A Safer, More Resilient California:
The State Plan for Earthquake Research

CALIFORNIA SEISMIC SAFETY COMMISSION

1755 Creekside Oaks Drive, Suite 100
Sacramento, CA 95833
www.seismic.ca.gov

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Executive Director

Robert Anderson
Karen Cogan
Henry Sepulveda

Sue Celli
Kyshia Davis
Henry Reyes

Adam Myers
Fred Turner

Executive Summary

California faces a staggering potential for losses from earthquakes and thus invests significant resources every year to reduce earthquake risks, a practice called mitigation. These investments are guided by our understanding of earthquakes, their effects on the built environment, and the technologies available to reduce their damage. Years of research by scientists and engineers in many institutions—universities, the commercial sector, and State and Federal government agencies—have contributed to the current understanding, and these researchers continue to accumulate new information at a remarkably rapid rate.

State Law requires the Seismic Safety Commission to "develop a final five-year statewide earthquake research plan as part of its five-year hazard reduction plan. The plan shall contain appropriate strategies to receive additional federal funding in order to implement the plan…"(Section 8899.15, Government Code). The Commission is also responsible for "encouraging research and helping to coordinate the earthquake safety activities of government at all levels" (Section 8870.7, Government Code).

In responding to this legislated mandate, the Research Committee of the California Seismic Safety Commission has surveyed a broad spectrum of research activities. This report summarizes its conclusions as to how the State of California should support and use this research to guide better its investments in earthquake mitigation. This plan replaces the *Research and Implementation Plan for Earthquake Risk Reduction in California: 1995 to 2000* (CSSC94-10).

Recommendations.

1. Coordination of research activities in the State of California.

Earthquakes threaten the entire infrastructure of California. Many federal, state, and academic organizations are thus involved in earthquake research for California. Private corporations, especially utilities, are also investing significant resources in earthquake mitigation. The State must encourage cooperation and coordination among these various efforts in order to maximize the return on its investment. First, the Commission should more actively address its mandate to coordinate earthquake research in the State of California. The Commission should provide an evaluation of the research goals of the relevant state agencies to the Governor and ensure effective coordination among them. Second, the Commission recommends that the State should direct its support through programs and centers that have proven effective agents for coordinating the efforts of scientists and engineers, helping to focus their research towards practical goals useful to California's mitigation efforts.

2. Research Priorities.

The State has already prepared a *California Earthquake Loss Reduction Plan* (CSSC, 2002) that highlights activities needed to reduce losses from earthquakes. Within these activities, several are recognized as critically important. These critical areas for State investment are where the Federal effort falls short of the level needed, or areas where the State can leverage a federal program into an activity particularly useful to reducing losses in California, as follows:

a. ***Improve hazard assessments.*** Improve the understanding of the likelihood, location, and size of future earthquakes, landslides and ground failure.

b. ***Support seismic monitoring.*** Support earthquake-monitoring networks to improve emergency response and create the data on future earthquakes that are needed to understand seismic hazard and to facilitate critical research programs. The State needs to maintain this support to sustain emergency response as one of the important goals of the system.

c. ***Develop cost-effective mitigation strategies***. Improve strategies for ensuring cost-effective loss reduction, including new technologies for earthquake-resistant design, incentives for retrofitting and for higher performance standards for new construction.

d. ***Systematically catalog post-earthquake investigations.*** Ensure the timely acquisition, analysis, and management of post-earthquake investigations in much more systematic and rigorous ways.

e. ***Understand our social and economic vulnerabilities.*** Understand the effects of earthquakes on our economy and how best to motivate the citizenry to take personal responsibility for their earthquake safety, including better tools to quantify the financial impacts of earthquakes and the costs of various mitigation measures.

f. ***Encourage new product development.*** Support research directly focused on creating products that can be used to improve seismic safety such as hybrid materials, wireless technologies, and earthquake response modification devices described later.

