Seismic Safety Commission Findings

A Report to the Governor and the Legislature on
Lessons Learned from Recent Earthquakes
In Turkey, Greece, and Taiwan

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Figure Credits:
Cover Photos: Left – Partial Collapse of Concrete Building in Taichung
Top Right – Collapse of Bridge due to Fault Rupture in Taiwan
Bottom Right – Mehmetcik Tent City of 4300 inhabitants near Düzce, Turkey – by Commissioner Snyder
Fig. 1 – Boğaziçi University; Fig. 12 – USGS/Dr. Ross Stein, Circular 1193; Fig. 14 & 16 – CIA background maps with SSC overlays; Fig. 15 & 17 – USGS background maps with SSC overlays; Other Figures – SSC Staff

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A Report to the Governor and the Legislature on Lessons Learned from Recent Earthquakes In Turkey, Greece, and Taiwan

Introduction

The year 1999 was one of the worst in recent history with regard to earthquake damage and loss of life. The Seismic Safety Commission sent teams to Turkey, Greece and Taiwan where severe earthquakes occurred and captured lessons applicable to California. This report summarizes those lessons.

The Turkey and Taiwan earthquakes were cataclysmic events — much larger than recent moderate earthquakes in California. Each of these events provides a reminder that major earthquakes can strike urban areas without notice and with devastating impacts. These earthquakes provide inescapable evidence that California must continue to prepare for major seismic events to strike.

On August 17, a magnitude 7.4 earthquake struck northwestern Turkey in the Province of Kocaeli near the city of Izmit. Life loss extended over 150 miles from Istanbul to Zonguldak. The earthquake occurred on the North Anatolian Fault that is similar in many respects to California's San Andreas Fault.

- Population in Region: About 2.6 million
- 17,255 killed and 23,781 injured
- Thousands missing or unaccounted
- 450,000 displaced from homes.
- Damaged or destroyed:
  - 283,240 residential units
  - 41,164 business facilities

On September 7, Greece experienced a magnitude 5.9 earthquake in the northwest portion of greater Athens. Compared to the earthquake in Turkey, damage was much less extensive.

Figure 1. Concrete building collapses in Gölcük after the August 17th Kocaeli Earthquake in Turkey.

- Population in Region: About 4 million
- 143 killed and 400 injured
- 100,000 displaced from homes.
- Damaged or destroyed:
  - 72,000 residential units
  - 8,000 business facilities

On September 21, the magnitude 7.6 Chi-Chi earthquake struck central Taiwan at 1:47 am local time. An aftershock of magnitude 6.8 on September 26th added to the damage.

- Population in Region: About 22 million
- 2403 killed or missing, 10,718 injured
- 100,000 displaced from homes.
- Damaged or destroyed:
  - 88,332 residential units
  - 57,040 buildings (including residences)

On November 12, a magnitude 7.2 earthquake occurred just to the east of Izmit, Turkey near the city of Düzce killing 550 people and adding further to the misery of those affected by the August 17th earthquake.

All three countries experienced disruptions to national economies, due to adverse effects on business and commerce.

The Seismic Safety Commission's Field Investigations

The Seismic Safety Commission sent a team to investigate earthquake damage in Taiwan in January 2000. Another team traveled to Turkey and Greece in March. The goals of these investigations were to:

- Meet with representatives of each country.
- Gather information on what they learned from their experiences coping with the earthquakes.
- Determine what pre-event actions lead to the high damage and loss of life.
- Determine what post-earthquake actions have been or will be taken to reduce losses from future damaging earthquakes.
- Identify what actions can be applied to California's earthquake risk reduction efforts, and
- Provide technical assistance to these countries including presentations of the state's Strategic Plan to reduce losses and speed recovery: *The California Earthquake Loss Reduction Plan* (SSC 97-02).

This report summarizes lessons from these earthquakes that can be applied to meet the objectives of *California's Earthquake Hazards Reduction Act of 1986* (Govt. Code 8871 *et seq.*).

Audience for This Report

The Commission developed these Findings and Recommendations for use by the Governor's Administration and Members of the California Legislature when considering earthquake safety policies.

