided an initial cost estimate of \$300 million to \$500 million, based on very quick calculations. Subsequently, that estimate has grown substantially to approximately \$4.5 billion. The Governor was the major driver for the ramp up of the retrofit program. A one-year gas tax increase got the program started. Some other transportation projects were delayed because of the retrofit program, but none were terminated.

In the period between the Loma Prieta earthquake and the Northridge earthquake, the retrofit program did not progress as rapidly as many, particularly the Legislature, would have liked. Then, the Northridge earthquake demonstrated the value of the retrofit program. Bridges that had been retrofitted performed well. Those that collapsed had not been retrofitted.

After Northridge, everyone (Governor, administration, CTC, legislature, and Caltrans) realized that the program must be accelerated. It was the right thing to do and public sentiment was behind it. The impetus for accelerating the program came from Caltrans. The Director of Caltrans made recommendations for the program and, after presenting the need, was directed by the Agency Secretary to develop a list of retrofit projects and a schedule. The Governor was briefed and directed that the program become administration policy. CTC adopted the retrofit program as policy and monitored the program to be sure Caltrans implemented it. After Northridge, Caltrans needed to know the total program scope and the capacity to deliver projects. Capacity included both funding available and technical resources (including consultants) for the design necessary to achieve quality. With the exception of the toll bridges and some of the local (non-State) bridges, the retrofit program is now substantially complete.

Figure 4 summarizes the key players in this decision and the major flows of information among them.

**Figure 4: Bridge Retrofit Program Decision**



## 6.2.2 Retrofit Prioritization Program

When the bridge retrofit program was established after the Loma Prieta Earthquake, a significant part of its implementation was setting priorities for bridges to be retrofit and for the retrofit program relative to other transportation projects. As a general policy, Caltrans overall priorities were:

1. Oversight of projects already under construction
2. New projects for safety improvements
3. State transportation improvement projects

Because the bridge retrofits were for safety and new funding was available for them, they did not compete with other transportation projects. Participants interviewed stated that safety was not traded off against other transportation system performance or with cost. Although no other projects were specifically eliminated because of retrofits, some were delayed somewhat. Thus, although not specifically acknowledged, tradeoffs were made.

A significant program issue was the prioritization of bridges for retrofits and decisions regarding which bridges would and would not be retrofit. Caltrans wanted to make the best possible use of the retrofit funding. A prioritization process was needed to meet three goals: 1) make sense (have high face value credibility); 2) be defensible; and 3) be repeatable. An initial prioritization model was developed prior to Loma Prieta. After Loma Prieta the retrofit program received tremendous emphasis and the prioritization model was refined extensively. For basic categorization purposes the approach was purposely not too detailed with the goal of identifying the high priorities and getting them funded for retrofit quickly. Experts with detailed knowledge of the State's geology were employed. The factors such as distance from the source, the hazard, the bridge capacity and average daily traffic (ADT) were all given weights. The model was never intended to imply precision, just a common sense tool to put candidate bridges in various buckets. The Seismic Advisory Board provided extensive input into the prioritization process, and had significant impact on the final version used.

The algorithm was run for all 24,000 bridges in the State as a first screen. For a closer examination on questionable bridges, the simple one page General Plan was used with a simple standardized (check the block) form. Some "hot"/problem bridges were found right away and these were immediately sent to design. If needed, a more comprehensive review was performed.

Caltrans made the decision to retrofit bridges above a relatively low risk score in the prioritization algorithm. This decision was made based strictly on safety and not on cost-benefit or other acknowledged tradeoffs.

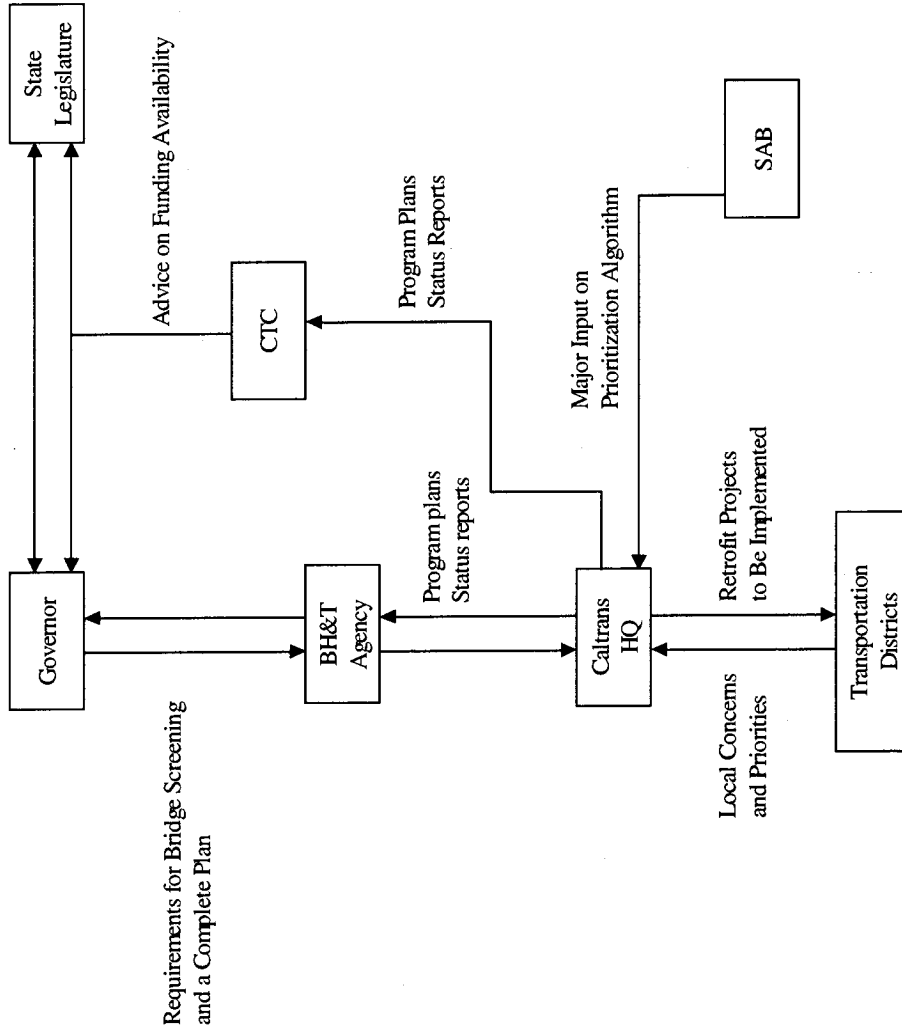
In deciding the implementation timing, for required retrofits determined by the prioritization, Caltrans made adjustments based on several factors:

- Looking at routes and regions in common sense bridge groups rather than single bridges
- Special cases such as the bridge that also carried the San Francisco water supply
- Community leader and local concerns

Prior to the Northridge earthquake, most of the retrofit projects were based on high risk and urgency. After Northridge, all projects had to be defined, planned, and scheduled with cost estimates.

Figure 5 shows the major information flow among the organizations involved in the retrofit prioritization.

**Figure 5. Prioritization of Retrofit Projects**





### 6.2.3 Carquinez Bridge Replacement and Retrofit

The Carquinez Bridge spans the mouth of the Sacramento River carrying I-80 northeast of San Francisco Bay. The westbound span was built in 1927. The eastbound span was constructed in 1958. It was under consideration as a “lifeline” bridge along with the Benicia Bridge (I-680). Either or both could be designated as lifeline since either would work and there are connections between them. The two basic criteria for a lifeline structure are:

- Be open to at least limited traffic within hours (no structural issues)
- Have repairable damage that can be conducted under load

The lifeline route concept required intense planning. The unique geography and the various Bay crossings in the San Francisco Bay area led planners to choose key linkages that would form a sensible network that must remain functional after the maximum credible earthquake event to allow essential life safety related operations to continue. It was decided to make the Benicia Bridge the lifeline route, but the lifeline standards were also wanted for the Carquinez Bridge. The Benicia Bridge was built in the 1960’s with the then current seismic criteria. In 1988 a toll increase to \$1 per toll passed via a voter initiative was to pay for replacement of the westbound structure of the Carquinez Bridge. The program to retrofit the Carquinez Bridge to lifeline standards was almost stagnant, but was spurred on as a result of the Loma Prieta earthquake.

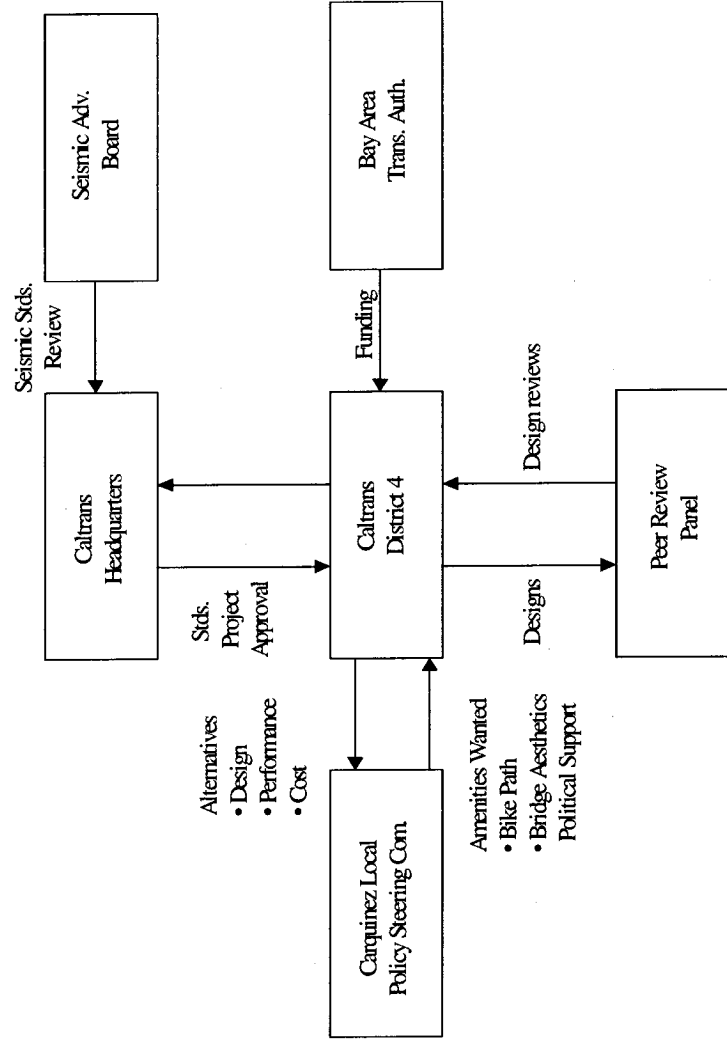
Caltrans held meetings in the early 1990’s about replacing and not retrofitting the westbound portion of the Carquinez Bridge. They had talked to the political representatives in the area and the policy steering committee. A decision was made to replace the older westbound section and then demolish the old bridge. This was an opportunity to provide a higher level of service and add redundancy and flexibility to the lifeline network as an alternative to the Benicia route. The eastbound span, built later to higher standard, would be retrofitted.

A policy steering committee was set up with local officials. Local city councils passed resolutions supporting replacement. A suspension type bridge was chosen for the new span. This would minimize the probability of ship hits damaging the bridge. (Thus more than seismic safety factors were considered in this decision.) For the new span, Caltrans got firm local support to wait the couple of years to get a new, high performance bridge built to lifeline standards.

The funding for the Carquinez spans consists of some \$120 million for the retrofit (eastbound span) and some \$480 million for the new replacement (westbound span), including a new interchange. The new bridge and interchange are 100% toll (bond) funded. The retrofit funds come from a separate account.

Figure 6 shows the major participants in this decision and the flow of key information

**Figure 6. Carquinez Bridge Replacement and Retrofit Decision**



## 7.0 Results

This section describes what was learned about the earthquake risk decisions studied in PG&E and Caltrans. The first subsection provides a general summary of key characteristics of these decisions common to the organizations and the decisions. The following subsections provide more detail about the individual decisions and describe some contrasts found between the two organizations.