3. Implement research results into practice.

To make a difference in earthquake risk mitigation, the community of owners, operators, regulators, and design professionals that create our buildings and other structures must ultimately adopt relevant findings of seismic research into their policies, codes, practices, and standards. Research program managers should plan projects to increase researcher awareness of industry practices, tailor balanced portfolios of basic and applied research having a range of payoff horizons, and maintain strong outreach components within their programs to ensure that proven research results are implemented in practice. At the other end of the implementation spectrum, infrastructure owner/operator/regulators need to support innovation and seek paths to put the research into practice.

4. Continue to Support Cost-effective Research

The activities recommended in this report for the state's support will directly contribute to improving the effectiveness of earthquake-mitigation expenditures, and thus contribute to the long-term health of the California economy. Because so much of the Nation's earthquake vulnerability is in California, the Federal government expects cost sharing from California on many of its research projects, but this also means that any California investment can leverage significant Federal funds.

Justification

Earthquakes present a major financial and safety risk to the future of California, the nation's most seismically vulnerable state. The 1994 Northridge earthquake cost our society $40 billion, yet it was far from the largest possible earthquake disaster. Moreover, the *seismic risk* (see insert) is growing — not because earthquakes are occurring more frequently but because the population and buildings in California, and thus the people and dollars at risk, are increasing. A recent study by the Federal Emergency Management Agency suggests that the expected annualized earthquake losses just in building damage in the state of California exceed $3 billion per year (FEMA, 1999) and constitute 3/4 of the Nation's total risk. This level of loss obviously does not happen every year but some years will be disastrous; a major earthquake in a metropolitan area could, like the 1995 Kobe, Japan, earthquake, cost hundreds of billions of dollars. Moreover, the loss of competitiveness and market share for California's economy during recovery could itself have serious consequences for the State for decades.

Seismic hazard describes the earthquake shaking that can be expected over the long term. The hazard depends on the proximity to active faults and the size of the earthquakes those faults might generate, and it can be expressed in the form of a seismic hazard map. In contrast, **seismic risk** describes the damage expected over the long term, usually measured as loss of lives or dollars. The risk depends not only on the seismic hazard but also on three additional factors: the region's *exposure* to seismic damage (its population, number of buildings, and infrastructure), the *vulnerability* of its built structures to seismic shaking, and the *resiliency* of its communities once damage has occurred. The seismic hazard levels in Alaska and California are both high, but California's risk is much greater, because of its greater exposure.

The losses can be reduced through planning and mitigation and the state has an obligation to do what it can. The experience of the last few decades has shown that mitigation — modifying our buildings and infrastructure to better withstand earthquakes — pays off in reduced losses when earthquakes do occur. The goal of earthquake research in California is to determine what mitigation will do the most good.

Thus, the state of California should support research that is focused on reducing earthquake losses, thereby creating a safer and more resilient California. The federal government, through the National Earthquake Hazard Reduction Program (NEHRP), sponsors a combination of basic and applied research on the causes of earthquakes, their distribution, and their damage to the built environment. The knowledge gained by this research is paying off in the ability to anticipate and reduce earthquake destruction. However, this information needs to be implemented into effective loss reduction mechanisms by the state government and the private sector through regulatory policies, economic incentives, long-term investments, and public education. The focus of the State research program should be to leverage the federal investment in earthquake research to meet specific loss reduction goals for California.

A. Coordination.

Earthquakes threaten the infrastructure of California and thus most State agencies address the problem in some way. A few agencies, such as the Seismic Safety Commission, have seismic safety as their prime mission. Several others, such as the Departments of Conservation, and Transportation have a large part of their mission involving earthquakes or earthquake mitigation. Many more agencies, including those regulating all utilities and essential services, such as the Energy Commission, Department of Water Resources, Office of Emergency Services, and Office of Statewide Health Planning and Development, need information about earthquakes to complete their mission. Each State agency responds to research needs of its specific legislative mandates.

The State could make more effective use of its research dollars by coordinating research across agency boundaries.

Beyond State agencies, many federal and private entities are involved in earthquake research in California. The U. S. Geological Survey and the National Science Foundation through grants to State and private universities invest many of the resources of the National Earthquake Hazard Reduction Program in California. While a major effort that contributes significantly to earthquake risk reduction in California, the goals of this program are set at the national level and federal appropriations have never reached authorized amounts. Many private corporations, especially utilities, also invest significant resources in earthquake mitigation in California. By bringing them to the table, the State could leverage its investment in research with the efforts of these other entities and be much more cost effective.