Turkey's Earthquakes in 1999

Most of the casualties in Turkey were caused by the collapse of new and old multi-story concrete buildings due to:

- Severe ground shaking
- Lack of consistent code enforcement
- Poor quality concrete and steel
- Soft stories and other irregular building configurations
- Soft, liquefiable soils in Adapazari and along the shores of the Marmara Sea and Lake Sapanca.
- Fault rupture under buildings straddling the faults also contributed to a smaller but significant number of collapses.

Approximately 100 people died due to land subsidence and flooding of low-lying buildings. An 8 foot tsunami caused localized damage around the Marmara Sea.

Figure 2. Severely damaged concrete building in Düzce, Turkey.

With few major exceptions, the Turkish Building Code has similar provisions to the codes used in California. However, Turkish buildings often rely on tall, slender concrete walls that are not typical in California. New unreinforced masonry wall construction, predominantly of hollow clay tile, is also allowed by the Turkish building code but is prohibited in California. Nevertheless, California has many older concrete frame buildings built before the mid-1970's that are expected to collapse in manners similar to those observed in Turkey. Similar examples of such collapses occurred in the

1971 Sylmar, 1989 Loma Prieta, and 1994 Northridge Earthquakes.

Seven months after the first earthquake, 86,000 still resided in snow-covered tents and an additional 135,000 were located in recently installed prefabricated houses:

- New "tent cities" are situated a considerable distance away from pre-existing facilities such as schools, stores, and hospitals.
- Ten new temporary schools have been erected.
- Four hospitals and four medical clinics damaged in the earthquake have been replaced by temporary medical and mental health clinics in new tent and prefabricated "cities."

Figure 3. Turkey made worldwide requests for "winterized" tents.

- Temporary housing needs are anticipated for at least another winter.
- Eight months after the earthquake, groundbreaking for new residential units was underway.

The Red Crescent has seen a significant reduction in donations, in part, because of Turkey's emergency increase in luxury taxes imposed to finance recovery. The Red Crescent was forced to reduce its operating budget by 38 percent.

Post-Earthquake Government Actions in Turkey

The Turkish Government's emergency response received criticism after the first earthquake. However, eight Provinces (which are similar in size to California's counties) were directly impacted with life loss, severe damage to residential and commercial buildings, disruptions to infrastructure and displaced populations:

- Each Provincial Governor was supposed to respond to the disaster, but many officials were also victims delaying their response.
- Turkish law at the time limited the military's authority to help respond to such a disaster. The Gölcük Naval base and its personnel suffered heavy losses.
- Non-governmental organizations (NGO's) sprang up and offered much of the relief to victims in the ensuing months after the first earthquake.
- Significant improvements in response due to enhanced government, military and NGO cooperation were reported after the smaller November 12th earthquake in Düzce.
- The World Bank agreed to finance a $US 1.8 billion reconstruction project provided the Turkish government make a number of major policy changes now under consideration. The most notable is mandatory earthquake insurance for all Turkish building owners. The details of this insurance are still under development and similar to a program in New Zealand.
- Turkey's disaster laws currently stipulate that the Government will pay for the replacement of destroyed housing and small businesses. The World Bank and others are urging that Turkey revise its disaster laws and construction practices and encourage more individual

responsibility for earthquake safety and recovery.

- The Turkish media and academia have criticized the government as moving slowly to establish meaningful reforms in earthquake-related policies.

- Building code enforcement is lacking, largely due to current laws and long-standing construction practices.

- As of March 2000, some changes in the bidding for and supervision of building construction have been instituted.

- Despite these nominal changes to laws in Ankara, it appeared that unsafe construction practices were still allowed in some provinces. For example as of March 2000, new unreinforced masonry buildings, vulnerable to collapse in future earthquakes, were observed under construction in Düzce.

Figure 4. New unreinforced masonry under construction on the site of a collapsed concrete building in Düzce, Turkey.

- Turkey's electrical distribution system performed remarkably well. This can be attributed to its inherent redundancy and Turkey's ability to reroute and restore loss of power quickly. Part of this success stems from the significant reductions in demand for electricity in the extensively damaged Provinces of Kocaeli, Sakarya, Bolu, and Yalova.

Greece's 1999 Earthquake

In contrast to Turkey and Taiwan, Greece's moderate earthquake last September appeared to be more like recent California experiences with moderate earthquakes.