### 7.1 General Earthquake Risk Decision-Making

This material is organized around the decision characteristics that were derived from the decision analysis framework used to guide the interviews. In particular the following characteristics are discussed (see also Appendix B for what is included in each decision topic area):

- Decision context
- Decision alternatives
- Decision criteria
- Uncertainties
- Implementation

#### 7.1.1 Characteristics/Context

External events drove the earthquake risk decision-making programs in both organizations. For Caltrans, the initiation of the seismic retrofit program and its infancy period followed the 1971 San Fernando earthquake. For PG&E, the initiation of their seismic retrofit program and its infancy period followed the evolution of the broader extension of seismic concerns from just a focus on nuclear power plants, particularly Diablo Canyon, to one that includes an examination of all facets of electrical and gas production, distribution, and delivery. The PG&E program developed from their strong social responsibility corporate culture and also from the lessons learned associated with the 1986 Palm Springs earthquake damage to high-voltage sub-stations. The 1989 Loma Prieta and 1994 Northridge earthquakes energized and greatly expanded the scope and priority, and thus the cost and schedule urgency, for seismic retrofit programs. The objectives of these programs were very similar in both organizations. The **first priority** is to protect the public safety while the **second priority** is to maintain functionality and to facilitate recovery/restoration after an earthquake. Additional priorities are to minimize legal liability and to minimize costs.

Overall, earthquake risk decision-making in PG&E and Caltrans is logical and is fairly sophisticated. The history of seismic related decisions studied in this pilot does not indicate any substantial departure from how decisions are approached and made in other non-seismic related situations. In general, most decisions are made either explicitly or implicitly in regard to political considerations and influences. If politics is the art of the possible, then decisions are, of necessity, constrained and influenced by the political environment. In the post Loma Prieta and Northridge earthquake era in California, the political realities dictated that significant and successful mitigation methods be immediately pursued and implemented. Right after the precipitating events, it was taken almost for Gospel that collapsing buildings and bridges, ruptured gas pipelines, and destroyed electrical power station circuit breakers could not be tolerated.

Caltrans operates in a more political environment but both PG&E and Caltrans were able to act quickly when events clearly showed considerable risk. PG&E used a carefully crafted balance of science and “scaring” to gain attention and to move the seismic safety decisions forward while Caltrans made seismic

upgrades a preemptive priority. Time pressure impacted all decisions studied, but some to a greater extent. The decision-maker(s) or decision-making bodies were simpler for PG&E. Caltrans, as a State government organization, had more complicated decision approving/directing relationship and was driven by politics to a greater degree.

For PG&E the burden of hot knowledge associated with both the Market Street building complex and the Butt Valley/Lake Almanor dam vulnerabilities created an urgency for evaluating and deciding what actions should be taken from both a life safety and legal liability basis. Through the Butt Valley/Lake Almanor dam challenge, PG&E learned the importance of getting stakeholders involved early. Well-established and well-maintained relationships with regulators and other utilities also proved invaluable. Open communication and informational exchanges was key as was the mindset to view the frequent corporate reorganizations as opportunities to educate new or transferred staff about the role and contribution of the Geosciences Department.

Local agendas complicated some of the Caltrans decisions. Examples of local agendas included the desire for the Cypress freeway relocation and for the signature span for the east section of the San Francisco Oakland Bay Bridge. Another possible agenda was internal where professional jealousy may have entered into the process because of the need for outside consultants to provide some of the characterization and design work normally performed internally by the Caltrans engineering staff. This attitude, directed toward the characterization contractor for the Carquinez Bridge, may have undermined, to some extent, the smooth functioning of the project team.

For both organizations, the decision-makers did not generally get involved in the details of the issues but just approved the well developed and thought out recommendations of the technical experts. Externalities and various stakeholder interests did play a role in earthquake risk decisions but probably not any more than they would play in other non-seismic related corporate decisions.

The potential problem of having the seismic safety programs' main benefit be a rather nebulous "loss avoidance" proved not to be a problem because of how the seismic issues were framed and approached in both organizations and because of the occurrence of the earthquakes. As stated before, since the upgrades just "had to be done", no specific tradeoff analysis or cost-benefit approaches were deemed necessary or relevant. It was clear that general organizational objectives and goals included a strong safety culture and responsibility towards the public, so the alternate use of the seismic safety related funds for other investments (safety related or otherwise) were not really studied or seriously considered.

### **7.1.2 Alternatives**

In general several earthquake risk management decision alternatives were considered. There was no evidence that any single option was considered for a simple yes/no decision. Both impact and uncertainty reduction measures were explored and pursued. Generally, a broad set of mitigation options were considered but often only after the almost automatic decision that something had to be done. Some extreme options were considered in some cases (e.g. sell Market Street building and move out of San Francisco and breach and drain dams losing power generating capacity), but they were included to insure a rich set of options was at least initially considered. There was no evidence that any extreme positions affected a framing bias. (See Appendix A and the alternatives section of the summary findings tables in the following subsections for examples of the fairly rich sets of alternatives for the decisions involved.)

Partnering and cost sharing, where possible, mitigated the cost consequences of many seismic related decisions. This made the decisions easier to approve. Thus decision alternatives that offer complementary features were usually preferred over other solutions. Examples include sharing trench cost

expenses with other utilities in the pipeline replacement program and capitalizing on the 20% Federal tax credit for the Market Street building retrofit for PG&E and in the creative contracting incentives employed by Caltrans after the Northridge earthquake to take full advantage of Emergency Management related Federal funding and to reduce the economic cost to the community due to the bridges being out of commission.

### 7.1.3 Criteria

Several difficulties arose in comparing earthquake risk management investments with other investments. The risk perception issue played a major role. It was clear that investing in other non-seismic highway safety efforts could, in all likelihood, save more lives. Most highway deaths have contributing personal actions (e.g. going too fast, inattention, not wearing a seat belt, DUI, etc.) and have a high degree of personal control involved with these “normal” highway fatalities. However, there is no personal control or contributing actions if a bridge happens to fall on a vehicle. Thus, the public would expect a much higher degree of safety. This is also true for the PG&E buildings and dams. Thus, cost-benefit analysis was generally not done or deemed appropriate. Seismic safety could not be traded off since, as was heard many times, “It doesn’t matter; we just have to do it.” Thus in the minds of the participants and decision-makers, the seismic safety expenditures could not, and perhaps should not, be justified only on a lives saved basis. One way around this challenge, that was apparently not considered, is to weight “involuntary” and “degree of personal control” types of deaths differently. (See section 7.5)

A salience bias was clearly in evidence. The likelihood of future earthquakes was not increased after the 1989 Loma Prieta and 1994 Northridge earthquakes, but the decision was made to invest billions in seismic upgrades to protect the public that was not even seriously considered prior to the “major earthquake events”. What did change was the general recognition that levels of seismic hazard were and would continue to be high in northern and southern California and that the consequences of future earthquakes could be severe. Indications are that the knowledge and liability considerations also played a significant role. A fervent desire to protect the public, along with political pressure, to a large extent drove the Caltrans decisions. Prudent self-interest (functionality, ability to serve customers, etc.) and the high priority on safety culture drove the PG&E decisions.

Relevant criteria were generally considered. Both organizations learned and improved their prioritization decision methodologies as time went on. In Caltrans, for example, the prioritization later included a broader perspective such as bridge groupings on particular routes rather than on each bridge taken individually. Similarly PG&E, in the pipeline replacement portion of the seismic risk management program, learned to take a broader systems look at the pipeline system and not just focus on individual pipeline segments. Also, through the suggestions of the Seismic Advisory Board (SAB), Caltrans applied a multiplicative prioritization model that was less conservative and would eliminate some bridges from the retrofit list.

In general, most of the criteria were explicit. The Caltrans prioritization model was fairly mechanical and appropriate. Care and forethought was taken to ensure that the prioritization process made sense, was defensible, and was repeatable. These Caltrans prioritization decisions were high importance and high number decisions so a much more mechanical and non-discretionary approach might be expected. A large number of the 24,000 California bridges needed evaluation. For the important but small number decisions for both organizations (e.g. Market Street Retrofit and Lake Almanor/Butt Valley dams (PG&E) and the toll bridges (Caltrans)) a very information intensive and highly discretionary process was utilized and was appropriate.

However, some criteria used in various decisions were not initially made explicit but became well understood by those closely associated with the decisions. Examples include morality with the question, “What is the moral thing to do” and identity, we are a San Francisco company, associated with the Market Street retrofit issue and the timing, spin, and other political considerations associated with the delay and delivery of bad news associated with cost increases and schedule slips (Caltrans).

Tradeoffs were difficult to assess in any meaningful way. Tradeoffs of other safety related investments with the seismic program were virtually never done. There is no evidence that discounting for costs or benefits was ever performed. Due to the way both agencies approached these decisions (seismic upgrades just had to be done and done quickly), this is not surprising.

One unusual departure from rational decision-making occurred in a prioritization model attribute weighting exercise in PG&E. Some individuals choose to place all weight on one or two, possibly self-serving, attributes to the total exclusion of other attributes. In effect, they were saying that all other factors had absolutely no importance in the decisions at hand. The interviewees choose not to tell the interview team who these individuals were and what the possible self-serving criteria were. The decision analysis facilitator and the staff from the Geosciences Department were very surprised and dismayed by these actions.

#### **7.1.4 Uncertainties**

Uncertainties certainly played a significant role in how decisions were approached, researched, and communicated. However, clear and reasonable decisions were generally made. By the time they made the various decisions, decision-makers generally had, or thought they had, the information they needed to proceed. One prominent exception related to the costs and schedule for the retrofit program in Caltrans. There was wide acceptance that the seismic upgrades needed to be immediately undertaken and that the benefit, improved public seismic safety, was clear, but because of a lack of time and staff the estimates for both cost and how quickly the work could be done were too low and too optimistic. In virtually all other decisions adequate information was either available or was sought, through research or additional study or testing, to facilitate reasonably informed decisions. Uncertainties always remained but this is the case in any complicated business decision even without the additional burden of seismic uncertainties. Seismic uncertainties drove both organizations to make conservative assumptions and conservative decisions.

Common uncertainties involved the seismic, geo-technical, and structural performance areas along with a wide range of non-technical uncertainties that included political, stakeholder, and public acceptance issues. University research and world-class experts (e.g. the Seismic Advisory Board, peer review boards, etc.) were used to address the technical uncertainties. These experts reviewed the assumptions and the treatment of the technical uncertainties and provide a scientific “stamp of approval” on the engineering design and engineering judgments applied. Also, public outreach, organizational cooperation, interpersonal relationships, and well refined communication procedures were used to address the non-technical uncertainties and move projects forward on success paths.

Uncertainties associated with technical information were generally not directly communicated to the decision-makers. Uncertainties were generally translated into conservatively assessed point value estimates based on careful analysis from the various research studies performed. However, many in senior management, in both organizations, had their roots in technical engineering fields so management generally appreciated and believed they understood the risks associated with the decisions they faced.

Concern for loss did factor into the decisions. The main driver in both organizations' seismic programs was life safety and the extreme fear of fatalities associated with any of their structures or facilities. Optimism only figured in relating to the cost and schedule estimates provided by Caltrans and this is partially explained by the compressed time lines required for them to supply the estimates demanded by concerned politicians. Engineering probability estimates were used at the staff scientist/engineer levels but were seldom communicated up through senior management or to the political leadership figures or the public. The public and the politicians generally just wanted to know, is it safe? In a simplistic manner they did not want to be burdened with understanding or confused by the details of the assumptions underlying that determination.