Academic consortia that bring together diverse researchers to focus on common goals, such as the Southern California Earthquake Center (SCEC) and the Pacific Earthquake Engineering Research Center (PEER), have proven particularly effective at focusing academic research efforts towards specific loss reduction activities. Of particular interest to the State are programs fostering cooperation between scientists and engineers in adapting new methods of seismic hazard analysis to the needs of performance-based engineering. This type of interdisciplinary collaboration is critical in establishing a firm technical basis for civic action and strengthening the resolve of public officials to improve mitigation strategies.

Research partnering really works. For instance, in the "NGA Project," PEER, SCEC, and USGS are coordinating research dollars of NSF, USGS, FEMA, Caltrans, PG&E and others to develop an improved understanding of how seismic shaking dies off as it travels away from the earthquake. By better predicting where the shaking will be the worst in upcoming earthquakes, we can save dollars and lives through more effective siting and construction of new facilities.

Recommendation 1: The Commission should establish a process to bring together the government and academic researchers and the primary users of seismic research in California to coordinate the various research programs. The goal would to be to enhance the dialog between researchers and research users to focus effort where it is most needed. Representatives should therefore be those with decision-making authority in their organizations. Entities that should be included are:

Federal

U.S. Geological Survey
Federal Highway Administration
National Institute of Standards and Technology
Federal Emergency Management Agency
National Science Foundation

State

California Geological Survey
Department of Water Resources
California Department of Transportation
California Office of Emergency Service
Department of Forestry and Fire Protection
Housing and Community Development
State Lands Commission
California Energy Commission
California Seismic Safety Commission
Division of the State Architect
Department of Insurance
Office of Statewide Health Planning and Development

Academic

University of California
Southern California Earthquake Center
California State University
Pacific Earthquake Engineering Center

Recommendation 2: The State should encourage research through academic consortia that focus researchers on loss reduction goals, and it should help them leverage federal funding to achieve the priority objectives of the California research plan.

B. Research priorities.

Research supported by the State should be clearly connected to the goals set forth in the *California Earthquake Loss Reduction Plan*. The Commission believes that the following recommendations will support the specific goals of California's Earthquake Loss Reduction Plan: to learn from earthquakes, to live with earthquakes, and to build for earthquakes.

Recommendation 3: Improve hazard assessments. The first step in developing a cost-effective program to reduce earthquake losses is to understand where earthquake damage is most likely. The big picture of earthquake risk in California is relatively well understood; the State straddles a boundary between major tectonic plates, resulting in a network of faults producing earthquakes at the highest rate in the conterminous United States. However, the unknown details of this picture – the exact distribution of faults, the times of earthquake occurrences, the patterns of shaking produced by individual earthquakes, and the response of local rock and soils to the shaking, lead to a high level of uncertainty with large financial consequences for California.

Therefore, a high priority research objective is to reduce the level of uncertainty in the hazard assessment. This goal includes:

- Develop a better understanding of the physics of earthquakes to permit a more accurate prediction of the consequent ground shaking and potentially the timing of future earthquakes.
- Continue investigation of earthquake history of faults to better understand how frequently earthquakes occur, their magnitudes and their relation to earthquakes on nearby faults.

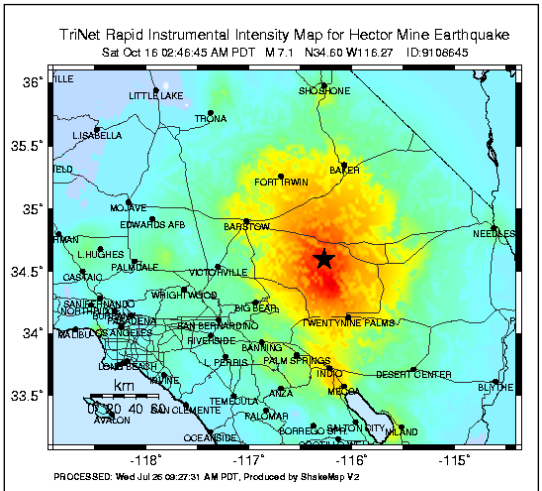
Student interns with the Southern California Earthquake Center map details of the San Andreas fault near Palmdale to determine the time of past earthquakes.

