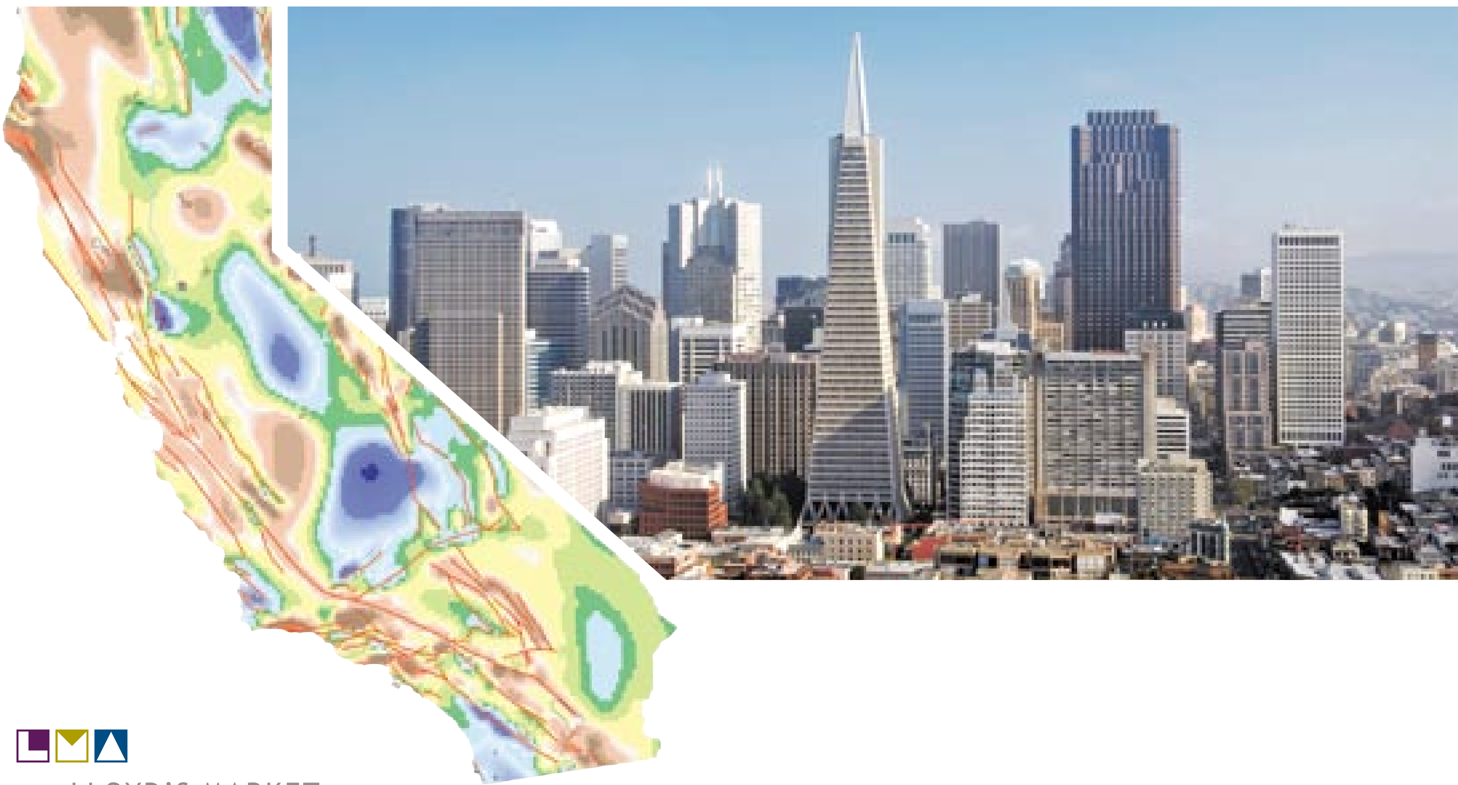
California Earthquake Risk



LLOYD'S MARKET
ACADEMY

Report from the
LMA Lloyd's Market Academy
Earthquake Seminar in San Francisco
May 2010

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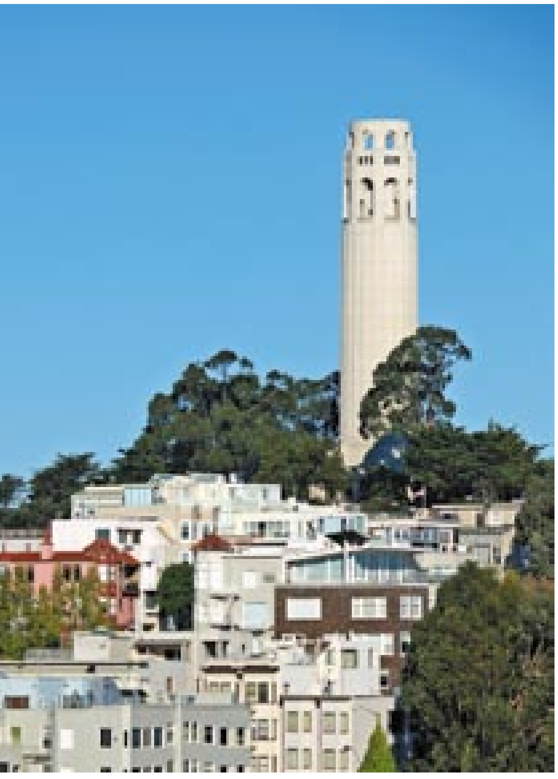
Contents

SPA Risk LLC



The 210ft Coit Tower, at the top of San Francisco's Telegraph Hill, stands as a monument to the city's fire fighters. Built in 1933, it was funded by a bequest from Lillie Hitchcock Coit, a wealthy San Francisco eccentric with an enthusiasm for fire fighting. The top of the tower is said to resemble the nozzle on a fire hose.

This publication has been compiled from "daily reports" supplied by the Earthquake Seminar attendees and edited by T. J. Hayday BA MBA FCII, Head of Professional Standards, Lloyd's Market Association.

October 2010

LMA Lloyd’s Market Academy

The LMA’s Professional Standards Committee (PSC) launched a two year pilot, early in 2010, with the aim of creating a community of learning and education that will underpin the future commercial success of the Lloyd’s Market.

The LMA Lloyd’s Market Academy is being positioned at the centre of this community; driving, developing and delivering a range of educational activities that will address the collective needs of the Lloyd’s Market, in order to sustain the market’s vitality and help to secure a profitable future for this world-beating financial institution.

As a thought leader, the LMA Lloyd’s Market Academy is looking to enhance performance, both individually and collectively, by uniting flair and ability with knowledge; by improving competencies; by harnessing innovation and creativity and by raising levels of professionalism.

The LMA Lloyd’s Market Academy aims to set a pattern of professional education from which current practitioners will derive benefit and to which they will look for guidance. In turn, the existence of such a renowned academy will help to attract future high quality entrants to the Lloyd’s Market.

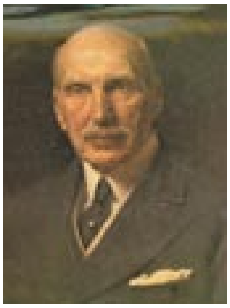
The LMA’s Professional Standards Committee believes that business education is a fundamental driving force for commercial success and that the LMA Lloyd’s Market Academy, working in partnership with managing agents, will be the key motivating influence and delivery mechanism for such success. It will create a model of superior training, development and business education at Lloyd’s ... specifically designed to underpin and secure sustainable high performance.

With its emphasis on “experiential learning”, the LMA Lloyd’s Market Academy has rebranded a select number of events that have been funded in whole, or in part, by the LMA’s existing Training and Education Trust (T&ET).

The Earthquake Seminar in San Francisco, held during May 2010, was the very first event to be run under the banner of the LMA Lloyd’s Market Academy.

LLOYD’S MARKET
ACADEMY

Frontispiece



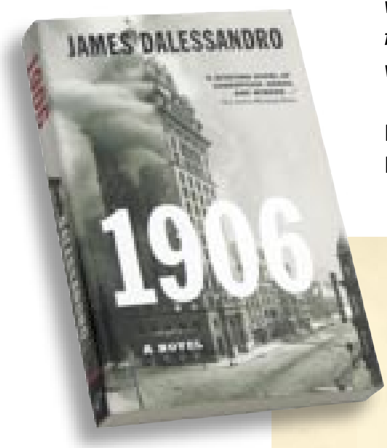
Cuthbert Heath

Eminent early twentieth-century Lloyd's Underwriter, Cuthbert Heath, is credited as being the "Father of Non-marine insurance" at Lloyd's. He famously enhanced Lloyd's reputation in the USA by instructing his agents to "pay all claims" in relation to the 1906 San Francisco Earthquake and subsequent conflagration, irrespective of policy wordings and proximate cause.