### **7.1.5 Implementation**

Beyond protecting the public safety and insuring continuity of service one measure of success of the earthquake risk decision-making program for PG&E is if the costs are allowable and can be passed on in the rate basis. For Caltrans, success beyond safety is achieved by pleasing the communities served and by keeping the politicians happy. Overall, by these measures, both organizations' programs are clearly successes. For the seismic program at PG&E to be able to stand up to both internal and external scrutiny they needed: an active program in place; an adequate staff; an adequate budget; and to have defensible priorities. For PG&E the program is successful, funding is not contentious, and management fully supports it. Currently, the PG&E program is transitioning from a mitigation to a maintenance focus. They had the right players, the risk work was done well, there was good cooperation (internally and externally), and most stakeholders are satisfied.

At Caltrans the program is also successful as they met head-on the challenges of North vs. South equity issues, competition for available staff, and the initial inability to set and maintain cost estimates and schedules. The Caltrans prioritization model worked well with value engineering contributing. Caltrans learned the importance of a credible and respected internal/external advocate, the value of seismic research, the importance of delivering on promises, and that it is important to give the community more than just a safe bridge, when possible.

Caltrans learned that clear communication, with a consistent message, is key. The press can be a strong player and that it is helpful to educate and inform interested members of the press about what you are doing and why. In this way, one can turn the press from a potential adversary into an ally for communicating the message. Caltrans learned to reexamine the general prioritization process to account for specific factors that were not involved with the typical bridge retrofit decisions. One excellent example of this is the San Francisco Bridge that also carried the city water service main into the city. It clearly was a special case and warranted special concern and reprioritization. Similarly, they learned that local and system wide implications must be considered and that all information and decisions should be carefully and completely documented.

Corporate attorneys tried to create barriers that would limit communication with external technical peer groups and other professional associations. These cultivated relationships with the associated open communication of common problems areas and lessons learned proved to be highly successful and necessary for the success of the programs. It was important to push back on those who would restrict these information exchanges due to concern over legal liability issues.

Communication with the public was kept very simple and this proved successful. For example, Jim Roberts from Caltrans was a very credible advocate for the bond campaign for funding seismic safety projects. However, contacts from both organizations agree that the public probably does not fully understand the objectives, the criteria (e.g. no collapse), and the real remaining risks associated with the

seismic safety programs and projects. The public generally understands that a massive seismic safety effort has been made. They were willing to pay the costs via the approved bond measures, higher tolls and rates, etc. They value and have some appreciation for the efforts but that appreciation will tend to fade over time since the bulk of the programs are now complete.

One important decision-making disconnect concerned the failure to adjust and modify the comprehensive Transportation Blueprint that was ratified by the California voters in 1990. The ability of government to meet transportation needs depends on public confidence. When transportation priorities were altered in response to seismic safety issues there was no attempt to modify or revise the recently passed Blueprint. Thus the funding stream and the corresponding designated transportation related improvements and priorities in this comprehensive plan were not followed. For a decade this situation persisted. This disconnect compromised voter approved bonds and specific legislation calling for the use of toll revenues.

## **7.2 Specific Results for PG&E**

Table 1 shows key characteristics of the PG&E decisions. In general, these decisions were made in a PG&E environment that was becoming more sensitive to seismic concerns, largely because of recent earthquakes. The influence of the Geosciences Department was growing, as was its credibility because of its success with seismic studies and planning at the Diablo Canyon Nuclear Power Plant. A dynamic and respected person to whom senior management listened led Geosciences. These investments in earthquake risk management were not compared to other investments. They were recognized as essential because of safety.

A broad range of engineering alternatives was considered for all of these decisions. Generally, some non-engineering alternatives were considered as well (e.g., selling the HQ building), though these were usually less thoroughly developed. The criteria used to evaluate alternatives were well understood and usually, at least to some extent, quantified. Safety was always the top priority criteria. For the most part, formal quantitative analyses such as decision analysis or cost-benefit analysis comparing alternatives were not performed



**Table 1. PG&E Decision Characteristics**

Decision Characteristics	Market Street HQ Retrofit	Seismic Risk Management	Butt Valley/Lake Almanor Dams
<p>Characteristics</p> <p>Context</p>	<ul style="list-style-type: none"> <li>• Major 1989 damage</li> <li>• Vulnerable to service interruption</li> <li>• No codes for functionality</li> <li>• Considerable time pressure</li> <li>• Balance science with scaring</li> <li>• Use outside project manager</li> <li>• Limit PG&amp;E staff involvement</li> <li>• Wanted no information leaks</li> <li>• Burden of “hot” knowledge</li> <li>• Had good working relationships with other organizations</li> <li>• Took advantage of 20% Federal tax credit</li> </ul>	<ul style="list-style-type: none"> <li>• Early on seismic concerns mostly associated with nuclear</li> <li>• North Palm Springs quake led to program</li> <li>• Includes gas pipelines, buildings, hydro and nuclear power generation/distribution</li> <li>• 1989 pipeline failures and high voltage switchyard damage validated program</li> </ul>	<ul style="list-style-type: none"> <li>• Systematic regional seismic analysis of dams in the Sierra undertaken</li> <li>• Evaluations and analysis done w/o regulatory drivers</li> <li>• Old dams built to less stringent standards</li> <li>• Susceptible to liquefaction</li> <li>• New faults found</li> <li>• Catastrophic failure possible</li> <li>• Possible loss of considerable PG&amp;E generating power</li> <li>• Failure risk (1 in 500 years)</li> <li>• JCO and draw down actions?</li> <li>• 1971 Southern California dam failure</li> <li>• Some stakeholders not happy with the upgrade and the lowering of the lakes (Issues: economic dependency, tourism, downstream water users)</li> <li>• Fisheries wanted Butt Valley dam removed</li> </ul>
<p>Alternatives</p>	<ul style="list-style-type: none"> <li>• Demolition</li> <li>• Sale</li> <li>• Move out (return later if retrofitted)</li> </ul> <p>Also, many alternatives for how to retrofit</p>	<p>For pipelines – pipe segments</p> <p>For buildings:</p> <ul style="list-style-type: none"> <li>• Demolition</li> <li>• Asset transfer</li> <li>• Seismic structural upgrade</li> <li>• Insurance</li> </ul> <p>Levels of building seismic upgrade:</p> <ul style="list-style-type: none"> <li>• Collapse prevention</li> <li>• Life safety</li> <li>• Immediate occupancy</li> </ul> <p>Life safety</p>	<ul style="list-style-type: none"> <li>• Rebuild</li> <li>• Relocate</li> <li>• Drain and restore natural habitat</li> </ul> <p>Many alternative methods to rebuild</p> <ul style="list-style-type: none"> <li>• Upstream or downstream methods to include: densifying materials, core walls, in-situ compaction, slurry wall, buttresses</li> </ul>
<p>Criteria</p>	<ul style="list-style-type: none"> <li>• Life safety</li> <li>• Functionality</li> </ul>		<ul style="list-style-type: none"> <li>• Life safety</li> <li>• Cost</li> </ul>

Decision Characteristics	Market Street HQ Retrofit	Seismic Risk Management	Butt Valley/Lake Almanor Dams
Criteria (cont'd)	<ul style="list-style-type: none"> <li>• Cost</li> <li>• Employee morale and safety</li> <li>• Timing</li> <li>• Technological feasibility</li> <li>• Legal feasibility</li> <li>• “Moral thing to do”</li> <li>• “We are a San Francisco company”</li> </ul>	<p>For each pipe segment: Age, type of pipe, seismic conditions, failure and construction impacts</p> <p>For buildings: Initial screenings, then prioritization performed (most weight on life safety and restoration of service) Cost Attribute weighting problem</p>	<ul style="list-style-type: none"> <li>• FERC performance criteria</li> </ul> <p>Also used fault maps to set priorities. Went beyond the existing code.</p>
Uncertainties	<ul style="list-style-type: none"> <li>• Historic preservation success</li> <li>• Twinning of quakes</li> <li>• Subsurface and piles</li> <li>• Capacity of floors</li> <li>• Ability of exterior walls (to withstand earthquakes)</li> <li>• San Francisco politics (Managers not comfortable with uncertainties)</li> </ul>	<ul style="list-style-type: none"> <li>• Hazards</li> <li>• Vulnerabilities</li> <li>• Liquefaction potential</li> </ul>	<ul style="list-style-type: none"> <li>• Seismic activity</li> <li>• Dam strength</li> <li>• Probabilistic analysis of floods</li> <li>• Pipe outlet performance</li> </ul> <p>Communication with senior management did not include probabilistic information or uncertainties</p>
Implementation	<ul style="list-style-type: none"> <li>• On time, under budget</li> <li>• Creative terra cotta cladding approach used</li> <li>• Makes more efficient use of building space</li> <li>• Street level retail added</li> <li>• Costs successfully passed on</li> <li>• Using best in field people paid off</li> <li>• Communication handled well</li> </ul>	<p>To stand up to scrutiny PG&amp;E must:</p> <ul style="list-style-type: none"> <li>• Have: program in place, adequate staff, budget and have defensible priorities.</li> <li>- Program is successful, funding not contentious, management supports</li> <li>- Currently transitioning from a mitigation to a maintenance focus</li> <li>- Does not necessarily reduce financial loss</li> <li>- Program is combined with other improvements for efficiency</li> <li>- Communication, info exchanges and relationships are key</li> <li>- View corporate reorganizations as opportunities to educate</li> <li>- Use lessons learned program (e.g. Kobe earthquake) to continually maintain and generate management support</li> </ul>	<ul style="list-style-type: none"> <li>• Well done overall</li> <li>• Had the right players</li> <li>• Good cooperation internally and externally</li> <li>• Risk work well done</li> <li>• Most stakeholders ultimately satisfied</li> <li>• Lesson: Get stakeholders involved early</li> </ul>

Uncertainty was a part of each of these decisions. It was addressed through various means: probabilistic analysis of seismic potential, ranges for cost estimates, qualitative descriptions of impacts, etc. Quantitative analysis was limited to technical analysis of seismic events and vulnerabilities. Generally, the technical staff and their immediate managers believed that communication with senior management using probabilities would not be effective (with the exception of some managers coming from an engineering background). Efforts were made to reduce uncertainty through research and development, studies, and hiring outside expertise.

Each of the decisions has been fully implemented, with the HQ retrofit and the Lake Almanor/Butt Valley dam upgrades completed; and the risk management program ongoing. The risk management program, as an ongoing program, has made numerous adjustments over its lifetime, e.g., completing most of the building upgrades and transitioning toward maintenance. The development of databases and technical tools, such as the gas pipeline database and a leak grading procedure has facilitated risk management decisions. Having accurate and comprehensive data available substantially improves the decision making process.

### **7.3 Specific Results for Caltrans**

Table 2 shows the key characteristics of the specific Caltrans decisions. Although there was a minimal bridge retrofit program and initial planning for the Carquinez Bridge prior to the Loma Prieta earthquake, its occurrence and impact (particularly the collapse of the Cypress Freeway) really created the context for earthquake risk management at Caltrans. In particular, it produced the political will to spend large sums of money on seismic upgrades. This political will translated into pressure on Caltrans to plan and implement the bridge retrofit program. Investments in seismic safety were not specifically compared to other investments. But with the level of funding involved, the Governor and Legislature undoubtedly implicitly compared them with other investments. Time pressure was intense to perform the retrofits, and while this pressure created some problems, e.g., frequent and large increases in cost estimates, it really facilitated retrofit efforts. It created a situation where innovative ideas were encouraged and responsibilities were delegated. Caltrans was an organization receptive to the political will and was prepared to jump on the opportunity.