But unlike California's early morning earthquakes, Greece's Magnitude 5.9 event occurred at 2:55 p.m. and trapped many victims in collapsed concrete buildings.

The entire Athens population of 4 million was shaken, but damage was scattered, directly affecting only parts of northwest Athens. As a result, many in Athens have an optimistic sense that they survived the "Big One" just like misperceptions held by most Californians based on previous earthquakes.

Traffic gridlock in Athens also served as a reminder of what California can expect. Traffic jams severely hampered emergency medical, search and rescue efforts.

Figure 5. Those remaining homeless from the 100,000 displaced in Greece are now living in prefabricated units such as these.

Actions by the Greek Government

The most notable action taken by the Greek government is their effort to step up earthquake education and outreach to the public. Their government now has an expanded agency with 50 employees developing seminars for schoolteachers, informative posters, building code enhancements for earthquake requirements, as well as television broadcasts.

As a result of efforts to extricate victims from collapsed buildings, the Greek government has also enhanced its urban search and rescue capabilities.

Several schools suffered serious structural damage and more than 150 schools experienced nonstructural damage. The loss of function in these schools disrupted normal life in thousands of households. Greece identified the need for pre-earthquake assessments of schools, evacuation procedures, emergency plans, earthquake education and training at all school levels as high priorities. This is similar to California's Field Act and the recent passage of AB 300 and SB1122 to identify and reduce seismic hazards in older schools.

Greece's success in developing a comprehensive post-earthquake recovery plan for the city of Kalamata after a prior earthquake serves as a model for California's needed statewide and local government recovery plans.

Taiwan's 1999 Earthquake

Damage from the September 21,1999 Chi-Chi earthquake was extensive and impacted a population of 22 million people located on an island with an area approximately eight percent that of California. This event was the strongest to occur in Taiwan in the last 100 years.

Over 2,400 people died, almost 11,000 were injured, with damage to buildings, homes, bridges, hospitals, port facilities, roadways, rail lines, electrical power generation and transmission systems.

Taiwan has used construction standards similar to California's Uniform Building Code for over 25 years. Those buildings built to comply with codes did well. However, new structures that did not do well appear to have been influenced by poor

Figure 6. Concrete building in Taichung that partially collapsed.

design and lapses in code enforcement. Many high-rise buildings (less than 50 meters) that collapsed were constructed without input from qualified engineers. Many collapses occurred due to inherent weaknesses of soft first stories. In some cases, it appeared that buildings that had qualified structural engineering design input did not carefully follow the design detailing during construction.

In sharp contrast to Turkey's quick recovery of its electrical distribution system, Taiwan's system was slow to recover in large part because it was highly dependent on a single junction station 10 km from the epicenter that suffered landslide and shaking damage.

The Shih-kang Dam failed since it straddled one of the faults that ruptured and released its water – 40 percent of the Taichung County's supply. Many other structures were severely damaged by fault rupture and ground failure.

Figure 7. Bridge collapsed due to fault rupture.

This serves to emphasize the importance of enforcing geologic and geotechnical considerations before constructing critical and other facilities.

Lastly, over 100,000 people were left homeless and posed a significant temporary housing challenge to the Taiwan government. This earthquake also illustrated how a search and rescue system can be overwhelmed.

Post-Earthquake Actions by Taiwan Government:

Taiwan established a Post Earthquake Reconstruction Commission by emergency decree from its President. Having only one responsible organization in charge of all post-earthquake issues helped speed recovery. The "921 Post-Earthquake Reconstruction Implementing Commission" is led by three Ministers of State and includes representatives from the Departments of Planning, Earth Engineering, Public Construction, Industry Rehabilitation, Life Reconstruction, Community & Housing, and Administration. The Commission has 29 to 33 members and a staff of 155.

Special post-earthquake legislation was passed to permanently speed post-earthquake reconstruction. Taiwan amended existing laws for:

- Distribution of relief and condolence payments
- Temporary resettlement of displaced persons (over 100,000)
- Allocation of emergency relief funds
- Resumption of schooling and counseling for students in disaster areas;
- Setting up special bank accounts for relief donations
- Participation of military forces in relief and reconstruction
- Loans for repair, rebuilding and purchase of homes

Figure 8. Temporary housing and hospital facilities in Taiwan were created in cargo containers after the closure of hospitals due to earthquake damage.