"1906"

"Three hundred miles of California coastline reconfigured. Santa Rosa, Palo Alto, San Jose, and several dozen other small towns reduced to rubble from Humboldt County to Monterey. Nearly half a million people sent running for their lives, more than thirty thousand buildings incinerated, including thirty-seven national banks, the Pacific Stock Exchange, two opera houses; hundreds of millions of dollars in smoke and ash." ....

.... "The city of San Francisco is no more. The Paris of the Pacific, the wealthiest and wickedest of American cities is now ash and memories. All that remains are blackened wharves, the iron puddle of a church bell, a mound of cinders where a school once stood, hilly graveyards of charred bricks and melted iron skeletons, an endless scorch mark that was once the grandest boulevard in the West. A city of four hundred and fifty thousand frenetic souls; shaken from its mooring, burnt to a crisp, vanished from the face of the earth."



Prologue: "1906: A Novel" by James Dalessandro
Published by Chronicle Books LLC

Introduction

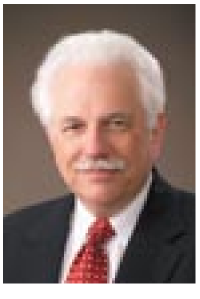
Lloyd's Market attendees at the **2006 San Francisco Centenary Earthquake Conference** were informed that:

The 1906 San Francisco Earthquake measured 7.9 on the Richter Scale and produced shake damage and Fire Following losses estimated at US$ 524 million (in 1906 dollars), of which US$ 180 million were insured. 28,000 buildings were completely destroyed and a total of 90,000 insurance claims were filed. Approximately 80 – 90% of the damage was caused by the fires that ravaged San Francisco in the three days following 18 April 1906. It is estimated that 3,400 people lost their lives.

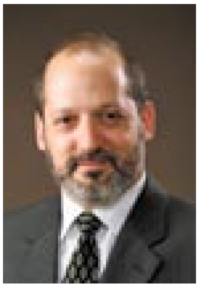
This report, entitled **California Earthquake Risk**, summarises the content of the **2010 LMA Lloyd's Market Academy Earthquake Seminar** in San Francisco, but it does not follow the programme chronologically. Rather, the material has been organised in such a way that underwriting, claims and catastrophe analysts in the Lloyd's Market will be able to derive genuine and practical benefit from reading about the key aspects of earthquake risk in California.

A 331 page pdf version of all the PowerPoint slides that were shown during the seminar is available on the LMA website: www.lmalloyds.com ... *see Appendix*.

The seminar presenters, facilitators and attendees appear in the Appendix.



Dr Charles Scawthorn



Dr Keith Porter

The seminar was facilitated throughout by **Dr Charles Scawthorn** SE, PhD and by his colleague **Dr Keith Porter** PE, PhD, both of **SPA Risk LLC**.

Dr Charles Scawthorn has more than 30 years of experience assessing risk and developing integrated mitigation programmes for natural and technological hazards worldwide. His clients include FEMA, OES, the World Bank, Global 1000 corporations and insurance companies.

He led the technical team developing the HAZUS® MH flood model. Charles has served on oversight committees for NSF-sponsored earthquake engineering research centres and on editorial committees for premier technical journals. He has authored over 150 journal and conference articles and recently edited the "**Earthquake Engineering Handbook**".

Dr Scawthorn's academic background
Emeritus Professor, Kyoto University (retired)
PhD, Kyoto University, Japan, 1981
MS, Lehigh University, PA, 1968
BS, Cooper Union, NY, 1966

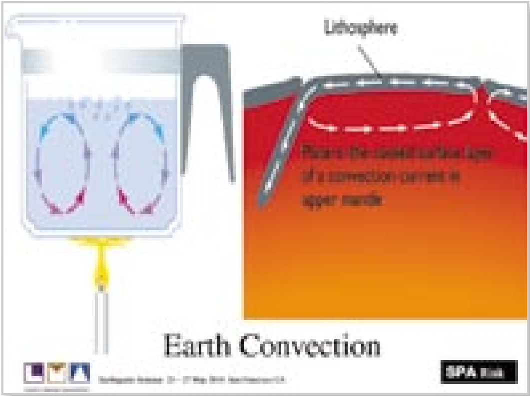
Dr Keith Porter has 18 years of experience assessing earthquake and hurricane risk for insurers, commercial and institutional building owners, and local governments.

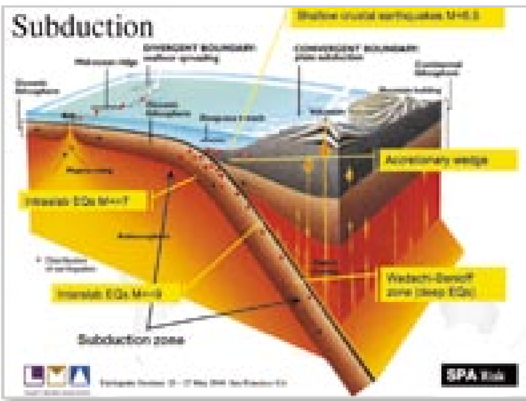
He has developed and applied a second-generation performance-based earthquake engineering methodology to assess probabilistic risk in terms of repair costs, casualties, and loss of use ("Dollars, Deaths and Downtime"). He is the author of over 50 academic publications on multi-hazard risk.

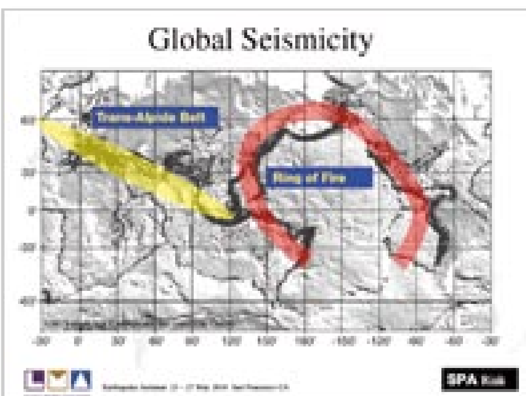
Dr Porter's academic background
Research Associate Professor, University of Colorado, Boulder, 2007 – present
GW Housner Senior Research Fellow, California Institute of Technology, 2000 – 2007
PhD, Stanford University 2000
MEng, UC Berkeley 1990
BS, UC Davis 1987

The Risk

1







The Science

Global Historic Seismicity

Earthquakes are vibrations occurring within the earth – major earthquakes of insurance concern most typically occur as a result of motion in or between a number of large "plates" comprising the Earth's crust or lithosphere – these are called tectonic plates.

Fifteen major and several dozen minor plates have been identified. However, it is estimated that this number will increase with further research.

Plates move as a result of the heat generated at the Earth's core, causing convection currents.

Faults are discontinuities within the surface of the earth, such as the boundaries where adjacent tectonic plates meet.

There are three main types of faulting:

1. Normal faulting (the discontinuity is in tension).
2. Reverse faulting (the discontinuity is in compression).
3. Strike-slip faulting (the two sides of the fault are sliding past one another).

The San Andreas Fault, in California, is a right lateral strike-slip fault and slips at a rate of approximately 2.5 inches per year.

The so called "Pacific Ring of Fire" and "Trans-Alpide Belt" account for 90% of the world's earthquakes.

Other key earthquake territories are Turkey and Japan. The North Anatolian fault in Turkey and the Nankai Trough in Japan have both seen a repeating cycle of rupture.

NB: Typical construction in Turkey is reinforced concrete frame with brick masonry infill. It is estimated that half of the building stock in Istanbul is non-engineered and at considerable risk of failure during an earthquake.

The **Uniform California Earthquake Rupture Forecast (UCERF)** is a collaboration of different scientists and engineers which has carried out research on the likelihood of earthquakes occurring throughout California.

The 800 mile San Andreas Fault is the longest in California and one of the longest in North America. This perspective view, shown opposite, generated using data from NASA's Space Shuttle, shows the fault running throught the Carrizo Plain – an important area of study for seismologists.

The latest version, **UCERF2**, states that California has a 99.7% chance of experiencing a magnitude 6.7, or larger, earthquake during the next 30 years. It is believed that such an event is slightly more likely to occur in Southern California than in Northern California.