**Table 2. Caltrans Decision Characteristics**

Decision Characteristic	Seismic Retrofit	Retrofit Prioritization Program	Carquinez Bridge
<p>Characteristics Context</p>	<ul style="list-style-type: none"> <li>- 1971 quake was program Genesis</li> <li>- 1989 and 1994 earthquakes drove and were necessary for program</li> <li>- Emotional and political reaction</li> <li>- Phases: restrainers, single &amp; multiple columns, toll bridges, local bridges</li> <li>- External pressure applied</li> <li>- Time was compressed for information required and for action</li> <li>- Retrofit a preemptive priority</li> <li>- Funds must be kept "clean"</li> <li>- Local agendas complicated decisions (e.g. Cypress freeway relocation, signature span for Bay Bridge)</li> </ul>	<ul style="list-style-type: none"> <li>- Tall 1950's era bridges vulnerable</li> <li>- 1989 and 1994 earthquake events</li> <li>- Time pressure, high priority</li> <li>- Needed method to prioritize large numbers of bridges that:                             <ul style="list-style-type: none"> <li>• Makes sense</li> <li>• Is defendable</li> <li>• Is repeatable</li> </ul> </li> <li>- Objective, get as many retrofits done as fast as possible</li> </ul>	<p>Old westbound 1927 span, heavy built up laced member bridge, needed new deck</p> <p>Newer eastbound 1958 span, light weigh, in good condition</p> <p>Not originally to be a Lifeline bridge</p> <p>Possible agenda - perhaps some professional jealousy was exhibited toward the characterization contractor</p>
<p>Alternatives</p>	<p>Bridge classes:</p> <ul style="list-style-type: none"> <li>• Ordinary, important, lifeline Bridge strategies:</li> <li>• Eliminate, retrofit (degree), other (e.g. seismic gates)</li> </ul> <p>Funding alternatives:</p> <ul style="list-style-type: none"> <li>• Increase sales tax</li> <li>• Increase gas tax</li> <li>• Use transportation bond</li> </ul>	<p>All California bridges</p> <p>The use of additive or multiplicative (probability based) models</p> <p>Need to reexamine prioritization based on special case situations (e.g. SF bridge that carried city water main)</p>	<p>Retrofit or replace</p> <p>If replacing, type of bridge:</p> <ul style="list-style-type: none"> <li>• Truss</li> <li>• Arch</li> <li>• Cable stayed</li> <li>• Suspension</li> </ul>

Decision Characteristic	Seismic Retrofit	Retrofit Prioritization Program	Carquinez Bridge
Criteria	<ul style="list-style-type: none"> <li>- Life safety</li> <li>- Loss of use</li> <li>- Used prioritization model</li> <li>- Sought political acceptability</li> <li>- Design engineers defined criteria and levels of performance</li> <li>- Cost /Benefit analysis not done</li> <li>- Tradeoffs not considered, "It doesn't matter, we have to do it"</li> <li>- Can't justify on lives saved due to risk perception of "lack of control"</li> </ul>	<p>Use easy to obtain input parameters / factors e.g.:</p> <ul style="list-style-type: none"> <li>• Distance from source</li> <li>• Hazard, ground conditions</li> <li>• Structural vulnerability (capacity, age, condition, etc.)</li> <li>• Importance/economic input (ADT, availability of detours)</li> </ul> <p>Factors weighted by SME's Produced risk factor score from 0 to 1 Cost/Benefit analysis not used</p>	<p>For Lifelines:</p> <ul style="list-style-type: none"> <li>- Be open within hours</li> <li>- Have repairable damage under load</li> </ul> <p>-Retrofit or replace factors: cost and maintenance costs, service life remaining, current shape/condition, performance, ability to handle additional loads</p> <p>Other factors: aesthetics, probability of ship hits, environmental impacts, construct ability, public response</p> <ul style="list-style-type: none"> <li>- Insure local and system wide implications considered</li> </ul>
Uncertainties	<ul style="list-style-type: none"> <li>• Costs for retrofit</li> <li>• Seismic hazard</li> <li>• Geo-technical performance</li> <li>• Soil liquefaction</li> <li>• Lack of knowledge and randomness</li> <li>• In particular, costs and technical issues for toll bridges</li> <li>• Reluctance to release seismic map info (legal / property value concerns)</li> </ul>	<ul style="list-style-type: none"> <li>• Seismic return period</li> <li>• Structural performance</li> <li>• Ground conditions</li> </ul> <p>Lack of knowledge and randomness</p> <p>Addressed by research</p> <ul style="list-style-type: none"> <li>• Development of math models</li> <li>• Scale and full sized tests</li> </ul>	<ul style="list-style-type: none"> <li>- Ground motions and propagation</li> <li>- Loads</li> <li>- Performance of materials</li> <li>- Condition of foundation</li> <li>- I bar pin functioning (corrosion?)</li> <li>- Modeling &amp; assumptions used</li> </ul> <p>Manage by codes, procedures, and factors of safety Address with extensive testing</p>

Decision Characteristic	Seismic Retrofit	Retrofit Prioritization Program	Carquinez Bridge
<p>Implementation</p>	<ul style="list-style-type: none"> <li>- Research and testing were key</li> <li>- Program successful and responsive</li> <li>- Events created support and will</li> <li>- Prioritization model worked well</li> <li>- Database and excellent staff needed</li> <li>- Challenges – competition for available staff, inability to set and maintain cost estimates</li> <li>- North vs. Southern CA equity issues</li> <li>- Caltrans poor at marketing itself</li> <li>- Transport blueprint compromised</li> <li>- Political considerations influenced info release timing and spin</li> <li>- Post Northridge incentives worked</li> <li>- An organizational advocate helps</li> </ul>	<ul style="list-style-type: none"> <li>- Best to prioritize groups of bridges on certain routes</li> <li>- Peer review panels helped</li> <li>- An internal advocate is important</li> <li>- Value engineering can add value and should be used</li> <li>- It is critically important to deliver on your promises</li> <li>- Early on, schedules were unrealistic and cost estimates were poor</li> <li>- Communication with a consistent message is key</li> <li>- The press can be a strong player and can be helpful</li> <li>- Need to involve and educate others</li> <li>- Have one person in charge</li> </ul>	<ul style="list-style-type: none"> <li>- It is effective to manage damage &amp; displacements via a circuit breaker concept</li> <li>- Upgrading beyond “ordinary” standard added no more than 5% to cost</li> <li>- Research was important</li> <li>- Lesson: give community more than just a safe bridge, if possible</li> <li>- Public happy with decision</li> <li>- Have design peer reviewed</li> <li>- Involve the entire team</li> <li>- Document all information and decisions</li> <li>- Communication and community outreach were handled well</li> </ul>

At the individual project level (e.g., Carquinez Bridge or other projects such as the San Francisco Oakland Bay Bridge or Cypress Freeway replacement) a comprehensive set of well-defined alternatives was developed and analyzed. Explicit alternatives were less clear. At all levels of decisions, research and development was incorporated into the alternatives and proved to be an effective component of the program/project. Local desires were an important consideration in developing and selecting alternatives, e.g., aesthetics and bike paths for the San Francisco Oakland Bay Bridge and Carquinez Bridge. Who benefited and who paid were important considerations. A balance between benefits to Northern and Southern California was needed. Users (tolls, gas tax) and taxpayers paid, and special efforts were undertaken to maximize the use of federal funds.

Decision criteria were explicit in the prioritization process, but less so for the seismic retrofit program decision and the Carquinez Bridge project decision. The seismic retrofit decision was political based on the need to protect the safety of the public. The alternatives for this decision were primarily the funding source. The Carquinez Bridge decision was made based on a relatively obvious superiority of the selected alternative.

Uncertainty was part of each of these decisions. R&D was used to reduce uncertainty. Peer reviews also were important for reducing uncertainty. Uncertainty was explicitly analyzed primarily in seismic occurrence and performance analyses, but also, to some extent, as ranges of cost estimates.

Each of these decisions has been fully implemented, but each included major adjustments during its life. The overall retrofit program, in particular, has been frequently adjusted. First, the Loma Prieta earthquake led to the substantial increase from the small effort that had been underway since 1971. Then, the Northridge earthquake showed the value of retrofits and led to another increase in effort and pressure to speed up. The focus on the toll bridges required more funding and new funding sources were created. More local influence was bought to the decisions through various means. And the ability to use external consultants was added. The prioritization process went through numerous iterations with substantial input from the Seismic Advisory Board, more attention to systems rather than individual bridges, and adjustments to meet local desires. The retrofit program has upgraded nearly all State bridges with the exception of some of the toll bridges. About 40 percent of the local bridges remain to be retrofitted. Construction has started for the new span of the Carquinez Bridge.

#### **7.4 Contrasts between PG&E and Caltrans**

The contrast between the public Caltrans organization and the private, though publicly regulated, PG&E may provide some insights into how earthquake risk decisions can and should be made in different types of lifeline organizations.

The major difference found in this study was the involvement and influence of many more organizations and stakeholders in Caltrans decisions. PG&E decisions certainly involve many external stakeholders, e.g., City of San Francisco and the Park Service for the headquarters building retrofit, and regulators and numerous local special interests in the Lake Almanor/Butt Valley dam retrofits. But Caltrans decisions typically include the CTC, the parent Agency, the Governor's office, the Legislature, regional transportation authorities, and many political interest groups. Specific projects also typically must work with local governments and special interests.

Another contrast is the attention that needs to be given to who benefits and who pays in Caltrans decisions because of their more political nature. For PG&E, the major issue with respect to who pays is the ability to get a program/project included in the rate base. Because of this single source of funding, who benefits does not typically become an issue. For Caltrans, this is a major concern and drives decisions. Northern and Southern California benefits must be balanced to get political decisions made.

The balance of State and local funding for projects must be considered. For example, the State will pay for the basic cost of some retrofit projects, but local funding must pay for amenities. Thus, source of funding becomes an important part of the alternatives for any earthquake risk program/project for Caltrans.

The degree of centralized control of earthquake risk management differed between the two organizations. Caltrans has a centralized control at headquarters that set priorities and managed the retrofit program. In PG&E, individual departments determine if programs/projects should be undertaken. The Geosciences Department provides advocacy, technical support, and coordination. Both approaches appear to work.

## **7.5 Summary of Key Emerging Issues**

The workshops and the interviews were used to identify key earthquake risk mitigation decision-making issues and areas that might be further studied in order to improve earthquake risk mitigation decision-making in the future. The workshop participants initially identified several potentially important issues. The interviews served to identify additional issues and to confirm or disconfirm what the workshop participants had identified as key issues. This study (the workshops and the interviews) led to the identification of issues needing additional study.

In this section only brief impressions and tentative recommendations are provided and offered for consideration in regard to these issues. These thoughts are mostly conjecture at this point. A detailed exploration and deeper analysis in the following phase is necessary to probe these issues in reasonable depth. These issues/questions include: what are logical or “optimal” earthquake risk decisions; what is acceptable risk; how should uncertainty be communicated; how should one manage earthquake risk without the earthquake; and what is the role of non-explicit values in this decision process? All these issues are highly correlated and interrelated.

An acceptable level of risk is a value judgment. This value judgment should be informed by an appreciation of the technical issues, uncertainties, and costs relating to earthquake risk mitigation. The appropriate level of risk to accept depends on the alternatives. It is the level of risk associated with the best alternative! Earthquake risk decision challenges differ only in a matter of degree from other non-earthquake related complex business decisions. The same decision elements are present but they are usually more daunting in earthquake risk decisions because of the factors described in section 2.2 (page 3).

Why is there so little mitigation action prior to major earthquakes? The answer probably is that people are risk taking in regard to losses (and generally are the opposite in choosing between gains). Thus, they will choose to gamble on a low probability high loss event such as a major earthquake rather than take a certain smaller loss in the cost of mitigation. They will usually spend too little on earthquake mitigation until an earthquake occurs. Afterward they tend to overestimate the probability of it happening again (salience/availability bias). The combination of this salience/availability bias, the political drivers to be seen as “protecting the public”, and the desire to avoid being blamed and held responsible for bad outcomes (attribution theory), all lead decision-makers to tend to over spend on mitigation efforts after the earthquake.