- Provide a better understanding of the regional interaction between earthquakes including triggering, both local and distant, and other factors that could affect the timing of earthquakes.
- Improve our understanding of the effects of local geology, especially basins and valleys, on the amplitude of ground shaking. Even though it is widely accepted that large bodies of soft soils amplify ground shaking, the degree of amplification is still debated. Underestimation of the amplification can lead to under-design of structures. Similarly, overestimation of the amplification, and its damage potential, leads to unnecessary design and construction costs.
- Improve our understanding of triggered events– landslides, liquefaction and tsunami -- and their risk factors. In localized areas, liquefaction (where the ground loses its strength and acts like a liquid during the earthquake) and earthquake induced landslides can cause significant damage beyond that caused by the shaking alone. For tsunami, the hazard in California is not well understood. California has little experience, at least south of Cape Mendocino, with tsunami generated by local earthquakes. There is evidence in the historic literature that they have occurred. How do

underwater landslides, earthquake-triggered or not, add to the hazard? Here again, modeling can help, but a better understanding of the frequency and type of fault displacement of earthquakes on under-sea faults is necessary.

- Completion of seismic hazard zone maps for all urban areas at risk in California. At the present time, only about one half of the communities at high risk from earthquakes have been zoned for liquefaction and earthquake-induced landslides. This leaves significant new construction without the benefits of determining appropriate mitigation against the ground-failure hazards. In addition, current zones only place a property in or out of the zone without a measure of the severity of the threat.

Recommendation 4. Support seismic monitoring. Beyond knowing where the earthquakes will occur, we need to document and predict how those earthquakes will move the ground. This is accomplished with seismic monitoring networks that record the fundamental data about the size and timing of earthquakes (the earthquake catalog) and how the ground moved during the earthquake (records of ground shaking). The earthquake catalog is used to determine rates of earthquake occurrence and thus probabilities for future events, as well as to understand the relationship between geologic structures and the earthquakes they produce. The ground shaking information is used to understand what controls the level and style of shaking, to predict what shaking will be produced in future earthquakes and, thus, how to build buildings to withstand that shaking.



Supporting Decision-Makers.
The M7.1 Hector Mine earthquake struck a sparsely populated region of southern California at 2: 47 a.m. on October 16, 1999. Caltrans procedures for a major event called for inspections of all roads within a large region surrounding the epicenter.
Within 5 minutes of the earthquake, the predecessor to CISN had posted a map on the Web, showing the distribution of shaking intensities in the earthquake. Using this information, the Caltrans dispatcher was able to determine that, because of the event's remote location, only a few roads would need inspection, thereby saving substantial effort and tens of thousands of dollars that morning.

The major seismic networks in California have combined to form the California Integrated Seismic Network (CISN). The CISN is funded by many agencies, including the U.S. Geological Survey as part of the Advanced National Seismic Network, the State through the University of California, the California Geological Survey and the Governor's Office of Emergency Services, and by private partners, including the California Institute of Technology, Southern California Edison, and the Pacific Gas and Electric Company.

The CISN is critical for the State's emergency response. The CISN's real-time products that provide rapid estimates of areas of strong shaking and probable damage have changed the nature of emergency response, allowing decisions to be made with much more information. The transformation of what had been solely research networks at academic and research institutions into critical emergency response tools has been accomplished primarily through additional resources from FEMA and OES. Creating a multi-purpose seismic system that serves both research and emergency response needs is an effective leverage of federal research dollars to

fulfill the State's needs. The State needs to maintain this support to keep emergency response as one of the important goals of the system.

But the CISN is also a fundamental research tool. We need data on past earthquakes to know what to expect in the future. The rate at which earthquakes occur, the shaking they produce, and the damage that they do must be measured. As the state at greatest risk, California is also the state with the most to offer to earthquake mitigation science, through the documentation of our earthquakes and their effects. The state should move toward real-time measurement of the response of buildings and other structures so that the integrity of the structures can be quickly evaluated. Measurements of ground motions should continue in order to provide the observational basis for improving prediction of strong ground motions. This is not only important for structural response, but also for improving estimates of ground failure. Measurements are needed in areas of saturated, soft soils and in mountainous regions to improve models of liquefaction and slope failure triggered by earthquakes.