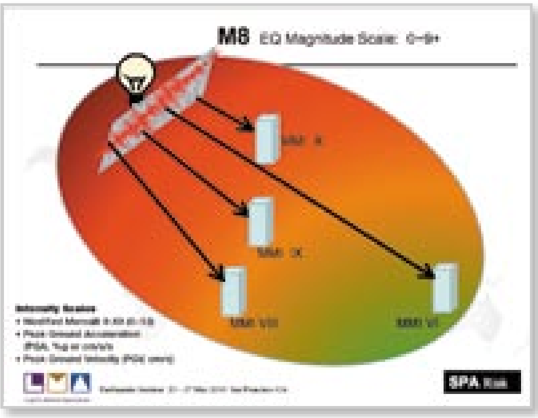
UCERF2 incorporates the time dependency theory that a fault that has recently ruptured is less likely to rupture in the future because of the stress that has been released. After a large earthquake occurs, there generally follows a "seismic shadow": a period of inactivity, because much of the stress that built up has been released.

The new version of the report, **UCERF3**, will incorporate triggering effects of earthquakes.

See: http://www.earthquakeauthority.com/%5CUserFiles%5CFile%5C06-25-2009_GB_Attachments%5CAI9_B.pdf

Earthquakes are measured using scales of **magnitude and intensity**.

Magnitude, in general, measures the overall size of the event in terms of the amount of energy released. Magnitude can be measured by the amount of slippage on the fault itself. The usual scale for this is called the Moment Magnitude.



Intensity is a measure of the effect an earthquake has at a specific location. It is usually qualitative, based upon recognised structural damage as well as human observations. The most common scale for measuring intensity is the **Modified Mercalli Index (MMI)**.

Following a significant seismological event, the **US Geological Survey (USGS)** produces various data and sets of maps, including:

1. A colour coded **Shake Map** based on instrumental observations of ground shaking.
2. A "Did you feel it?" map which relies on individuals logging onto the USGS system, entering their address and answering a series of subjective questions which determine the extent of the shaking at their particular location.

Waves from an earthquake travel through the ground as well as at the surface. These can be amplified or diminished depending on the different types of soil that they travel through. This is called **attenuation**. Earthquake waves have a broad spectrum of motions. Different vibration types affect different types of building, according to design factors such as height and materials of construction. For example, the rule of thumb for a building's natural period is 0.1 second per floor of a building – a 10 storey building has a period of one second and a 40 – 50 storey building has a period of 4 – 5 seconds.

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Seismic Risk

Earthquake Risk comprises three factors:

1. **Hazard**
2. **Vulnerability**
3. **Value**

Hazard is a measure of the earthquake effect and **Vulnerability** is the amount of damage given the hazard.

Risk management of earthquakes requires a decision to be made on the mitigation of the risk using one or a combination of four methods:

1. **Structural mitigation** – build the building strong enough to withstand the earthquake.
2. **Locational mitigation** – building in the right place – that is, one with lower hazard.
3. **Operational mitigation** – emergency planning and response.
4. **Risk transfer** – purchase of insurance or alternative risk transfer in order to receive financial assistance.

Depending on the type of construction, as well as the occupancy, the costs of building will be weighed against the design level required.

There is a chain of causation which needs to be broken, *see left*, to reduce the primary loss and damage, including secondary hazard and loss.

Earthquake occurs

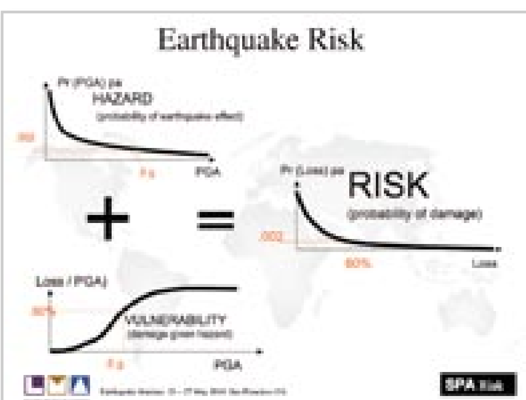
Primary Hazards
Faulting
Shaking
Liquefaction
Landsliding
Tsunami...

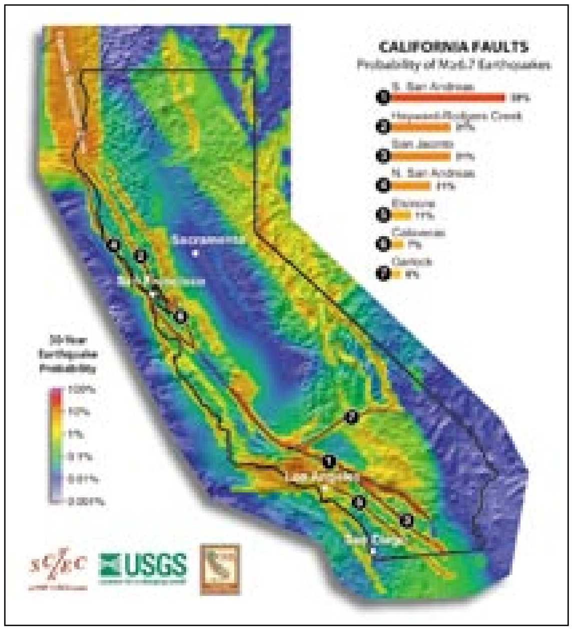
Primary Damage
Building / Structural
Non-structural / Equipment

Secondary Hazard / Damage
Fire
Hazmat
Flooding...

Primary Loss
Life / Injury
Repair costs
Function
Communications
Control...

Secondary Loss
Business / Operations Interruption
Market share
Reputation...





UCERF map of earthquake probabilities for the major California faults. The southern San Andreas Fault has the highest probablility (59% in the next 30 years).

Seismic Hazards

The phenomenon and / or expectation of an earthquake-related agent of damage, such as fault rupture, vibratory ground motion, inundation (e.g. tsunami, seiche or sloshing waves, dam failure), permanent ground failure (e.g. liquefaction) and fire or hazardous materials release.

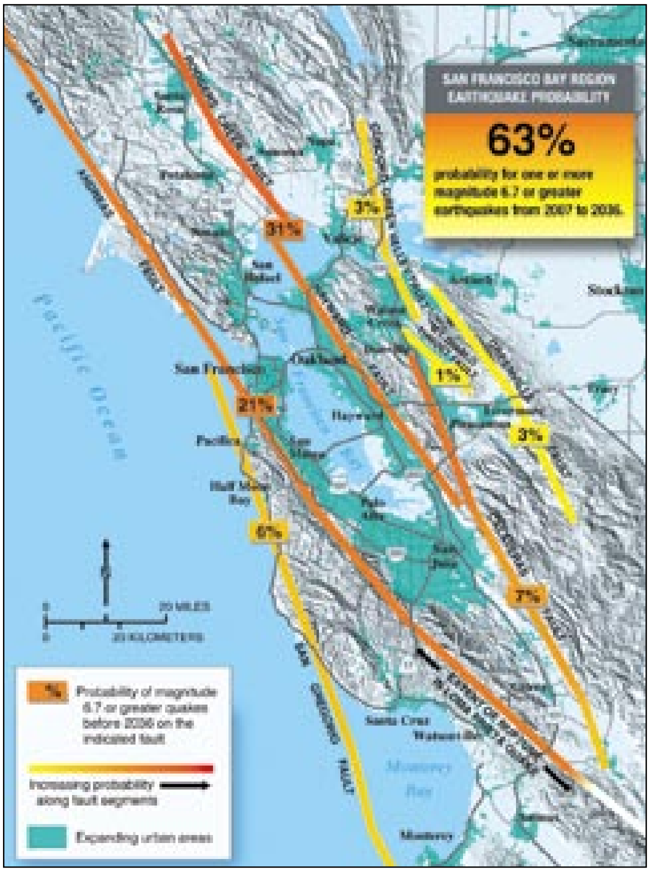
Shaking – vibratory ground motion, which can last for as long as several minutes over a wide area with damage to large numbers of structures.

Land-sliding / subsidence – significant change in soil conditions.

Liquefaction – a process resulting in a soil's loss of shear strength due to a transient excess of pore water pressure.

Tsunami – long waves of small steepness generated by impulsive geophysical events of the seafloor or coastline such as earthquakes and submarine or aerial landslides. Notoriously, they can export "death and destruction at distant coastlines".

Fire Following earthquake – ruptured gasoline lines, cracked water lines, electrical fires and explosions, can all contribute to fires that can become wide-spread conflagrations.



UCERF map showing the probabilities for earthquakes of magnitude 6.7 or greater in the next 30 years. The overall probability of a magnitude 6.7 or greater earthquake in the Greater Bay Area is 63%.