Cost benefit analysis as part of a decision analysis to maximize expected utility, (expected utility theory, EUT) would be a logical approach and the preferred way to address earthquake risk mitigation decisions. With the EUT model one can make effective use of probability and probabilistic inference. The appropriate way to weight and value life is an issue here. This is why cost/benefit analysis was not actually used to assist in earthquake risk decision-making. No one was willing to value and tradeoff the benefits of lives saved versus other safety related investment options. Many project interview subjects seemed to believe that more lives could be saved by straightening and widening roadways, adding



dividing lane barriers, trimming trees, and providing better signs than in investing in massive and expensive bridge retrofit mitigations. Attribution theory again comes into play. Loss of life due to a bridge or building crashing down on someone, if the technology exists to prevent this, points blame squarely at the corporate and political decision-makers. Cars losing control on dangerous roadways can at least be explained by contributing factors on the part of the drivers (driving too fast, inattention, etc.) so Caltrans would not get all of the blame. So Caltrans is expected to spend more on bridge mitigation than on fixing or improving bad roads, even if the bad roads cause more fatalities. An appropriate approach in using EUT is to weight lives differently in these two cases. Thus, one can still make logical and consistent cost vs. benefit decisions. However, putting values on lives or varying the weighting of “involuntary” vs. “degree of control” lives offers challenges since many decision-makers are reluctant to do so, but it does offer a consistent and defensible way to make earthquake risk mitigation decisions and would be preferable to how it is presently done. Also, the huge economic consequences as a result of earthquake related failures need to be explicitly considered.

The communication of uncertainty also poses challenges. Politicians and corporate decision-makers often just want to know, is it safe? A simple yes/no answer that relieves them of much responsibility for any future adverse outcomes in that they can hide behind the fact that the engineers said it was safe! Engineers and scientists provide the caveats and assumptions behind their determination of “safe” but often those assumptions are missed or forgotten on the part of decision-makers and the non-technical public. PBEE creates a continual range of performance alternatives for facility owners and decision-makers to consider. Some desired that decision science provide clear “edges” of performance within the continuum. In fact, decision analysis cautions against edges or simplistic thresholds. For example, a similar problem exists in drinking water standards. Regulators want to say that above some exact threshold (say contaminants in parts per million) that water is unsafe and just below this threshold, the water is safe. In reality, there is a continuum here also and a range of possible alternative standards based on many other factors. Sadly, decision science offers no easy solution. The decision-makers said they had sufficient useful information to make earthquake risk mitigation decisions but perhaps they only believed they did. Phase II should track some cases of how precise technical information (performance, capacity, and hazard) gets used and translated into the language of the decision-makers and the public.

Managing earthquake risk without the earthquake is a difficult challenge but is possible. Lessons learned from areas familiar with earthquakes can be transferred. A compelling scientific case must be made. Presentation of data is critical. Graphics and pictures can make potent arguments and should be used. Detailed technical analytic information is required as the underpinning for recommendations but is usually not understandable, appropriate, or effective for directly convincing decision-makers. Champions for earthquake mitigation should study and learn some of the lessons from social science in terms of biases and heuristic decision-making and consider using them in their “marketing” efforts in the same way advertising firms do. This could be explored more deeply in Phase II.

Non-explicit values (or at least those that were not explicit initially) are another prime area for future exploration in the next phase. Theoretical models of values offer relevance for deeper investigation. In this initial pilot project there is much evidence that these values play a significant role. Identities (PG&E- “we are a San Francisco company”, “it is the moral thing to do”), corporate culture, and structural constraints all surfaced in the interviews during Phase I. There is considerable work in sociology and economics (e.g. valued-based action, contingency theory, resource dependency theory in organizations, etc.) that might be very helpful and enlightening.

## **8.0 Pilot Findings**

In addition to identifying issues for further study and improvement, this pilot study identified initial tentative findings (such as lessons learned and best practices) that can inform earthquake risk mitigation

decision-making currently. The initial findings focus on how earthquake risk decision-making can lead to more effective decisions and implementation of earthquake risk mitigation.

Two types of findings were derived from this study. The first focuses on findings regarding earthquake risk decision-making in lifeline organizations. These findings should be considered tentative because they are based on only two organizations. But these two organizations are probably at the leading edge of organizations making or needing to make these decisions, so the findings are tentative until investigation of additional organizations can be performed. These findings should provide background for a set of guidelines that organizational champions and lifeline organizations could use to enhance the effectiveness of their earthquake risk decision-making.

The second type of findings derives from the pilot nature of this study. It addresses methodological issues – how subsequent research might be conducted to improve its effectiveness. These findings should guide the research design for subsequent phases of the PEER Lifelines Program.

## **8.1 Earthquake Risk Decision-Making**

Although the limited data in this pilot from only two organizations and several decisions does not allow us to draw definitive conclusions regarding lessons learned in risk management decisions, it does offer some suggestions that may have immediate use. They are intended to focus on efforts that an organization can make in this earthquake risk decision-making context that will lead to more effective decisions and implementation of earthquake risk management. These findings must be qualified as to their potential generalizability to other organizations and locations. PG&E and Caltrans may be atypical in many ways. They tend to deal with small disasters everyday. Both organizations studied operate in California in high-risk earthquake environments. Both organizations are monopolies and may have atypical corporate cultures. In addition, the effectiveness of the mitigations (at least those taken after 1994) have not been fully tested and evaluated in real life situations i.e. future major earthquakes.

The five areas explicitly addressed in the interviews organize these suggestions.

### Decision Context

1. Earthquake risk management and related decisions requiring significant resource commitments are most successful soon after actual earthquakes. Otherwise, it tends to not get much attention from senior management, customers, the public, or other parties that can drive these decisions. The organization, however, should not just wait for the earthquake to occur. Advanced preparation – probably only a low level will be supported – significantly enhances the organization's ability to respond to the opportunities presented. Some of the preparation activities that may be useful include: identification of responsible individuals and organizations, databases with information on the systems/structures that could be impacted and integrated with seismic information, up-to-date knowledge of related seismic R&D, and identification and access to external consultants with needed expertise. More detail on these specific preparation activities is provided in additional lessons learned below.
2. Earthquake risk management programs/projects do not typically have to compete directly with other investments. Their life safety nature does not encourage tradeoffs. This may become increasingly more challenging since current industry conditions (deregulation, increased and variable energy costs, etc.) create a more competitive environment than in the past. Nevertheless, determining and communicating additional benefits can help justify a program/project, particularly with some stakeholders. Some typical additional benefits are increased functionality for the system/structure, particularly after an earthquake; and local socio/economic impacts such as aesthetics, recreation opportunities, and job opportunities.

## Alternatives

3. Consideration of earthquake risk and other natural hazards should focus as much as possible on the lifeline systems rather than the individual components (e.g., transportation routes, not individual bridges; gas distribution system, not individual segments).
4. Research and development is a major contributor to successful earthquake risk decisions and programs/projects, and should be supported to the level possible. R&D may be model development, database development, testing of earthquake impacts, and development of new structural techniques or components. As such it can reduce uncertainty in the decisions and mitigate impacts.
5. Maximize the coordination of earthquake risk projects with other projects, e.g., bridge retrofits with widening, building retrofits with tenant improvements, or gas pipeline replacement with other utility work.
6. Establish multiple levels of protection from earthquakes, e.g., collapse prevention, limited functional use within some time period, and full functional use within some time period.

## Criteria

7. Care should be taken in establishing earthquake risk management programs/projects as absolute top priorities, particularly without good estimates of costs and benefits. Certainly safety should be a top priority, but initiating any earthquake risk management actions should be based on sound analysis and determination that the actions are cost-effective and more important than other actions. Reasonable priority should also be given to considerations of overall network performance and continuity of service.
8. When algorithms are developed and used to assist prioritization, they should not be too detailed. They should be used as guides and good starting points, but should be complemented by the exercise of good judgment to adjust their results.
9. A retrofitted bridge or building looks the same and functions the same on a day-to-day basis, so it is difficult for the public to see the benefits. For most earthquake risk management programs/projects, the benefits will not be apparent until an earthquake occurs, so the public needs to be educated and frequently reminded of the value of such programs/projects.

## Uncertainty

10. Cost-benefit analysis is not used during alternative selection and design but probably should be. Costs are uncertain at this point and benefits are primarily prevention of loss of life as well as the prevention of property loss and the substantial economic and social costs resulting from loss of use. These costs are difficult to estimate but is not impossible (see section 7.5) in a cost-benefit analysis. Cost-benefit analysis can be used effectively in value engineering after a design is selected.
11. Probabilistic rather than deterministic analysis of earthquake hazards produces more complete and accurate results and is an effective part of performance-based earthquake engineering. The data and tools to perform probabilistic analyses are rapidly developing and should be used whenever possible.

12. While it may be difficult, organizations should look for ways to get senior decision-makers to accept uncertainty in cost estimates early in the development of earthquake risk programs/projects. This will help to avoid surprising cost increases, until accurate estimates can be made.

### Implementation

13. An organizational champion for earthquake risk management is critical as is the organizational culture to nurture that champion. This person must be credible, have access to senior management, and be an organizational risk taker willing to push back on rules that do not make sense. The champion should also be able and willing to take criticism and keep it from distracting staff working on specific programs/projects.
14. Peer reviews of earthquake risk management programs and projects are essential. They provide credibility and increased confidence even if they do not identify problems. They have proven to be cost-effective, saving more than they cost, even though they can often create considerable additional work for the program/project. Peer reviews should be performed by the best available experts with varying technical backgrounds and interests to minimize the effects of individual biases.
15. The lifeline organization should participate in cross-organization technical groups to share up-to-date information and experiences. These groups may be informal working groups, more formally constituted groups, or professional societies. Efforts should be made to ensure that participants in such groups can openly share information with minimal organizational communication constraints.
16. A core group of professionals within the organization should be identified as the technical lead for earthquake risk. It may have specific technical capabilities related to earthquake risk or may draw on these capabilities from throughout the organization.
17. Lifeline organization seismic engineers should study the results of earthquakes around the world. If possible, visit the earthquake site. If not, read reports and communicate with other organizations that have visited the site.
18. Key earthquake risk management staff should develop and expand contacts across the organization and communicate the value of earthquake risk management and the organizational capability.
19. Whenever possible, all employees in lifelines organizations should be educated to “think seismically,” e.g., during regular training or with regular earthquake emergency response exercises.
20. Efforts should be made to create an environment in the organization in which key earthquake risk professionals will feel motivated and rewarded. This environment would include opportunities for intellectually challenging work, opportunities for professional contact outside the organization, direct encouragement from key management, opportunities to complete projects providing a sense of accomplishment, and recognition both from the organization and from professional colleagues.
21. Databases should be created with comprehensive information on the systems/structures at risk and the seismic hazard. Such databases facilitate rapid response, both to earthquake damage and

to requests for information that may be critical to decisions, e.g., from the press, regulators, public organizations, etc.

22. Make full use of external organizations (e.g., regulators for PG&E, CTC for Caltrans) to support earthquake risk management programs/projects. Their support can be particularly helpful in communicating with critical external stakeholders and breaking down barriers.
23. Develop close working relationships with Federal agencies heavily involved in the program/project. The PG&E relationship with the National Park Service because of the preservation of the historic headquarters building proved to be beneficial both financially and for getting the project done quickly. Also, PG&E has successfully partnered with USGS and FEMA. The day-to-day working relationship between (e.g., linked databases) Caltrans and the Federal Highway Administration was essential to rapid response after the Northridge earthquake.
24. Rapid action after an earthquake will make initiating programs/projects easier. That is when the interest and will to act and invest is highest. It becomes more difficult to expedite work as time passes.
25. To expedite actions, senior management should set goals and then turn staff loose to achieve the goals through any means possible. Creativity is therefore encouraged and rules (bureaucratic processes) are bent where they can be legally and safely.
26. Communications with external parties should be carefully managed. There should be a consistent message, relatively simple and constant. The number of people involved in communications should be limited and they should be people who can communicate technical information in lay terms. Assigning a single person responsibility for managing communication will facilitate managing the message.
27. In communicating with the press, find a journalist who understands the problem and is willing to invest the time to gain thorough knowledge. Then give this journalist as much information and access to knowledgeable staff as possible. This will help to ensure that a complete and accurate message is communicated to the public.
28. External advisory groups should be used to enhance credibility and technical accuracy. They should report to a level in the lifeline organization where they will be listened to and will receive attention.