Recommendation 5. Develop cost-effective mitigation strategies. Once we understand where the earthquakes will be and how they will cause the ground to shake, we must address how that shaking will affect our buildings. California has building codes and a regulatory environment capable of achieving a much higher degree of earthquake resistance than was possible in the past. These advances have come about through research on how construction behaves during earthquakes, and how to improve that behavior through application of new technologies. We are at a time when small research investments still are reaping a large benefit in terms of earthquake mitigation for new construction. We also must address the problems posed by existing construction built to earlier, less rigorous, building codes. The research goals to accomplish these objectives include:

Cost-Effective Mitigation Strategies
One University of California campus has promoted a close working relation between earthquake professionals and researchers, resulting in cost savings and improved seismic safety.
For example, redevelopment of an existing building required assessment of its foundation. Research on elements of the foundation found them to be much stronger than current code provisions had predicted. This enabled the project to use the existing foundation, at a net cost savings exceeding $600,000 on this project alone. The results were disseminated to earthquake professionals so the cost savings will be multiplied.

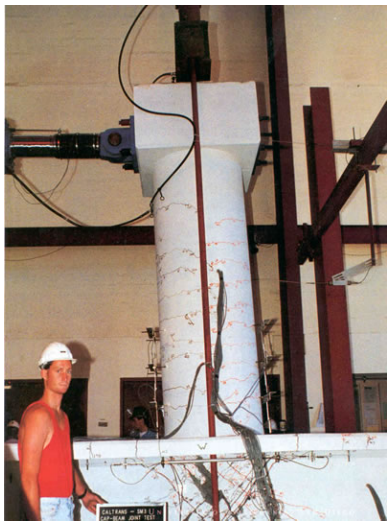
More cost-effective mitigation strategies
On another university campus, earthquake engineers approached seismic retrofit of an existing hazardous building using new engineering tools developed through California-funded research. The new approaches allowed the building to be retrofit using a scheme that was much less architecturally intrusive. It allowed the building to remain fully occupied and functional during retrofit, brought retrofit construction costs down from an expected cost of $5.8M to actual cost of $1.8M, and resulted in a building whose seismic performance rating was so improved that the university could use it as part of its post-earthquake emergency system.

- Continue and expand research efforts in support of performance-based earthquake engineering design so that the infrastructure critical to safety, security, and jobs (for example, emergency response facilities, bridges critical to economic activity of a region, and high-tech industrial facilities) is available when it is most needed following the next big earthquake.
- Determine what losses could be expected from the likely earthquakes and whether we can afford to risk these losses, or whether it would be cost-effective to raise the standard in the building codes and require improvements to older construction.
- Because it may not be feasible to mandate higher standards, we should fund research to identify incentives that would encourage owners

to design for higher earthquake performance levels.

- Determine how to cost-effectively mitigate the risk from existing structures. Identifying existing structures that *might* pose a seismic hazard is relatively straightforward and can be accomplished with existing technologies. The problem is that it is often too costly to seismically retrofit the entire infrastructure. The challenge, then, is to develop techniques for sorting out those structures that pose the highest risk and that can benefit most from seismic retrofit, then direct our mitigation resources to those structures.
- Identify cost-effective mitigation strategies for the most hazardous existing construction. Appropriate research can establish the financial and safety aspects of the existing hazardous construction problem, and develop appropriate policy or incentives to address it. Furthermore, research can identify effective technical solutions to mitigate deficiencies in existing construction.

Recommendation 6. Encourage new product development. New technologies can help solve many of the problems we face in creating a more earthquake-resistant constructed environment. The ground will continue to move in future earthquakes but structures can potentially be built to ride out the shaking without damage. The State should support research directly focused on creating products that can be used to improve seismic safety. Examples include:



A bridge column test specimen after it has been cracked by a simulated earthquake at UC San Diego. Caltrans funded this research.