Major earthquake recovery legislation passed in early Jan 2000 required:

> "Due importance…to professional inspection of building structures. Supervision during construction must be strengthened, and a three-tier system of quality control stringently enforced as follows:
>
> - Contractors must carry out work strictly in accordance with their contractual obligations.
> - The responsible project authorities must strengthen their supervision of the work.
> - The agency in charge of the project must carry out unscheduled inspections of the work."

Figure 9. This concrete column buckled due to inadequate reinforcing steel.

Taiwan benefits from one of the best seismic monitoring networks in the world. Information recorded by this network during the earthquake and aftershocks will provide valuable ground motion data for use in California. The State and Federal Government are continuing to enhance similar networks in California.

- Taiwan is now considering land use restrictions up to 50 meters on each side of thrust faults. California currently has similar, narrower restrictions for strike-slip faults.

Figure 10. Many structures were destroyed or damaged not only from the strong shaking, but also due to significant fault rupture.

What was New About These Earthquakes

- Turkey and Taiwan offered insights into the effects of major earthquakes much larger than recent moderate California earthquakes. Dollar losses were only $16 billion and $8 billion in Turkey and Taiwan respectively. California can expect dollar losses on the order of $200 billion after future major metropolitan earthquakes in the Bay Area, Los Angeles, San Bernardino or Riverside.
- Thrust faults like those in Taiwan serve as a reminder that they can cause damage due to fault rupture as well as shaking in California.
- The differing performances of electrical systems emphasize the importance of redundancy and the elimination of "choke points" such as those in the San Francisco and San Diego regions.
- In spite of efforts by international search and rescue teams, passersby and other victims made most of the successful extrications. California can expect to face far more collapsed buildings than available urban search and rescue teams can handle.
- The World Bank's response to recovery financing in Turkey serves as an indication of what California might expect after future earthquakes.
- Taiwan's massive earthquake occurred in a region previously zoned as having only moderate earthquake risk. California has similar regions such as San Diego and Sacramento where earthquakes are not considered as high a risk as elsewhere.
- California gained insights into how each country addressed the needs of large numbers of displaced victims.
- The Taiwan earthquake was one of the most comprehensively recorded events with many near-source records of intense shaking. Researchers will benefit from this wealth of new information.
- The Seismic Safety Commission established informal contacts with officials in Turkey, Greece and Taiwan. Strong relationships already exist between researchers. The Internet facilitates the exchange of information at greatly reduced costs. Formal memoranda of understanding would be helpful to legitimize this exchange.

Successes	Improvements Needed
Fire-resistant construction – even when collapsed – minimized fire losses.	**Ignoring collapse-risk structures before the earthquakes.**
Redundant electrical distribution systems that avoided "choke points."	**Non-redundant electrical distribution systems with major "choke points."**
Strict enforcement of seismic safety in large, independently reviewed structures built to internationally recognized codes and standards.	**Lack of building safety enforcement – including land use planning, design, inspection, plan review, and material quality.**
Numerous strong motion recording stations linked with real-time emergency communications systems.	**Scarce strong motion recording stations located far from the regions of most intense ground shaking unconnected to emergency communications systems.**
Neighbors helping victims and non-governmental organizations working in close collaboration with governments.	**Over-dependence on government-only emergency response efforts including official urban search and rescue teams.**
International cooperation and sharing of information and lessons learned.	**Lack of planning for earthquakes that extend over large regions affecting millions.**

Figure 11. Summary of policies in Taiwan, Turkey, and Greece and how they worked.