## **8.2 Research Methods**

As a pilot study, the primary objective of this research was to determine if the methodological approach used could answer the research questions from the approved interview protocol (see Appendix B), and how it could be improved. The following observations and recommendations address this objective based on the experience of the research team in conducting the study described here.

### Planning

1. An active and effective liaison from each organization being studied is essential. These people should be familiar with the objectives and approach of the study and should be active members of the research team. They also should be in a position in the organization to identify potential decisions to be studied and people to be interviewed, or have access to and support from others who can help with these functions. The initial contact and request for participation from

individuals within their organizations was highly successful and led to a 100% participation of all individuals who agreed to and were scheduled for interviews!

2. Focusing on specific decisions is an effective way to study how the organization actually makes earthquake risk decisions. It ensures that the information gathered is directly relevant to decision-making and is a reasonably accurate representation of how decisions actually are made rather than how they are supposed to be made.
3. Decisions to be studied should be identified as far ahead of time as possible. The program/project categorization of decisions is useful for identifying a range of decisions, but should not be adhered to slavishly when decisions that clearly are representative of the earthquake risk decisions faced by the organization do not neatly fit the categories. Interviewers and others on the research team should become as knowledgeable as possible about the decisions through informal briefings (e.g., from the liaison person) and any available written information.
4. The two page project summary sheets (see Appendix E) prepared to provide overview information on the project proved to be highly successful. Including the sponsor, performing organization, project purpose and approach, products, benefits, confidentiality, interviewers, and contact information was right on target. When printed front and back the project summary provided all key information on one single sheet of paper for easy read ahead reference and as a handout prior to each interview.
5. The upfront agreement on confidentiality (part of the two page project summary sheets), the limited uses of the interview data, and the promised lack of direct attribution for statements made during the interview proved successful and led to candid and forthright comments on the part of the interviewees. The confidentiality agreement added to the comfort level of the participants who might have had some less than pleasant experiences with organizational outsiders and the press in the past.
6. Planning the interview protocol should focus on information topics to be covered, not on specific questions. The decision-analytic framework used to organize information on the decisions in this study provided a good information organizing tool and starting point for interview content. However, the categories chosen were incomplete. "Decision modeling" and "analysis" should be added to the five decision topic categories explored in the pilot phase. The highly refined and detailed decision protocol was not necessary. The dynamics of actual interviews vary greatly and each interview takes a different course based on the information provided and the personalities and interests of the participants. The time involved with the manipulation and refinement of a comprehensive decision protocol turned out to add little value. Interviews need to be tailored by the experienced interviewers based on changing needs for information. Individual roles in the decisions made many questions inappropriate for some individuals and other probing questions warranted inclusion based on the knowledge gained through the process on the part of the interviewers and on the unique perspectives of the party being interviewed.
7. The number of interviews required for adequate investigation cannot be determined a priori. Some redundancy in reporting is good and helpful in discovering if a pattern exists. A good rule of thumb would be to continue interviews until one gets interviews that largely repeat what others have said. Two to three interviewees may be sufficient for relatively straightforward decisions in private organizations. More complex decisions in public organizations with more organizations and stakeholders involved will need more interviewees to bring in the major relevant perspectives. Having 18 individuals from Caltrans interviewed was probably excessive. The Caltrans decisions had many more players and political and legislative interests. Because of this complexity, more interviews were certainly needed than the eight done for PG&E. However,

some of the duplicate interviews from a particular perspective, added little value. For example, three members of the Seismic Advisory Board (SAB) were interviewed when one or two probably would have sufficed due to limited role the SAB had on the decisions concerned.

8. Ordering the interviews to ensure that broad general appreciation for the decisions came early on proved successful. Care was taken to order the interviews in a sensible manner to allow for a broad decision overview perspective early in the interview process. Interviews with key individuals with broad involvement and wide knowledge of several decisions at multiple levels were scheduled during the first interview periods. This allowed the study team to gain detailed project and program knowledge that was immensely helpful in understanding the details associated with the decisions and help lead to more focused later interviews on significant decision related issues.
9. For complex, public organization decisions with a larger number of interviewees, planning ahead for the obtaining specialized information from specific interviewees will be useful, will focus the interview, and will save interview time by avoiding redundancies and obtaining the unique knowledge of the interviewee. Refining targeted questions for latter interviews improved the process. Once the study team had a good general understanding of the decisions and the roles of key individuals involved, the study team could refine and target specific questions as part of the preparation for the following interviews.
10. The process of having liaisons communicate with interviewees well in advance of the interview time (e.g., a couple of months) with subsequent follow up by the interview team to schedule specific interview time a few weeks before the interviews worked well. Interviewing and immediate follow up are relatively intense activities for the interviewers, so, if possible, interviews should be limited to two per day for any one interviewer.

### Interviews

11. One to one and a half hour interviews are about the right length. Most of the information that is wanted can be obtained in this time frame without loss of interest or focus on the part of the interviewee or interviewer. Somewhat longer interviews may be needed and can be conducted effectively if more information is needed (e.g., on multiple decisions) or from a particularly key and knowledgeable person.
12. Telephone interviews are effective. Face-to-face interviews are better; particularly for the first few interviews while the interviewers are becoming familiar with the decisions. But telephone interviews can be used for interviewees who would not otherwise be available, and could be used to reduce data collection costs.
13. Taping interviews is easy and cheap, even if the tapes are rarely used. The tapes could be more important if they are substituted for written notes as suggested below in 15.
14. Having one or more organizational representatives present during all interviews added to the credibility of the project and provided comfort to the interviewee for dealing with individuals on the study team they did not know. Knowledge that the organizational representatives had vetted the study team saved time and allowed for the interviews to be focused and to proceed quickly.
15. Two interviewers in a single interview may be more than is necessary, particularly if the organization liaison is participating in the interviews. Using a single interviewer would reduce data collection costs. If the single interviewer approach is taken, however, but two or more interviewers are going to be used to interview different people, having all interviewers participate

in the first few interviews will facilitate rapid learning about the decisions and the organization and will build a common information base for the interviewers.

16. The interviewer should control the interview, probably more than was done in this study. This control should include limiting the opening description of the decision and the interviewee's role to a brief summary rather than a large part of the interview. It should also lead the interview through the specific content areas defined, preferably in the order defined. At the same time, this control must be balanced with letting the interviewee provide the information that he/she thinks is important. Otherwise, useful information may be missed. Maintaining firmer control can cut down on the time used going over redundant information already gained from past interviews and allow more time for going into depth on key details.

#### Interview Follow-up

17. The value of preparing written notes and providing them to the interviewees should be carefully considered in light of the cost of this activity. Experience in this study indicates that the cost of these notes for a one and a half hour interview is \$300 to \$500 in interviewer time. If the interviews are taped, an alternative might be to provide the interviewee with a copy of the tape.
18. Without written notes to prepare, interviewers could spend time immediately following the interviews on a preliminary analysis of how the interview material addressed the key issues identified for the study.

#### Data Analysis

19. If possible, the study should allow time and resources for an analysis workshop in which the study team, liaison people, and other outside experts review and discuss the answers to the research questions. This would enhance the credibility and validity of the research results, ensuring a broader perspective on the issues.
20. Specific questions to be answered by the information from the interviews (e.g., Appendix C) should be identified ahead of time as much as possible. This facilitates both the interviews and the data analysis.

### **9.0 Next Phase of Research**

Phase I of this project, the pilot study, was designed to help us better understand and identify earthquake risk mitigation decision-making issues and concerns in lifeline organizations by conducting workshops and interviewing a wide range of decision-makers in two lifeline organizations on the frontier of earthquake risk mitigation decision-making. The primary objective of Phase I was to determine how best to proceed in Phase II of this project in order to develop earthquake risk mitigation recommendations, guidelines and lessons learned that can improve future earthquake risk mitigation decisions in Caltrans, PG&E, and other lifeline organizations. Key questions that need to be addressed are:

- *What should be the goals and objectives of Phase II?*

The goals and objectives of Phase II will be based on an assessment of what was achieved in Phase I, what is feasible for the next phase, and of the needs and desires of the sponsoring organizations and other potential stakeholders/beneficiaries. Basically, Phase II can either



- (1) Provide a better understanding of the current state of earthquake risk mitigation decision-making in lifeline organizations and a more comprehensive descriptive accounting of lessons learned and best practices that can be used to improve future earthquake risk mitigation decision-making and/or
- (2) Go beyond this descriptive, inductive approach to employ a more deductive theory driven approach. This approach would help generate more prescriptive recommendations informed by theory and research regarding how earthquake risk mitigation decision-making could be improved in the future.

Several questions need to be addressed in order to decide whether extending and/or expanding the inductive, descriptive approach would be worthwhile, i.e.:

- (1) Is there significantly more to gain from getting richer and more in-depth descriptive information from Caltrans and PG&E?
- (2) Do other lifeline organizations have sufficient experience in dealing with earthquake risk mitigation decisions that expanding the descriptive information gathering to include additional organizations would add significant value?

In addition, several questions need to be addressed in order to determine whether a deductive approach directed at developing prescriptive recommendations would be preferable.

- (1) Do we have a clear enough sense of the key issues affecting earthquake risk mitigation decision-making in lifeline organizations that we can identify the theoretical areas of greatest interest to and benefit for improving decision-making?
- (2) Would a more in-depth theoretical investigation of these key issues promote greater progress in understanding and improving earthquake risk mitigation decision-making in lifeline organizations than would the inductive, descriptive data gathering approach?

- ***What methods would be most useful?***

Phase II methods depend on the answer to the questions above. Basically the decision regarding method(s) is whether to expand the inductive interview approach or the more deductive, theory-driven approach.

Providing a better understanding of the current state of earthquake risk mitigation decision-making in lifeline organizations and a more comprehensive descriptive accounting of lessons learned and best practices that can be used to improve future earthquake risk mitigation decision-making could be done by expanding the inductive interview method to include additional lifeline organizations and/or obtain more in-depth information about earthquake risk mitigation decision-making in Caltrans and PG&E. But while the interview method used in Phase I was appropriate for providing a descriptive understanding of earthquake risk mitigation decision-making and identifying issues and lessons learned, it is less appropriate for developing prescriptive recommendations for improving earthquake risk mitigation decision-making in the future. Extending the workshops may be more suitable to exploring and identifying how advances and developments in decision theory and research could help improve earthquake risk mitigation decision-making in lifeline organizations. These workshops could involve

- (1) Experts in areas of greatest relevance to earthquake risk mitigation decision-making in lifeline organizations,
- (2) Key stakeholders from Caltrans, PG&E, and the other sponsoring organizations, and
- (3) Representatives from other key lifeline organizations that may be facing similar or somewhat different issues and challenges with respect to earthquake risk mitigation decisions.

The focus of the workshops would be to determine how decision theory and research could help improve upon the current state of earthquake risk mitigation decision-making in a variety of lifeline organizations. These workshops would bring together theoretical experts and field experts to identify similarities/dissimilarities across lifeline earthquake risk mitigation decision-making contexts and develop prescriptive recommendations regarding how to best address the identified key issue areas in the different earthquake risk mitigation decision-making contexts confronting diverse lifeline organizations.

- ***Recommendation***

It is the recommendation of the authors to pursue a deductive theory driven approach to Phase II. Many significant questions arose after examining the pilot phase interview data and they beg to be answered. A comprehensive theoretical approach appears to offer the best method to address the unanswered questions from the descriptive/inductive pilot Phase I approach. Workshops that focus on key issues that include both academic subject area experts and a range of earthquake mitigation decision-makers at various levels ranging from high level political decision-makers to engineers within the lifeline organizations may provide the best means of advancing our knowledge of the earthquake mitigation decision-making process and how it might be improved in the future.