- ***Hybrid Materials.*** During the past few years, technological advances have emerged that hold great promise to improve the effectiveness and reduce the cost of mitigation. Opportunities are almost within our grasp for much more widespread use of new hybrid materials that are lighter, cheaper, and more resilient than anything currently available to the engineering community. Their development will make it significantly less expensive to design, construct, or retrofit buildings, bridges, and other structures to resist earthquake motions.
- ***Wireless Technologies.*** We are making great strides in information and wireless technologies. The installation of wireless networks of sensors in buildings and structures that can transmit real-time information on performance to transportation and highway officials, emergency responders, and researchers would improve our response capabilities in each of these areas dramatically. Research is needed to place these sensors in the highest risk urban areas and to determine how to interpret the information to evaluate the response of our built environment to earthquakes.
- ***Response Modification Devices.*** Not only are we looking to the development of new

Search and rescue opportunity.

People trapped inside collapsed buildings have a good chance of survival if rescued promptly; a chance that rapidly diminishes quickly as hours pass. The rescue workers know this, but the scarcity of effective tools and equipment greatly limit what they can do without adding to the injuries of those trapped. Using cutting torches and other small hand and power tools to remove building components, essentially piece by piece, they undertake a process resembling fighting a fire with a "bucket brigade."

A similar problem in freeing people from wrecked automobiles led to the development of the "jaws of life". Effective earthquake rescue needs "jaws," too.

materials and technologies, but new design tools are also on the horizon. Researchers are focusing on the development of a range of "response modification devices" designed to dissipate the shaking from the earthquake in non-destructive ways. These new tools offer an economic means to protect historic structures, and maintain functionality of hospitals and other critical facilities in the immediate aftermath of an earthquake. These "smart buildings," designed with sensors, energy dissipating and isolating devices and hybrid materials are at the cutting edge of advances in earthquake engineering and hold great promise to reduce future losses in our State.

Recommendation 7. Conduct post-earthquake investigations. Once the earthquake occurs, many types of ephemeral data need to be collected, to improve future research efforts. This information captures the lessons that emerge from earthquakes and is crucial to improving understanding of how to reduce earthquake losses. Post earthquake data collection includes documenting:

- The impact of earthquakes on the ground on which buildings, bridges, ports and harbors are built, to understand how ground shaking and ground failures affect those structures;
- The response of buildings, bridges, lifelines and other structures, to compare their actual performance to laboratory simulations and design expectations;
- The performance of the built environment under actual earthquake forces, so new structures of all kinds can be better designed and existing structures more effectively strengthened to resist damage in future earthquakes and other extreme events;
- Economic damages and losses to government, businesses, and families, to improve predictive risk and loss models
- The performance of the emergency response system, to understand how it reacted, and how it can be improved to make communities more disaster resistant; and
- The number of deaths and injuries and their causes, the number and types of people who require shelter and housing, to help communities better prepare for future disasters of all types.

The Acorn building in Paso Robles collapsed in the December 22, 2003 San Simeon earthquake, killing two people. The building was torn down within weeks so data for an engineering analysis of why it collapsed had to be collected quickly.

This information enables engineers to improve the design and construction of new structures and to strengthen existing structures to withstand future events; such information has been a primary basis for improvements in building codes, making California a much safer place to live. It helps emergency responders and recovery managers develop more effective plans, and it enables communities and the State of California to plan for and reduce the social and economic impacts that earthquakes cause.

All of this information is critical to reducing future losses in California, but unfortunately some of these data are highly perishable and can disappear in the first few hours or days after an earthquake. As communities attempt to recover, damaged buildings and bridges are quickly removed or repaired. Even adverse weather can wash away important geotechnical evidence of damage to ports and harbors before researchers can study the extent of ground failure or

liquefaction. On the other hand, data on societal and economic impacts must be collected in a coordinated manner over a period of months or even years in order for researchers to fully understand how different social, ethnic, and economic communities were affected. It is important that a coordinated, multi-phased data collection effort be mounted after every significant earthquake.

Opportunity lost. Researchers from many agencies collected detailed data on household damages and losses from the 1994 Northridge earthquake immediately after the event. Unfortunately, the lack of systematic data collection and storage, concerns about privacy, and insurance regulations reduced access to and use of these data by researchers who are trying to understand the full range of impacts of the earthquake to help reduce future losses.