Fault Rupture in the San Francisco Area

Earthquakes occur in the San Francisco Bay Area when the faults beneath California suddenly slip. Because faults are weaknesses in the rock, earthquakes tend to occur repeatedly on these same faults. The California Geological Survey publishes maps of the active faults in the Bay Area that reach the surface as part of its work to implement the requirements of the Alquist-Priolo Earthquake Fault Zone Act. These maps show not only the most comprehensive depiction of fault traces that can rupture the surface, but also the zones in which cities and counties require special geologic studies to prevent the building of structures intended for human occupancy from being built across the fault. In these zones, surface rupture hazard must be disclosed in real estate transactions.

Note, however, that strong earthquakes can occur when the fault rupture does not extend to the surface, and that fault-related damage is rare when compared to shaking-related damage.

See: http://quake.abag.ca.gov/faults/

Risk Mitigation

Building Codes and Mitigation

Different types of buildings are constructed worldwide and there are different sets of **seismic building codes**, and compliance with such codes, that vary from country to country. California and Japan have strict building codes which are enforced.

In California, old buildings only have to comply with the building codes that were in force during the year they were built. There is no enforcement of retrofit to comply with new codes, unless the building has a major renovation.

In theory, every city in California has its own version of the building code (adopted from the **International Building Code – IBC**), although in practice most adopt the IBC with little change. Each city can define at what point building updates trigger a seismic retrofit.

NB: Insurers, following a fire loss on a building, may be required to pay for earthquake retrofits as part of a claim, regardless of whether the insured purchased earthquake insurance or not.

Prior to 1950, construction in California was often of reinforced concrete frame with unreinforced masonry infill. This construction caused problems because the infill was very rigid and tended to fall out of the frame during an earthquake, as it was unable to resist the tension.

Apart from strict adherence to building codes, the best way to protect older or weaker structures is to seismically retrofit them i.e. to strengthen them with steel reinforcements and bracing.

Situated on the Hayward Fault, many buildings at the University of California, Berkeley have been base isolation retrofitted.

In some structures, more sophisticated techniques, such as the installation of seismic dampers (shock absorbers) and steel and rubber isolators, offer added protection as the buildings are then able to move independently from the ground ... *see **base isolation** below*.

Retrofitting, especially on a large scale, may be expensive (especially where state or publicly owned buildings are concerned) and money and financing represent major considerations.

Not all state or national budgets can accommodate the sums required to retrofit all buildings and most programmes, if they exist at all, tend to concentrate on the most vulnerable buildings in the most congested urban areas.

Reinforced concrete detailing should have longitudinal bars within confined loops. Modern construction (post 1976 IBC) requires more and stronger confinement.

Reinforced concrete shear walls are very strong and prevent earthquake shock waves penetrating construction to columns or other building components.

Steel **moment resisting frame** construction was developed to resist lateral forces on columns and beams. Until 1994, the joints in this type of construction were thought to be very reliable. The Northridge Earthquake showed that the connections in this type of construction cracked before the expected yield point prompting **FEMA (Federal Emergency Management Agency)** to conduct a full scale test of these types of joists. This led to a change in the construction codes.

NB: There are still a great number of these types of connections in California, especially in downtown San Francisco.

Base isolation is a common retrofit for government or historic buildings that cannot be replaced. This type of retrofit is very expensive as it involves lifting the building off its foundations and placing bearings underneath that absorb the forces in an earthquake.

The rebuilt City Hall, San Francisco, (left) was retrofitted with a base isolation system following damage in the Loma Prieta Earthquake of 1989.

Los Angeles City Hall (right) is designed to withstand an earthquake of magnitude 8.2 following its base isolation retrofit.

What Does Good Look Like?

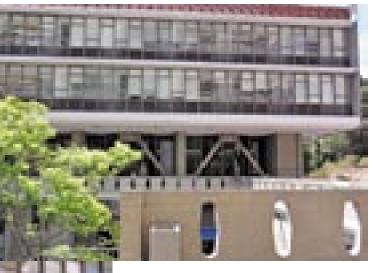
Engineering / Retrofitting at UC Berkeley

The University of California, at Berkeley, (UCB) is extremely vulnerable to an earthquake. The Hayward Fault runs through part of its campus; actually bisecting the 73,000 seat Memorial Sports Stadium.

Injury and loss of life to students and faculty, severe business interruption and reputational damage following a major earthquake could seriously downgrade the world-ranking status of this academic institution. UCB incorporates the prestigious Seismology Department and its facility for monitoring and recording seismic data, the main attributes of which are:

1. Along with other networks, UCB operates over 3,000 monitoring stations.
2. Current technology includes broadband stations and underwater monitors.
3. Earthquakes can now be identified and plotted within 15 seconds.
4. Test groups are researching an "early warning system".

First of the SAFER buildings, Hildebrand Hall was retrofitted with concrete shear walls and used unbonded brace technology – lateral forces resisted by each member – made of steel and concrete, enabling each brace to act equally well in tension and compression.



A major programme of engineering and retrofitting has been undertaken to strengthen key historic and academic buildings across the UCB campus.

As part of the Earthquake Seminar, attendees participated in a walking tour of the UCB campus, inspecting disaster resistant buildings. The key features of which were:

As indicated above, the UC Berkeley campus sits astride the Hayward Fault.

Catastrophes can have unique impacts on universities, threatening their very existence and continuity.

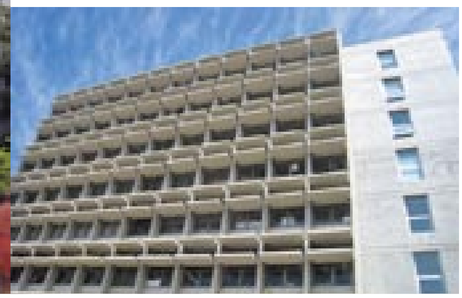
After completing a study of the impact of a major earthquake (based on a serious Hayward Fault event) UCB concluded that they could sustain up to 30% of capital losses, 20 months downtime, which would result in huge job loss in the region, as well as a loss of funding, with a potential consequential loss for the wider Northern California economy.

UCB have introduced the **SAFER** programme – **Seismic Action Plan for Facilities Enhancement and Renewal**:

1. Building survey carried out in 1978 and retrofitting of residence halls, libraries and administrative buildings.
2. Later survey in 1997 and a commitment of capital.
3. US$ 20 million per year committed for this programme for 20 – 30 years.
4. Base isolation technique used on historic Hearst Mining Building (built 1907) was retrofitted in 2002 at a cost of US$ 80 million.

The goals of UCB's programme are to create a "DRU" – a **Disaster Resistant University**, so that losses are reduced, plans can be laid for recovery, teaching and research can resume, business can return to former levels of income and buildings can be reoccupied quickly.

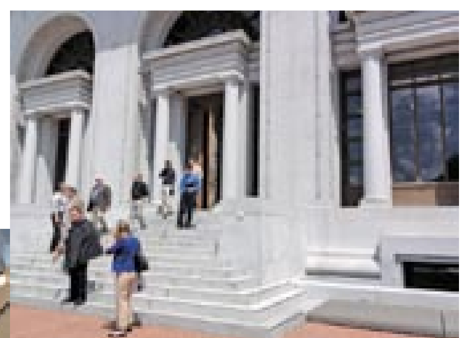
In addition to the seismic renovations, the Wurster Hall retrofit included new mechanical systems, electrical wiring, fire sprinklers, and telecommunication systems.



Latimer Hall used exterior concrete box columns for the retrofit, to provide strength to the main structure; shear walls provide longitudinal shear strength.

The Hearst Memorial Mining Building's base isolation system consists of 134 steel and rubber-laminated composite columns which can move 28 inches in any horizontal direction.

Barker Hall laboratory building cost US$ 14 million to retrofit – shear walls were added to the sides.



History and Research

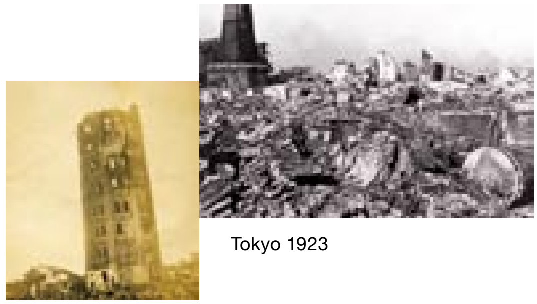
From paleo-seismology (establishing the pre-historical record) to catastrophe modelling; from the study of tectonics to building design and engineering; from earth science to “prediction” techniques, increasingly rapid technological advances have been made over the past century, but most scientists are still of the opinion that “there is still a long way to go” and that there is still rich research soil to be tilled.