The two key issues to consider are what key issues these workshops should address and who the participants should be. The following issues that were identified in the Phase I workshops and/or interviews are candidates:

- How are earthquake risk mitigation decisions being made in the leading lifeline organizations and how well would these decision-making processes translate to lifeline organizations confronting different environmental contexts and/or to other types of lifeline organizations?
- What is meant by performance-based decision-making? What is/should be the link between PBEE and earthquake risk decision-making and how does one define a successful earthquake risk mitigation decision from this performance perspective?
- How can earthquake risk mitigation champions encourage decision-makers (both lifeline organizational decision-makers and political decision-makers) to begin to seriously assess earthquake risks in the absence of a major earthquake event? Consider marketing, effective presentation of data, taking advantage of and countering biases and heuristics, etc.
- How important is it that top-level decision-makers understand risk probabilities and uncertainty and how can engineers better communicate risk and uncertainty to these decision-makers? Is it also important for decision-makers to understand the potential affects of uncertainty on the non-technical, non-engineering aspects of the decision-making process?
- How do non-rational decision factors, including organizational and individual values, culture, politics, and personalities factor in the decisions? Does uncertainty heighten the importance of non-rational and non-technical components of decision-making?
- What are the nature, use, and effect of non-explicit decision criteria?
- How are alternatives (physical design, financing, etc.) generated and evaluated and how could the way alternatives are defined and evaluated impact the decisions? Identify and analyze systematic patterns and strategies in how decision-makers generate and select from alternatives.
- What can be done to position organizations to be able to more effectively and rapidly respond to a salient earthquake event?

Once key issues are selected for the workshops, the specific literatures and relevant subject area experts to be invited can be determined. Some of the relevant literatures include:

- Decision science and decision analysis (see Appendix D)
- Case-based reasoning (see Appendix D)

- Expected utility theory and deviations from rational decision making (see Appendix A)
- Risk management
- Modeling and communicating uncertainty
- Bounded rationality
- Value rationality and value-based action
- Corporate cultures/corporate identities
- Structural constraints
- Organizational contexts/environments
- Systems theory
- Theory of politics and political decisions (path dependence, how public opinion affects political outcomes, etc.)
- Negotiation
- Blame attribution theory
- Innovation adoption/diffusion
- Performance-based decision making

The sponsors of the project have made tentative suggestions regarding additional lifeline organizations that might be invited to participate in subsequent phases of this study. The tentative listing of additional lifeline organizations includes:

- (1) BART (Bay Area Rapid Transit)
- (2) East Bay MUD (Municipal Utility District) for water
- (3) California State DWR (Department of Water Resources)
- (4) Pacific Bell for telecommunications
- (5) Oil pipelines (Chevron in Richmond)
- (6) Port of Oakland
- (7) Bonneville Power Administration
- (8) Bureau of Reclamation
- (9) Army Corps of Engineers

Once goals and methods are determined and the organizations on this tentative list have been briefed and surveyed as to their needs, level of interest, and proposed representatives, a final list of organizational participants and representatives from each can be made.

## **Appendix A. Deviations from Rationality**

**by Edgar Kiser (based on Rabin 1996)**

### **Issue: Framing Effects**

How a choice is put to us often affects what we choose. We are more likely to buy a \$10 item if it is framed as a \$11 item with a \$1 discount than as a \$9 item with a \$1 surcharge. This also explains why hidden taxes (VAT for example) seem less onerous than obvious ones (like the clear deletions on our paychecks).

### **Issue: Extremeness Aversion**

People are drawn to what seem to be moderate or compromise choices, and tend to avoid extreme ones. This leads to opportunities for manipulation, and biases in decision-making. Take two wine lists. One has a bunch of \$20 bottles, a bunch around \$30, and a bunch around \$40. The second is exactly the same as the first, but adds a bunch of bottles around \$50. Studies show that customers looking at the second wine list will be much more likely to buy a \$40 bottle of wine than those looking at the first. There is no rational reason for this – but in the first case buying the \$40 bottle seems extreme, in the second case it seems moderate. The general point is that adding an extra extreme choice to the set of alternatives alters the choice. This means that how people think about the choice set is important. If someone in a meeting makes an extreme suggestion, even if nobody wants to do it, the suggestion itself could alter the final decision.

### **Issue: Loss Aversion**

Contrary to economic theory, studies show that people don't weigh gains and losses equally. In other words, losing \$5 makes you more sad than gaining \$5 makes you happy. This makes people risk taking when it comes to losses and risk averse when comparing gains. As a result, people often go to great lengths to avoid uncompensated losses. To put it another way, people would rather take a chance on a possible large loss instead of accepting a certain small loss. This is important here because insurance (including any activities that would mitigate the loss due to a possible negative occurrence) is a certain small loss, and taking your chances with the earthquake is the possible large loss. So if these studies are right, the prediction is that people will generally not do enough to protect against and prepare for earthquakes.

### **Issue: Optimism Bias**

This is a simple issue – we underestimate the risks of something bad happening to us, even when we know the general odds. Most smokers don't think *they* will get cancer, most criminals don't think *they* will get caught (so deterrence theory, a subset of rational choice theory, is often wrong).

### **Issue: Discount Rates/Time Horizons**

We all discount future costs and benefits relative to present ones, but we do so at different rates – some of us save as much as we can for the future whereas others choose to spend all of our current income. There are both individual/psychological variations in discounting, and variations caused by the circumstances in which we choose (the latter may be material/structural or due to organizational cultures).

**Issue: Anchoring**

The idea here is that when people are estimating probabilities, they begin with an initial estimate (often guess) – the anchor – and then adjust from there when they get new information. Studies show that anchors bias outcomes, because people don't correct enough when they get new information. People with different anchors will end up with different estimates even if they have the same subsequent information. Therefore, it is important to figure out what people's anchors are.

**Issue: Salience/Availability Heuristic**

This is another bias in estimating risks – if an unlikely event has happened recently, we tend to think it is more likely; if it has not happened for a long time, we think it's less likely. The questions to think about are both recency and event magnitude (how much does it distort risk assessments).

**Issue: Satisficing/Bounded Rationality**

Put simply, the issue here is that people are often either not smart enough or don't have the time to do the kind of calculations that economists think they do in order to maximize utility. Instead, they "satisfice" by choosing a course of action that may not be the best, but is good enough. This sets up much of what is below, because it raises the question of how they decide what is good enough – what sort of "heuristics" or mental shortcuts (anchoring, framing, status quo bias, salience) do they use.

**Issue: Analogical Reasoning/Case-Based Decisions**

This is not a deviation from rationality but is something that expected utility theory does not address will. We all use analogies and particular cases when we're making decisions. Therefore, which analogies and which cases we use often affect our choices. Thus it would be a good idea to figure out what common analogies or cases are being used in these organizations (in terms of the cases of earthquakes in Turkey, Mexico, and California – which of these cases, or what aspects of these cases, are considered relevant/irrelevant?)

## **Appendix B. Detailed Interview Questions**

### **Overall Description of the Decision**

Describe the decision. How did it occur?

Probes:

Key events/timing

Participants

Turning points

### **Decision Context**

Why was this earthquake risk management decision needed? Probe: What organizational goals/objectives were met by this activity?

Why did the decision get made at this time? Probe: Did external events influence the decision?

Was there time pressure to make this decision?

What was the basis for deciding to pursue this activity rather than other investments?

Who were the decision-makers? Have they had similar roles in other risk decisions?

Was there an organizational advocate? What role did the advocate play?

What was the role of stakeholders in the decision? Probe: Were there hidden agendas on the part of key decision-makers or stakeholders?

Were any strategies considered to allow stakeholders to pay or otherwise provide resources to receive higher priority? If so, what?

### **Decision Alternatives**

What alternatives were considered? Probe: Was any type of insurance alternative considered?

How were the alternatives created?

Were any partnering or cost-sharing approaches considered?

### **Decision Criteria**

What criteria and analyses led to the selection of this particular alternative? Probe: Was cost/benefit analysis used?

How were non-quantitative criteria used?

What tradeoffs were made among the criteria?

What other impacts besides the impacts on component(s) being directly targeted were considered? How?

Was an "acceptable level of performance" established? If so, what was it and how was it established?

How was earthquake vulnerability determined and factored into the decision?

Who paid for the risk mitigation activities and who received the benefits?

How did the timing of costs versus benefits affect the decision?

What was the role of regulators, legal relationships, adversary groups, or other stakeholders?

How was the basis for the decision communicated within the organization and with external parties?

### **Uncertainties**

What uncertainties were considered?

How did these uncertainties affect the decision?

What information was used to describe the uncertainties?

From where and whom did this information come?

Was there too much or too little information about uncertainties?

Was information about uncertainties understandable to managers, stakeholders, and customers?

Would this decision have changed with more information available? If so, how?

### **Decision Implementation**

How has the decision been implemented?

Were the results those anticipated? If not, how were they different?

How have results been evaluated?

Are stakeholders interested in the results?

Do you have any personal concerns with this decision, either the decision itself, the process by which it was made, or its implementation?

## **Appendix C. Interviewees**

### **Pacific Gas and Electric Company**

Bruce Benzler, Director, Building Services, at the time of the HQ Building retrofit

Shan Bhattacharya, currently Vice President, Distribution and Planning, previously Chief Civil Engineer, Maintenance and Generation, and Manager, Hydro Generation

Jeff Butler, Manager, Hydro Generation at the time of the Butt Valley and Lake Almanor retrofits

Eric Elsesser, Founding Principal, Forell/Elsesser Engineers, Design Consultant for HQ Building retrofit

Kent Ferre, Program Manager, Building Seismic Risk Management

Bob Gross, currently Director, New Business, and former Director, Gas Transmission and Distribution

Pat Regan, currently with FERC, former head, PG&E dam safety program

Woody Savage, currently USGS, formerly PG&E Geosciences Division

### **Caltrans**

Abbas Abghari, Supervising Engineer, Office of Earthquake Engineering

Mike Barber, currently with Earth Tech, Inc., formerly Caltrans Design Project Manager for Carquinez replacement structure

Jack Boda, Acting Chief Deputy Director, District 4, formerly Executive Assistant to Chief of Engineering Services, formerly Program Manager for capital projects

Joan Boruki, currently Supervising Planner, NT&R, formerly Federal Liaison, formerly Assistant to Director, Caltrans; formerly Division Chief, Budgets

Jim Gates, retired, formerly Supervising Bridge Engineer

Mickey Horn, currently Acting Chief, Division of Project Management; formerly head of Engineering Services for Retrofit Program

I. M. Idriss, Seismic Advisory Board Member; Professor, UC Davis

Irene Itamura, retired, formerly Branch Chief, Project Development, District 4

Will Kempton, Consultant; Smith, Kempton, and Watts

Martin Kiff, retired, formerly Caltrans Deputy Director, Finance

Brian Mahrone, currently Project Manager, Bay Bridge replacement structure, District 4

Mehdi Morshed, currently Executive Director, High Speed Rail Commission; formerly Staff Director, California Senate Transportation Committee



Dennis Mulligan, currently Golden Gate Bridge District, formerly Caltrans Program Manager, Toll-Bridge Retrofit Program

Joseph Penzien, Chair, Seismic Advisory Board; Principal, International Civil Engineering Consultants

Bob Remen, retired, formerly Executive Director, California Transportation Commission

Jim Roberts, retired, formerly Chief, Engineering Services, Caltrans

Frieder Seible, Seismic Advisory Board; Professor, UC San Diego

Jim Van Loben Sels, currently Consultant, Parsons Brinkerhoff; formerly Director, Caltrans

## Appendix D. Decision Science and Decision Analysis

Organizational decision problems have greatly increased in number and difficulty and, as a result, organizational decision-making has become too big and too complex for individual managers or teams of managers to handle in an ad-hoc manner. Adequate decision-making in today's organizations can require a massive amount of information and experience, a variety of subject matter experts, stakeholder involvement, and specialized approaches, methodologies and tools. As a consequence, decision-making has evolved from a form of pure art on the part of individuals to a combination of art and science. While managers will always have to rely on their intuition and experience, they can no longer afford to ignore developments in the field of decision science to help them make effective decisions.