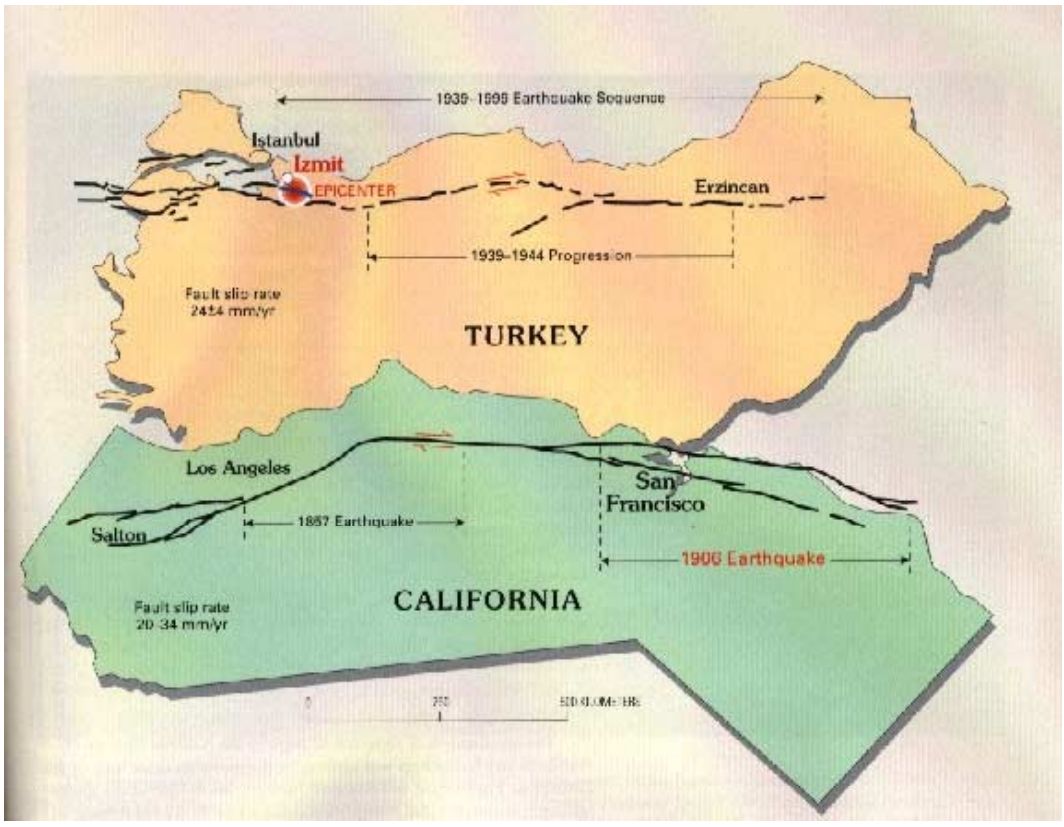

Figure 12. Comparison of Turkey's and California's similar faults.

Recommendations

1. **Accelerate the *California Earthquake Loss Reduction Plan* (SSC 97-02)** – Update the plan, set priorities, delineate responsibilities and commit to timelines.
2. **Comply with Codes** – Follow latest seismic regulations and guidelines:
   - Improve quality of construction
   - Provide for more trained building inspectors
   - Hire more licensed professional engineers to check plans
   - Survey and publicize State and Local Government Building Code Enforcement Effectiveness
3. **Establish and train neighborhood and business emergency response teams** to encourage self-reliant preparedness, first aid, and light search and rescue. Resources are needed for training, organization, and procurement of basic supplies.
4. **Develop emergency shelter and interim housing plans and resources** to accommodate up to several hundred thousand homeless earthquake victims.
5. **Develop Long-term Earthquake Recovery Plans** for local governments and state agencies.

Figure 13. Life in tent cities has settled into a routine. Most of the 211,000 still-displaced victims in Turkey are expected to continue to live in temporary and interim housing well into next year.

6. **Emphasize the mitigation of nonstructural hazards**. – They can cause unacceptable economic losses and casualties, they result in disruptions to vital functions, and retrofits are relatively easy to accomplish.
7. **Identify and retrofit buildings at risk of collapse** – Inventory them, establish seismic retrofit requirements and incentive programs. Such buildings include older non-ductile and precast concrete, soft-stories including wood-frame apartments, tiltups, and unreinforced masonry construction.
8. **Enhance government search and rescue capabilities** – Improve readiness to help extricate victims from collapsed structures.
9. **Increase the state's emergency fiscal reserves** in light of anticipated large economic losses after major metropolitan earthquakes. For example, California's current $500 million reserve proposed for the 2000-01 budget is quite small in comparison to the $200 billion plus that is expected in direct losses from a major metropolitan earthquake.
10. **Revisit proposals to relax seismic requirements in low to moderate seismic zones –** The 2000 International Building Code should be amended for all occupancies to prohibit collapse-risk construction in the Central Valley and parts of Eastern California.
11. **Establish a channel for international collaboration and information exchange** – California should initiate an international workshop concentrating on topics related to earthquake loss reduction efforts. Subsequent workshops can be hosted periodically by different countries so that flows of information can be encouraged and maintained.