The science of seismology is, therefore, still relatively young:

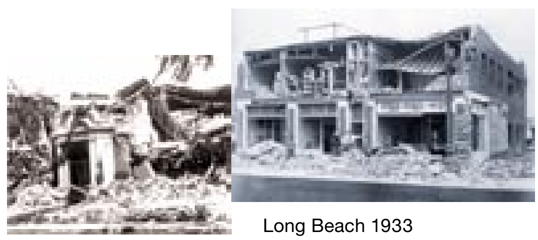
140 years ago	First knowledge of earthquakes / scientific approach.
75 years ago	Magnitude defined and first strong motion record.
50 – 80 years ago	First earthquake engineering building code.
45 years ago	Theory of plate tectonics (understanding of seismogenesis).
40 to 60 years ago	First seismic hazard maps.
46 years ago	Liquefaction “discovered”.
35 years ago	First ductile detailing requirements.
35 years ago	First loss estimation.
25 years ago	Loss modelling companies “born”.
Last 10 to 15 years	Uptake by insurance industry.

NB: 50% of the building stock in California and Japan is seismically obsolete. The percentage is much higher almost everywhere else in the world.

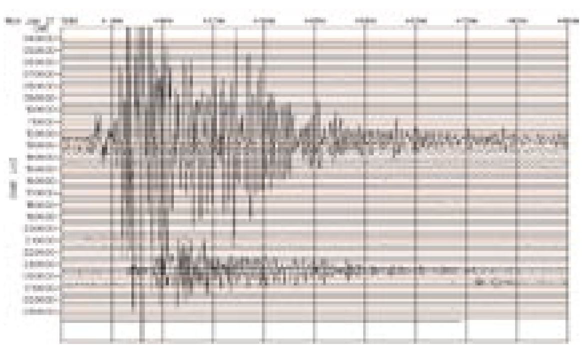

San Francisco 1906


Tokyo 1923


Santa Barbara 1925


Long Beach 1933

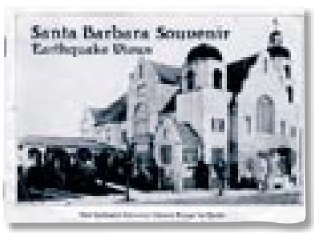

Kobe 1995


Northern California Earthquake Data Center seismogram of the Northridge Earthquake.

Nobi 1891

San Francisco 1906

Left: Harry Fielding Reid
Below: Alfred Wegener



Above: Charles Richter
Right: George Housner
Below: C. Allin Cornell
Below right:
Karl Steinbrugge

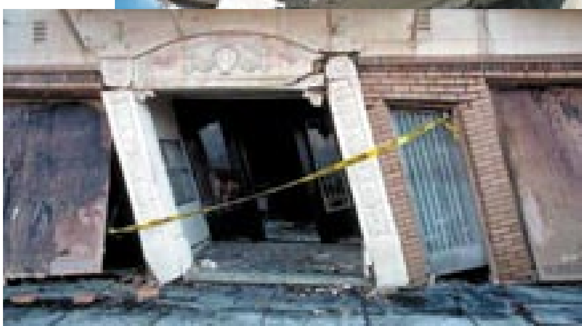
Haiti 2010

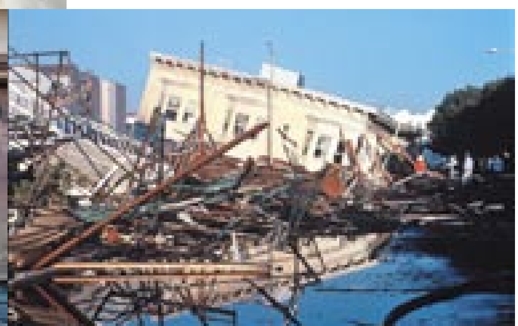
Key Milestones in the Modern History of Earthquake Science

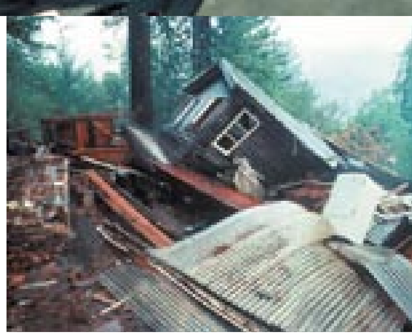
1850	Modern Earthquake Science began with Mallet who mapped dynamics and plate boundaries.
1867	Sansom produced detailed fire maps of NYC at building level.
1880	First functional seismometer developed by Milne, Ewing and Gray. Milne also founded Japanese Institute of Seismology.
1881	Rossi and Forel are credited for the first modern intensity scales.
1891	Nobi Earthquake became first thoroughly investigated event since the birth of seismology. Omori developed first scale of intensity.
1906	San Francisco Earthquake. Isoseismals mapped including review of structural impacts on damage caused. Seismological Society of America founded. Japanese engineers visit San Francisco and assess shake and Fire Following damage.
1911	Reid proposes Elastic Rebound Theory after review of 1906.
1913	Wegener proposed concept of plate tectonics, but is ridiculed in the earthquake community.
1923	Tokyo Earthquake.
1925	Santa Barbara Earthquake.
1929	Seismological Society of Japan re-established.
1930	Freeman (founder Factory Mutual) proposed strong-motion detection network in USA. Subsequently authorised in 1932.
1933	Long Beach Earthquake. First recording of strong earth motion with seismological instruments.
1935	Richter defines seismological magnitude.
1951	Probabilistic acceleration maps of Japan and seismic probability maps of USA drafted.
1952	Housner pioneered USA earthquake engineering science.
1964	Hydrological Engineering Centre developed HEC-1 flood risk assessment.
1968	Cornell, a civil engineer, was the first to note building codes within his seminal paper “Engineering Seismic Risk Analysis”.
1970s – 1980s	Steinbrugge and Shah recognised as leaders in the field.
1986 – 1987	First modelling engines produced loss estimates.
1989	Loma Prieta Earthquake, California. *See page 16.*
Post 1990	Earthquake models became more sophisticated and considered the hazard, values at risk and their vulnerability. Leading to HAZUS and GEM.
1994	Northridge Earthquake, California. *See page 17.*
1995	Kobe Earthquake, Japan.
2004	Sumatra, Indonesia, Indian Ocean “Boxing Day” Tsunami.
2010	Haiti Earthquake.
2010	Chile Earthquake.

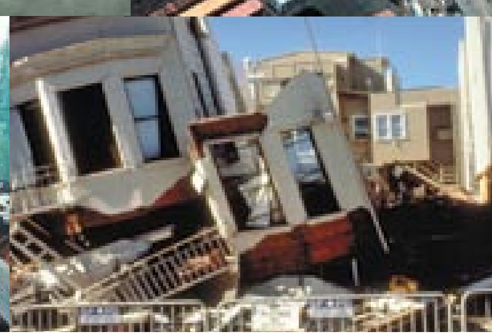
Loma Prieta Overview – 1989

- US$ 7 billion loss.
- Damage in multiple cities.
- 26% of loss was housing and 60% apartments (multi-family housing).
- Inordinate impact on lower income housing.
- Social Issues: 60% of loss was to multi-family, long-term renters.
- Recovery was 75% over 10 years.
- There were problems with temporary shelters: a politically charged issue.









Northridge Overview – 1994

- US$ 26 billion loss.
- 50% residential.
- A largely suburban “middle class” event.
- Wood frame housing considerably affected.
- 49,000 apartments destroyed.
- 100,000 SBA loans to families.
- 288,000 FEMA repair grants.
- Northridge spawned creation of the **California Earthquake Authority (CEA)**.

US Seismic Hazards Research

USGS – United States Geological Survey

National Earthquake Hazard Reduction Program (NEHRP) founded in 1977, under the Earthquake Hazards Reduction Act.