**Decision science primarily consists of:**

*Decision theory* (the development and application of scientific theories to decision-making situations, and *Decision analysis* (the development and application of rational approaches to decision-making).

### Decision Theory

Two theoretical orientations can be examined in relation to decision-making (Zeckhauser, Keeney, Sebenius 1996; Gilboa and Schmeidler 2001):

### Descriptive Versus Prescriptive

A descriptive theoretical orientation attempts to describe, explain, or predict how decisions are made. A prescription orientation attempts to provide recommendations regarding how decisions should be made. Descriptive theoretical orientations deal with "first-order" reality, prescriptive orientations deal with "second-order" reality in the sense of being rational or logical interpretations of first-order reality. Because we tend to be less concerned about how decisions are made than with how decisions should be made, theories of decision-making are typically prescriptive. Prescriptive theories are an idealized version of real behavior. Judging the validity of prescriptive theories is more difficult than evaluating descriptive theories. Instead of observing the relationship between the theory and behavior through direct observation, it requires determining whether persons accept the theoretical recommendations as valid or appropriate. The fact that persons deviate from a prescriptive theory does not necessarily invalidate the theory. However, prescriptive theories should influence first-order reality, i.e., how decisions are actually made, if they are understood and considered valid (accepted).

### Decision-Making has been Dominated by Two Main Theoretical Paradigms (Gilboa and Schmeidler 2001):

*Rule-based deduction*—Rule-based deductive decision-making is based on if-then logic and should be used when a problem (or some component of a larger problem) is repeated frequently and little uncertainty exists such that little reasoning is required upon each recurrence.

*Probabilistic inference*—This classical decision-making paradigm has dominated decision science because decision science is more concerned with complex decisions which by nature involve uncertainty rather than routine and certain rule-based decision-making. Probabilistic inference has traditionally taken the form of expected utility theory (EUT) coupled with Bayesian probabilistic analysis. It is an ideal, prescriptive paradigm that focuses on how decisions should be made even if all too often it is not an adequate description of how decisions are made. Elaborations on the basic theory typically involve modifying the assumptions to account for deviations from expected utility rationality. Some of these deviations result from constraints to rational decision-making, such as imperfect information (bounded rationality) or time constraints. Others involve non-rational biases, such as judgmental biases, reference point biases, and framing biases (see Appendix A for an elaboration of some of the many deviations and

biases from rational decision-making). When these non-rational biases are brought to the attention of the decision-maker, many, but not necessary all, tend to be corrected for (at least to some extent), suggesting that decision-makers generally accept the theoretical recommendations of how decisions should be made.<sup>1</sup> EUT is most suitable when uncertainty is present but the decision-maker has sufficient data to analyze it. EUT requires that the decision-maker imagine all possible outcomes and all relevant states. In complex problem situations this can be extremely difficult. But even if the decision-maker could imagine all outcomes and states, her task would not be done. Next she would have to assess the utility of each outcome and form a prior expectation over the state space. The requirements of this paradigm are very demanding and often fail to describe what people actually do when making difficult decisions.

### Other Paradigms are Now Gaining Ground

*Case-based decision theory* (CBDT)—This paradigm stems from the claim, dating at least back to Hume, that people reason by analogies.<sup>2</sup> So far this paradigm has not been subjected to the same degree of formal modeling as the other two paradigms but this is changing. In contrast to EUT, CBDT only requires the decision-maker to know some seemingly relevant past cases (the more relevant past cases the better). Thus, when neither probabilities nor possible states of the world are easily accessible or imaginable, CBDT may be a more appropriate approach. Like EUT, CBDT is also a prescriptive theoretical model but it is projected that there is less of a disparity between the recommendations that stem from this model and how decision-makers actually make decisions (Gilboa and Schmeidler 2001).

A complete description of human reasoning and decision-making would have to include all of these paradigms and perhaps others yet to be systematically formulated. Similarly, a complete analysis of a complex problem may require a combination of paradigms. As noted above, each paradigm tends to be best suited to particular types of problems or particular components of a complex, multi-faceted problem. While military and political experts may indeed try to identify all possible scenarios and assign probabilities to them, this is by no means the only reasoning technique they use (Gilboa and Schmeidler 2001).

### **Decision Analysis**

Decision analysis is a term used to describe a body of knowledge and professional practice for the logical illumination of decision problems. It is the result of combining aspects of systems analysis and statistical decision theory. When their concepts are merged, they can reveal how to be logical in complex, dynamic, and uncertain situations. The term decision analysis identifies a collection of technologies for assisting individuals and organizations in the performance of difficult inferences and decisions. Probabilistic inference is a natural element of any choice made in the face of uncertainty. Complex inference and choice tasks are decomposed into smaller and presumably more manageable elements, some of which are probabilistic and others preferential or value-related. The basic strategy employed in decision analysis is “divide and conquer.”

The label decision analysis does not, in fact, provide a complete description of the activities involved. A more precise term for describing the emerging technologies for assistance in inference and choice would be the term decision analysis and synthesis. When all available knowledge has been applied, the problem is reduced to one of preference; thus the best alternative will depend on the desires of the decision-maker.

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<sup>1</sup> For example, Tversky and Kahneman (1981) show that persons feel embarrassed when it is shown to them that they have fallen prey to framing effects and often correct for this in subsequent decision situations. This is an example of demonstrating that persons accept the prescriptive theoretical recommendations regarding how rational decisions should be made.

<sup>2</sup> Hume (1748) argued, “From causes which appear similar we expect similar effects. This is the sum of all our experimental conclusions.” This suggests that the main reasoning technique that people use is drawing analogies between past cases and the one at hand (Gilboa and Schmeidler 2001).

Decision analysis developed from operations research and management science and seeks to apply logical, mathematical, and scientific procedures to the decision problems of top management that are characterized by uniqueness, importance, uncertainty, long run implications, and complex preferences about time and risk. Thus, decision analysis provides a logical framework for balancing all these considerations. It permits mathematical modeling of the decision, computational implementation of the model, and quantitative evaluation of the various courses of action. (Howard and Matheson, 1977; Schum, 2001)

### **The Future of Decision Science**

As the field of decision science continues to progress and mature, attention will go beyond developing new and improved theoretically based decision models and more sophisticated analytical techniques and tools. It will attempt to better understand the goals of decision-making, the decision environment, and to determine the best models and methods or combinations of models and methods to achieve the desired goals within the given decision context.

The classical EUT model assumes the goal of utility maximization, focusing on the selection of means to maximize desired goals. This theory has been elaborated to account for the fact that utility maximization can be pursued for any one goal or maximize utility across multiple competing goals. Effective techniques to address multi-goal approaches and system performance optimization technologies are becoming more available. However, performance optimization, even for the system as a whole, may not be the best performance goal. It is not uncommon for the goal of decision-making to be to satisfice (see Appendix A for a definition of satisficing). Because so many decisions confronting organizations are highly complex and difficult to definitely resolve, an attempt to find the optimal solution may not pay-off.

In addition to the degree of certainty/uncertainty characterizing the decision context, the scope and inter-dependency of the desired performance outcomes and the scope and inter-dependency of the decision-makers can all affect the choice of decision models and techniques.

Finally, it has become increasingly clear that decision-making cannot be reduced to these decision-making paradigms and analytical techniques. Decision science has been taking a broader view of decision-making that includes all the stages from initial problem identification and formulization to solution implementation (Lee and Moore 1975, Clemen 1995). The initial decision context and framing of the decision influences whether and how a problem is identified and has a great deal to do with how decisions subsequently evolve. Also, it has become very clear that a decision will only be as good as its implementation. Stages of decision-making typically include:

*Problem identification and decision formulation* (understanding the overall decision context, decision framing, identifying decision-makers and stakeholders and their values)

*Alternatives development* (formulation and analysis of alternatives)

*Modeling* (problem definition, specification of variables and criteria, weighting)

*Analysis* (uncertainty analysis, sensitivity analysis, etc.)

*Solution selection and implementation* (solution design, implementation plans, processes, feedback, success indicators, and lessons learned)

## Appendix E. Earthquake Risk, Decision-Making in Lifelines Organizations

### Project Overview

**Sponsor:** The project is sponsored by the Lifelines Program of the Pacific Earthquake Engineering Research Center (PEER), supported with funds from the California Energy Commission, California Department of Transportation, and the Pacific Gas & Electric Company. The Federal Emergency Management Agency is a sponsoring partner for the project. PEER is headquartered at the University of California, Berkeley (<http://peer.berkeley.edu>).

**Performing Organization:** Battelle Memorial Institute

**Project Purpose:** The overall purpose of this PEER project is:

To improve understanding of how lifeline organizations make decisions about earthquake risk, particularly what information is used and how information is communicated within and outside the organization.

To identify potential improvements in the decision-making process.

To transfer general recommendations about decision-making to a broad range of lifeline organizations

This project is multi-phased. The purpose of the current pilot project is:

To test data collection and analysis methods for broader application in the subsequent phase.

To provide the participating organizations, PG&E and Caltrans, with preliminary analysis on earthquake risk decision-making in their organizations

**Project Approach:** The current research will focus on a specific earthquake risk decisions in two organizations. Several current and former staff members of these organizations who are knowledgeable about these decisions will be interviewed in depth. The results of these interviews will be analyzed with respect to issues in risk decision-making.

**Products:** The primary products of this pilot project will be:

A project report and plan for the next research phase for PEER

Briefings on preliminary results and analysis for Caltrans and PG&E

### **Benefits:**

To PEER: (1) Transfer knowledge about successful earthquake risk decision-making and potential improvements to a broad range of lifeline organizations; (2) Recognition for the support of improved earthquake risk decision-making in lifeline organizations.

To PG&E and Caltrans: (1) Identify lessons learned from past earthquake risk decisions; (2) Receive recommendations that can improve earthquake risk decision-making in the organization; (3) Receive recognition for successful earthquake risk decision-making.

To Interviewees: (1) Collect and systematize their thoughts on a specific earthquake risk management decision; (2) Receive a written summary of the interview that documents the decision-making process; (3) Learn about issues and biases that influence decision-making.

### **Confidentiality:**

The research team recognizes that there may be sensitivities involved with risk management decisions. The interview will be done only with the participant's consent and the participant may decline to answer any

question. The interviews will be taped, if the participant agrees; and these tapes will be used only by the project team and will not be released to any other parties. Multiple managers will be interviewed in each organization, in separate interviews. The data will be combined during the analysis into more general points. The data will be managed by the research team and not released to others except in the synthesized form of a research report. Participants and other organization representatives will be given an opportunity to review any research reports prior to their publication. To protect the participant's anonymity, the Battelle researchers will not report participant names in association with specific responses. The interviewers may be accompanied by one of the organization's own representatives who participates in the PEER Lifeline Program.

**Interviewers:**

Dr. David Seaver has been a line and program manager with Battelle Pacific Northwest National Laboratory for over 14 years. He has an M.A. and Ph.D. in Mathematical Psychology from the University of Michigan with an emphasis on decision processes. His career has focused on the application of decision analysis and risk management in the energy, environmental, and defense areas. He has recently led the development of project risk management for a multi-billion dollar environmental project.

Mark Robershotte has been a Staff Scientist with Battelle Pacific Northwest National Laboratory for over seven years. He is a licensed Professional Engineer with MS degrees in Engineering Economic Systems and in Civil Engineering (Construction Engineering and Management) both from Stanford University. Since coming to the Pacific Northwest National Laboratory he has been applying high-level decision analysis, programmatic risk management, engineering management, modeling, and other analytical methods and processes for Federal, State, and local government agencies. Prior to coming to Battelle, he taught Decision Analysis, Operations Research, and Engineering Management at the United States Military Academy for six years as an Associate Professor.

Contacts: Please feel free to contact any of the following if you have questions about this project.

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