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Figure 14. The yellow highlights indicate the approximate extent of strong ground shaking and life loss in the August 17th, 1999 Izmit, Kocaeli, Turkey Magnitude 7.4 Earthquake. (*MMI VIII & greater from USGS 1193)*

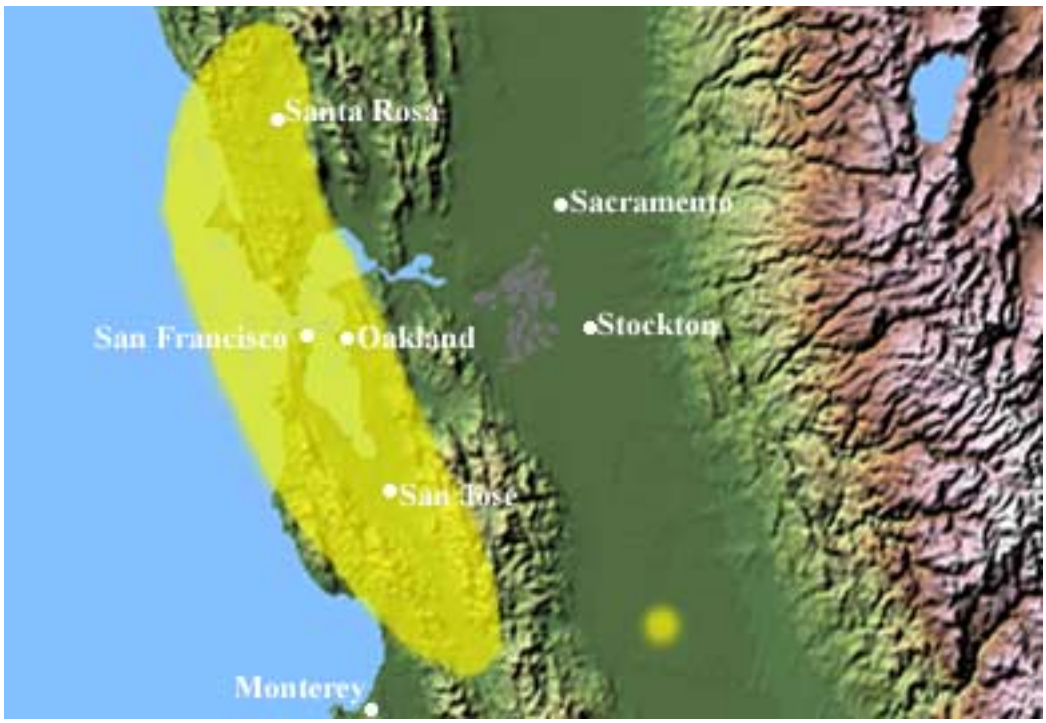

Figure 15. Yellow highlights from Figure 14 are overlaid to provide a rough indication of the areal extent of the effects of a hypothetical strike-slip fault with a similar magnitude 7.4, and with similar attenuation, site effects, and infrastructure vulnerability if it were to occur in Northern California.

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Figure 16. The yellow highlights indicate the approximate extent of strong ground shaking and life loss in the September 21, 1999 Taiwan magnitude 7.6 Earthquake. (*PGA 40%g and greater from NCREE)*

Figure 17. Yellow highlights from Figure 16 are overlaid for a rough indication of the areal extent of a hypothetical thrust fault scaled for a maximum Magnitude 7.0 earthquake expected on the Sierra Madre Fault assuming similar attenuation, site effects, and infrastructure vulnerability if it were to occur in Southern California. The red outline is similar in size to the region of strong shaking in the Magnitude 7.6 Taiwan Earthquake.