Many agencies and organizations are involved in this activity including the U.S. Geological Survey, the California Geological Survey (for geoscience data) and the Earthquake Engineering Research Institute (for engineering construction and design, lifeline, and social and policy data). The State should support the existing groups that undertake post-earthquake data collection in California. A fund for this purpose has been set up, one that holds unspent funds over fiscal year boundaries (Section 8690.45 Government Code). Rules should be established for use and replenishment of the fund. The State should make a commitment to keep the fund at a certain level. Use of the fund should be coordinated through one State agency. The Commission, responsible for coordination of research, would be the natural agency to coordinate the funding of post-earthquake investigations. Administration of the fund would have to include having instruments in place so that funding can be provided rapidly following earthquakes to qualified investigators.

Recommendation 8. Understand our social and economic vulnerabilities. To actually reduce losses, the results of the research on hazard and building response must be incorporated into land use planning and other public policy. The cost-effective application requires a detailed understanding of our economic vulnerability as well as means to motivate our citizenry to undertake personal responsibility for their earthquake safety.

Damage to the Turley Wine Cellars in the December 22, 2003 San Simeon earthquake.

An important tool to accomplish this is software to estimate losses from known geologic and engineering factors. The State should support the development of an open and more robust loss estimation capability. Both the methodology and the inventory must be improved in order to provide more realistic estimates of future losses and to assist in determining cost-effective mitigation measures. The methodology must be publicly developed and maintained, so that new research can be readily and easily incorporated into model improvements.

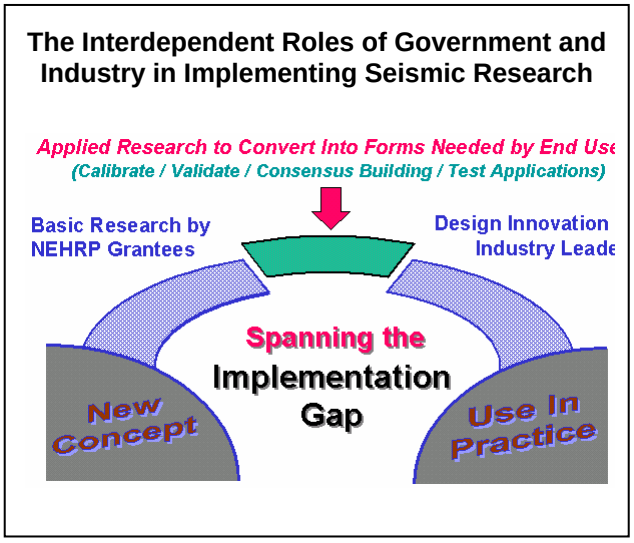
This will help evaluate the cost-effectiveness of mitigation, provide validation for proprietary models used for earthquake insurance, and improve emergency response planning.

Other social and public factors that affect earthquake policy also must be understood, including:

- How to make better use of the roles of regulatory agencies and the insurance and lending industries in promoting improved seismic performance?
- Which existing California laws and programs inadvertently work against improved seismic performance?
- How does the cost of tax incentives and other creative lending or financing programs compare to the financial cost that will be incurred by the State and Federal treasuries, if no action is taken?
- What new or more effective programs could enable individuals, small business owners, major corporations, as well as government agencies, to take the steps necessary to create a safer society?

C. Implementation of Research Results.

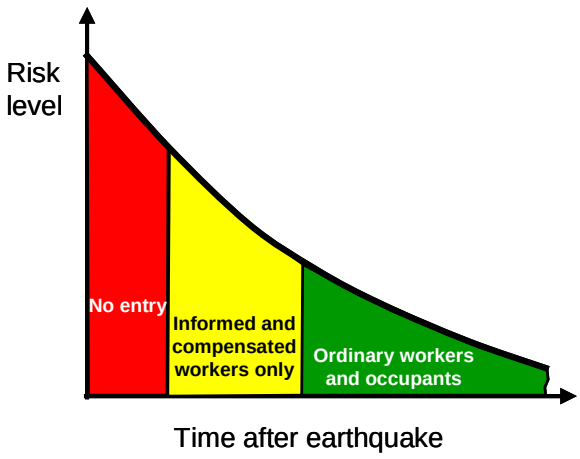
To have a real impact on earthquake risk mitigation, the community of owners, operators, regulators, and design professionals must ultimately adopt relevant findings of earthquake research into their policies, codes, practices, and standards. Unfortunately, it is widely recognized that far too much valuable research does not find its way into practice in a timely and efficient manner. The consequences are missed opportunities to reduce life and property losses for the State of California.