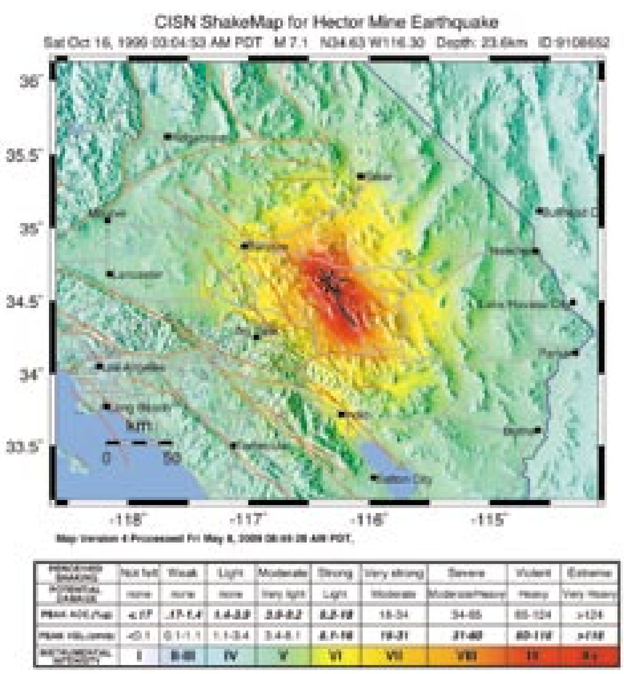
Main goals of the programme are:

1. Develop effective measures for earthquake loss reduction.
2. Promote the adoption of such methods of mitigation.
3. Improve upon the understanding of earthquakes and their effects on communities, buildings, structures and lifelines.

Role of the USGS in NEHRP:

1. Assess seismic hazards.
2. Provide earthquake monitoring and notifications.
3. Conduct targeted research needed to reduce the risk from earthquake hazards nationwide.

There are various ways to demonstrate earthquake "risk". Acceleration is a common method. Different earthquakes emit energy at different frequencies and levels which all affect different buildings in different ways.



An "active fault" is considered one which has moved within a 10,000 year span.

Hazard maps are produced every six years.

Data sources for seismic hazard assessment:

1. Seismicity – insufficient data.
2. Quaternary faults – those which have slipped within the last 1.8 million years and their movements.
3. Geodetics – networks of GPS beacons to measure gradual ground deformation (circa 700 across Western United States).
4. Attenuation relations – relationship between ground shaking and distance from fault. Low frequency shaking travels further and earthquakes tend to be low frequency "heavy".

The last California earthquake of magnitude > 7.0 was the Hector Mine fault slip in 1999, which last moved circa 100,000 years ago.

Shaking levels tend to fall off relatively quickly in California due to the large number of earthquakes and fault lines having broken up the Earth's crust, causing it to become a poor transmitter of seismic waves.

There are no precursory indicators of earthquakes. The only indicators are other shakes, i.e. earthquakes being an indicator of aftershocks.

A "large" number of high "stress drop" events are currently being observed in Southern California.

The NEHRP publishes new building provisions every six years which are used as the foundation for building codes.

There is uncertainty in the scientific community about the magnitude of the New Madrid earthquakes of 1811 and 1812, in the Mid-West USA. The fact that significant shaking was felt a great distance away from the fault may be due to the efficient transmission of shaking by the old rock common in the region.

The USGS produces geological hazard map overlays of seismic activity and scenarios which can be found at:

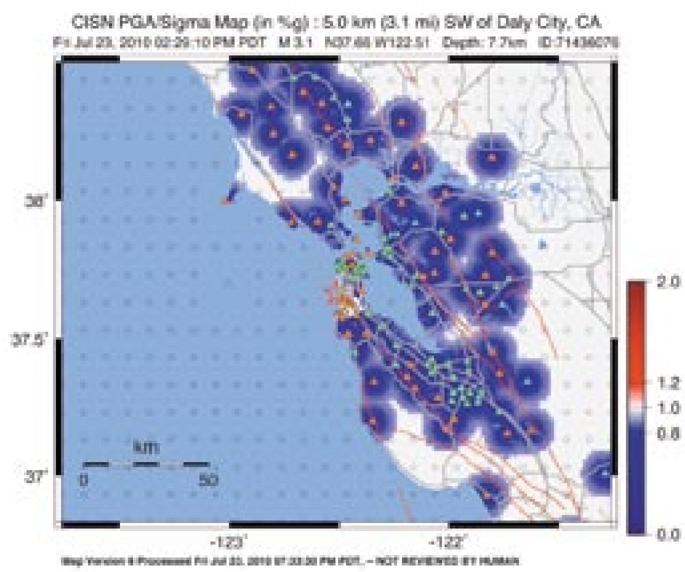
http://earthquake.usgs.gov/hazards/

UCERF Maps are produced in collaboration with the California Geological Survey:

http://pubs.usgs.gov/of/2007/1437/

The cost-benefit of different building codes is being researched and assessed by deriving loss vs. ground motion vulnerability models for varying structure types.

Basin effects: river deposits are composed of relatively loose soils which transmit “waves” more slowly. They still, however, transmit the same energy levels so the shockwaves are amplified. Normal basins can result in two to three times amplification, up to ten times in a “bad scenario”.



The Marina area in San Francisco, for example, is built on rubble from the 1906 Earthquake and is so badly consolidated that estimates place amplification in this area up to 100 times.

Advanced National Seismic System (ANSS)

Part of the USGS that is tasked to provide timely and accurate data for seismic events.

The network comprises a planned 6,000 strong-motion instrument network (there are currently 2,000 in place, while Japan has 10,000) in 26 “at-risk” urban areas with seven regional centres in addition to the national backbone:

http://earthquake.usgs.gov/monitoring/anss/

The ANSS is part of the **California Integrated Seismic Network (CISN)** which is tasked with serving emergency response, engineering and scientific communities:

http://www.cisn.org/

The USGS also produces **Short-Term Hazard Maps** which provide 24 hour forecasts for aftershocks.

These maps are based upon Omori’s Law and the Gutenberg-Richter relation and forecast rupture probabilities, not ground-shaking:

http://earthquake.usgs.gov/earthquakes/step/

Shake Maps produced by the USGS are near real-time maps of shaking intensity and ground motion for earthquakes in the USA. These maps are produced within five to ten minutes of an earthquake:

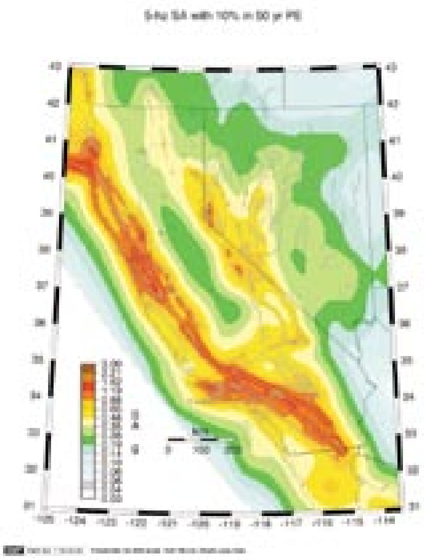
http://earthquake.usgs.gov/earthquakes/shakemap/

A similar global product is provided by the **Prompt Assessment of Global Earthquakes for Response (PAGER)** at:

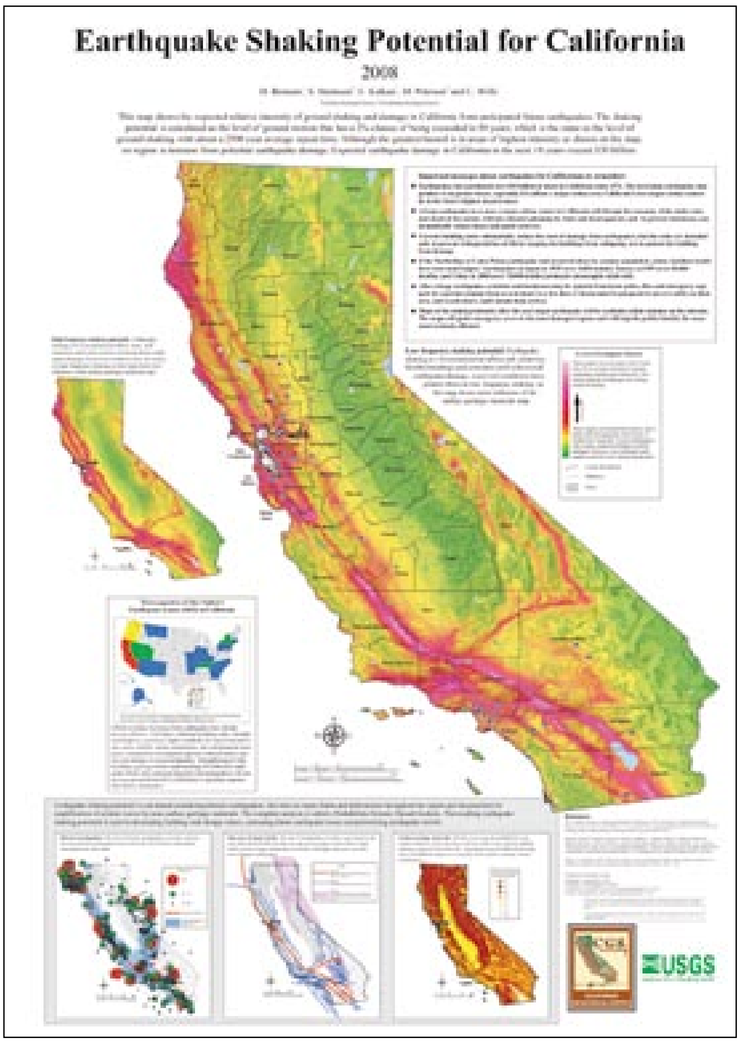
http://earthquake.usgs.gov/earthquakes/pager/

The USGS also provides a customisable notification system:

https://sslearthquake.usgs.gov/ens/



USGS National Seismic Hazard maps display earthquake ground motions for various probability levels across the United States and are applied in seismic provisions of building codes, insurance rate structures, risk assessments, and other public policy.



Issued by the State of California Conservation Department, this map shows the relative intensity of ground shaking and damage in California arising from anticipated future earthquakes.

Pacific Earthquake Engineering Research Centre (PEER)

An interdisciplinary alliance between academic, government, and business entities; PEER's mission is to develop and implement earthquake engineering technology to meet the needs of a range of stakeholders. It benefits from close relationships between its members and the international research community.

The California Seismic Safety Commission recognizes PEER as the foremost earthquake engineering arm.

PEER's scope of activities include earthquake engineering research related to:

1. Vulnerable existing buildings.
2. New buildings (looking into new technology).
3. High performance earthquake simulations.
4. Transportation systems (bridges and railways).
5. Lifeline systems (e.g. power distribution).

The Next Generation Attenuation (NGA) Models

NGA is an estimate of the ground motion and associated uncertainty.

PSHA (Probabilistic Seismic Hazard Analysis) is the rate (or probability) of exceeding various ground motion levels at a site (or a map of sites) given all possible earthquakes.

Traditional data sets to derive attenuation equations are not sufficient. The main reason is due to the "Vs30" factor which is a measure of the make up of soil and rock content within the first 30 metres of the earth. Research is being carried out into:

1. Magnitude scaling – there can only be so much energy released. Earthquakes are theoretically limited.
2. Distance scaling.
3. Effects of different fault movements.
4. Site conditions – soil nonlinearity, which takes into account the Vs30 factor.

PEER is reasonably close to establishing correlation between all the NGA models (only three made it to the current stage of research).


NGA has had a significant effect on earthquake financial loss estimates. In most cases, there were reductions as a result of more information being included.

The most material effect on the insurance and reinsurance market was due to the change to the RMS model (which used the weighted mean of the three NGA in V.9 RMS).

The NGA equations have decreased loss estimates due to lower average ground acceleration.

NGA 2 is to follow, specifically revising the NGA West and looking at NGA East for the first time.

Richmond Field Station

A library dedicated to earthquake study, the **National Information Service for Earthquake Engineering, NISEE**, includes an online catalogue for which users can register at:

http://nisee.berkeley.edu/

UC Berkeley "Shake Table" and research facilities

The PEER Earthquake Shaking Table was the first of its kind, and at 20ft x 20ft is still the largest multidirectional shaking table in the USA.

The shaking table is configured to produce three translational components of motion; vertical and two horizontal plus three rotational components: pitch, roll and yaw.

These six degrees of freedom can be programmed to reproduce any wave forms within the capacities of force, velocity, displacement and frequency.

The shaking table can subject structures, weighing up to 100,000 lbs, to horizontal accelerations of 1.5 G.

The concrete shaking table is heavily reinforced with both traditional reinforcement and post-tensioning tendons.

Two earthquake simulations were presented, involving the study of earthquake impacts on railroad bridges, pictured centre left.

Preparedness

Earthquake Policy in California

California Seismic Safety Commission – CSSC

CSSC's role is to advise the State Governor and California legislature on earthquake policy and to support CalEMA (California Emergency Management Agency) in the implementation of the State's Multi-Hazard Mitigation plan via the Earthquake Loss Reduction Plan:

http://www.seismic.ca.gov/pub/CSSC_2007-02_CELRP.pdf

USA Regional Seismic Risk by Annualised Earthquake Losses

- California – US$ 3.5 billion
- Pacific Northwest – US$ 0.57 billion
- Central – US$ 0.38 billion
- Rocky Mountain Basin and Range – US$ 0.25 billion
- Northeast – US$ 0.25 billion
- Southeast – US$ 0.16 billion
- Hawaii – US$ 0.06 billion
- Alaska – US$ 0.05 billion
- Great Plains – US$ 0.04 billion

All of California is in Zone 3 or 4, with 3 being the second highest risk in all of the USA, yet some officials do not feel that the whole state is at risk. 500 earthquakes a week is not uncommon in California but the majority of these are too small to be felt directly. Each city must have a pre-approved disaster plan in order to qualify for post-event support from FEMA.

California's loss reduction plan is separated into 11 sections ranging from Geosciences to Recovery. The state partnered with Japan in order to produce the documentation:

http://www.seismic.ca.gov/pub/CSSC_2007-02_CELRP.pdf

CSSC produces a guide for Homeowners:

http://www.seismic.ca.gov/pub/CSSC_2005-01_HOG.pdf

and Commercial Property Owners:

http://www.seismic.ca.gov/pub/CSSC_2006-02_COG.pdf in respect of Earthquake safety.

All commercial and homeowners property sales require an Earthquake Hazards Disclosure form. The CEA offers incentives to homeowners who comply with updated seismic retrofit guidelines. Estimates for an average domestic retrofit ranges from US$ 2,000 to US$ 10,000.

State Government law requires engineers to demonstrate any earthquake risk and indicate how it will be mitigated for buildings in a seismically active area. Examples of such statutes are:

Unreinforced Masonry (URM) Law Update

- 1986 State law.
- Cited 26,000 URM buildings in Earthquake Zone 4.
- 18,144 buildings have been retrofitted or demolished as a result. 8,000 of these were in Los Angeles.
- Commercial URM buildings must display warning signs if they have not been retrofitted.

Proposition 13

- "All buildings cannot be subject to tax assessment, if they undergo retrofitting, to remove any financial disincentive to improving earthquake safety".

Major California Seismic Retrofit Projects

- 2,200 CalTrans (California Transit Authority) bridges / overpasses completed.
- Bay Area Rapid Transit (BART) is ongoing at a cost of US$ 1.0 billion.
- San Francisco Public Utilities Commission Water Delivery System is ongoing, at a cost of US$ 4.0 billion.
- PG & E (Pacific Gas & Electric) – dams, pipelines, transmission lines completed at a cost of US$ 2.0 billion.
- UC Berkeley SAFER programme ongoing at a cost of US$ 250 million.
- Hospital Seismic Safety Retrofit programme is ongoing at an annual cost of US$ 10 – 24 billion.

The intention of retrofitting is primarily to reduce loss of life, not to reduce financial damage.

An example of successful earthquake legislation is the Field Act 1933, which mandated structural improvements in public buildings (elementary and secondary schools and community colleges) and requires continuous inspections during construction. 70 schools were damaged in the Long Beach Earthquake but no deaths occurred. The Field Act does not apply to state colleges and universities; they are responsible for carrying out their own inspections.

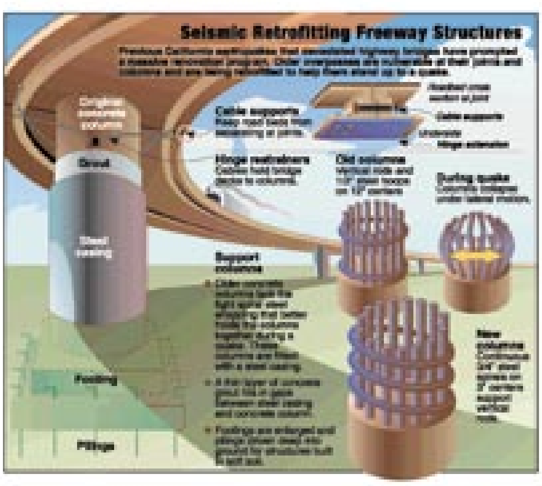
California's wildfire evacuation plans are based on a two-dimensional fire front which wouldn't be appropriate for Fire Following Earthquake where conditions for ignition would be perfect for multiple ignitions. Fire Following is considered to be a very large risk and potentially catastrophic.