The process of research implementation can be viewed as an interactive process with three foci: 1) basic research, 2) applied research, and 3) industry adoption. Basic research is typically conducted by specialized researchers working in academic or government laboratories. At the other end of the process are architects and engineers who design earthquake-resistant structures, the owners who hire them and the regulators who oversee the process. The role of applied research is to span the gap between these two groups by selecting and converting basic research discoveries into design tools and policies that can be used. Applied research supplies a critically important, and often overlooked, component to the implementation process by developing tools so stakeholder communities can apply the new results in a practical setting.

Recommendation 9. Support research implementation activities. Managers of basic research programs must work to coordinate their efforts where they can lead toward useful products. It is important to note here that the very nature of basic research is the high-risk process of discovery, and not all basic research can or should be focused toward short-term implementation goals.

However, program managers interested in reducing seismic risk should make researchers aware of industry practices, tailor balanced portfolios of basic research having a range of payoff horizons, and ensure strong outreach components within their programs. At the other end of the implementation spectrum, infrastructure owner/operator/regulators need to adopt a proactive posture that supports innovation and seeks paths for rapid implementation. Finally, the critical role of user-focused applied research must be better recognized and supported in order to assure that research advances that have immediate uses can be more rapidly adapted to practice. State-of-the-art project management methodologies and techniques should be applied where appropriate in order to produce timely deliverables of research products.



Research collaboration between seismologists, engineers, and industry has demonstrated benefits. In this example, research scientists and engineers helped California utilities develop a post-earthquake building tagging system that recognized the reduced risk of aftershocks with time after an earthquake

D. Continue to Support Cost-effective Research

The State of California and its citizens and businesses invest large sums in capital construction every year. The Construction Industry Research Bureau estimated that $64 billion was spent on total construction activity in 2002. At least $3 billion was spent on activities to reduce future earthquake losses. California must make sure that this investment in earthquake mitigation is used effectively.

Seismic research is critical to achieving this goal. Past research has uncovered important information on the seismic hazard and how to build more safely, helping California avoid disasters that occur in other parts of the world even in moderate earthquakes. Research has provided information technologies such as ShakeMap, which in the 2003 San Simeon earthquake facilitated emergency response and business recovery. These and other past investments in research have led to reduced losses and greater resiliency in California today. But the work is not finished. We need to continue this investment by the State to make the State more resilient and to leverage the significant Federal investment in earthquake research in California. If California is seen as not contributing its share, the Federal and private sector investments in research could decrease.

To be most effective for the State of California, the research should be directed toward the most critical seismic issues facing the State. To ensure that this happens, it should be:

Planned. The research should be well-planned, directed at clear and specific goals and with a well-defined purpose in the overall research plan. Even though serendipity always plays a role in the best science, planning is essential.

Coordinated. Much of the earthquake research in the United States takes place in California and the State's support should complement and leverage, not duplicate, the federal research efforts.

Educational. Experience gained during NEHRP demonstrates that a consensus to invest in risk reduction is best achieved through an active collaboration among scientists, engineers, government officials, and business leaders, working with an informed populace. A corollary is that earthquake research will contribute most to risk reduction when it is carried out in a context that educates potential users of the technology.

Extensible. Earthquakes are not the only hazard facing California and the best efforts will make use of the results in other fields and be of use in multi-hazard risk reduction. For instance, application of earthquake-resistant engineering design principles can help protect structures from collapse in a terrorist bombing.

The history of earthquake research in California has shown that the investment in research is more than paid back in losses that do not happen in the next earthquake. The State needs to continue its investment so that the billions of dollars it spends each year in earthquake mitigation is spent effectively.