Impacts on agriculture of the April 2010 El Mayor-Cucapah Earthquake in Baja California were changes to water channels and damage to drainage that ruined 140,000 acres of crops. Over 180 miles of canals were damaged and cattle farming was at risk due to lack of water.

A US$ 11.0 billion water bond is being discussed in California in order to improve water distribution state-wide.

The Sacramento River delta levees are constructed of compacted soil; a small earthquake nearby could result in catastrophic levee failures.

The San Francisco Bay Area proved resilient to disruption when a short portion of the Bay Bridge collapsed in the 1989 Loma Prieta Earthquake.



Two ferries were contracted from Washington within 48 hours and coped well.

Loss of market share due to a perception of damage is a large risk to businesses. Electronics industries in Silicon Valley would be a good example of this risk.

California is susceptible to tsunamis and strong currents as part of the aftermath of an earthquake. Ports are heavily exposed to these events and tsunamis constitute a major concern.

The Great ShakeOut

USGS collaborates with a large number of US authorities to run the Great ShakeOut drill as part of the Earthquake Country Alliance.

More than 6.9 million Californians participated in the 2009 California ShakeOut which was aimed at raising earthquake awareness and preparedness.

The event was based upon a 7.8 Magnitude earthquake along the southern San Andreas Fault causing US$ 213 billion of damages (based upon the FEMA HAZUS model) and 1,800 deaths.

See: http://www.fema.gov/plan/prevent/hazus/

and http://pubs.usgs.gov/of/2008/1150/

Housing Performance Issues

There are current concerns over housing performance Issues.

Typically 50% of earthquake losses arise from housing, of which 90% are building losses as distinct from contents damage.

However, historically, people in California have not generally prepared their homes well for earthquake safety. There is a pervasive view that ... "It won't happen to me" ... or that ... "FEMA will be there to help me."

2
Risk Transfer

Local Insurance

California Earthquake Authority (CEA)

After the Northridge Earthquake, in 1994, it became mandatory for insurers operating in California to offer earthquake insurance every two years. This requirement created a shortage of insurers willing to offer homeowners' insurance within the State of California.

As a response to this shortage, the CEA was formed, in 1996, and operates along the lines of a mutual insurer, but has a public board. It underwrites only residential earthquake insurance. The CEA does not insure commercial or industrial properties and is not subject to federal income tax. Californian licensed insurance carriers are required to participate on the following basis, although some insurance companies, including Travelers and Fireman's Fund, have decided to offer earthquake cover on their own rather than join the CEA.

Before an earthquake, participating insurers underwrite the policy, issue it and collect premiums which are remitted to the CEA. After an earthquake, the policyholder reports the claim to carrier, who handles the claim with their catastrophe adjusters and disburses all claims payments. The CEA thereafter reimburses the original participating carrier 100% plus a handling fee.

The CEA is the largest provider of residential earthquake insurance in the USA and represents 78% of all California residential earthquake insurance policies. The only reason that the CEA will refuse to accept a risk is if the policyholder has prior structural earthquake damage which is unrepaired.

The companies that join the CEA have to offer earthquake insurance but the policy holder does not have to purchase it.

The CEA aggregate claims paying capacity is currently about US$ 9.7 billion. Because the CEA operates as a mutual, in the event of an extremely large earthquake that causes extensive damage the CEA may not be able to meet its claims obligations and subsequent payout will be on a pro-rata basis.

In the event that the CEA could not continue in business, member companies would have to begin writing earthquake coverage again.

It is estimated that only 8% of residents in California buy earthquake protection.

Buildings that were constructed between the years of 1960 – 1979 are charged the highest rate by the CEA because these were the years of construction that were the poorest for earthquake resistance.

Underwriting

Exposure to actual earthquake damage depends upon the following key factors, under the acronym "TAPS":

T: Type of property (design susceptibility to damage residential, commercial or industrial).

A: Age of property (design, construction, seismic retrofitting / safety features).

P: Proximity to known faults.

S: Soil type (from hard rock to the propensity to liquefaction on in-fill).

Commercial take up rate of earthquake insurance is circa 10%. Residential take up rate of earthquake insurance is estimated to be even lower. Typical earthquake deductibles are 10 – 15% of value.

Events within a 168 hour window are considered a single event.

A hypothetical Californian earthquake reinsurance portfolio would, ideally, be spread broadly across the state. It might comprise a book of residential or commercial coverage, or both, given that a high percentage of residential properties are for multi-family occupation – apartments and condominiums.

Coverage for earthquakes in some commercial and industrial properties may require specific expertise. Risk management is key. For direct and facultative coverage, if the risk is stand alone, the PML to premium multiple determines profitability and requires superior modelling, systems and distribution.

As regards reinsurance, if earthquake exposure is consolidated with other reinsurances, a higher PML to premium multiple may be possible, but marginal contribution to reinsurer capital requirements for multizone programmes may be limited. If measures other than risk adjusted return is used, a higher multiple may be possible and some privately owned companies have been known to discount modelled output for net retained losses.

Claims

Earthquake Claims Adjusting

Earthquake Claims Adjusters are required to have Earthquake Accreditation under the California Insurance Code.

Homes in California are subject to 50 – 60 inspections during construction. In comparison, for example, Iowa homes (Mid-West) are subject to none and other states are subject to four or five inspections on average.

Standard checklists are used to assist in the review process of earthquake claims.

Most buildings will deform on just 1 inch of lateral movement.

A crack / movement of more than 1/8 inch in a home's foundation requires an engineer review.

90% of Californian homes are built on concrete slabs.

Clues are available in cracks as to whether damage predates a seismic event, or is a genuine earthquake claim:

1. Look for contamination, debris, impressions or pulling on other materials e.g. under-carpet crack in floor.
2. If impression in the underlay, then crack has been there a while. Any attempt at previous patching over should be visible and suggest an older crack.
3. Cracks across tiles or flooring are likely to be sudden, especially if concrete underneath cracked in same place.
4. Any rusting of exposed steel in reinforced concrete suggests age.
5. Shifting of walls when base remains static are likely to be earthquake damage.
6. Distortion in framework leads to sticking doorframes and multiple cracked windows.
7. Multiple "X" cracks around window frames suggest sudden lateral acceleration.

Attic inspection should provide further clues, especially if structural wooden connections have become misaligned or separated.

Similarly, inspection of crawlspace may uncover misaligned ducting and plumbing.

If stucco wall cracks run across multiple panels continuously, that is likely to suggest sudden lateral movement. Over time, cracks would form within a panel, or in each of multiple panels, but not across multiple panels.

The burden of proof is on the adjuster – if a viable alternative cause cannot be found, claims have to be associated with earthquake damage.

Concrete is susceptible to cracking over longer periods with distinct patterns.

Most cracks are superficial but are frequently reported as earthquake damage – settling, shrinkage and swelling of wood frames can easily cause cracks emanating from corners.

Earthquake cracks in walls are usually “X” shaped.

Horizontal cracks in buildings are most likely from settling and not earth movement.

Old damage on attic trusses can be seen to have aged on the interior.

Attic and crawlspace damage gathers dust easily – a useful guide to age.

Legal

A Legal Guide to Earthquakes in California

Most affected insurance: residential property, commercial property, commercial general liability and professional liability (engineers, contractors etc.).

Standard exclusions on the CEA policy form:

1. Fire or explosion.
2. Water damage resulting from flood, rain, surface water, tsunami, tidal water or spray.
3. Water below the surface that exerts pressure on or seeps or leaks through a building (including liquefaction). Except: water from interior sources, municipal lines.
4. Pollution.
5. Earth movement, unless caused by earthquake and the loss manifests within a year (aimed at landslides).
6. Power failure.

There is currently a considerable level of negative equity on mortgages.

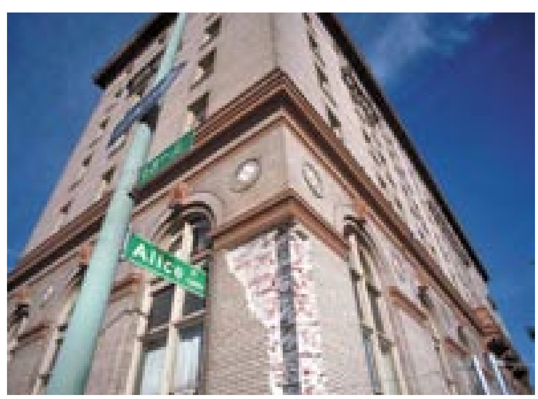
NB: Fire Following is not covered by the CEA and nothing in Section 10088 (Earthquake exclusion) exempts an insurer from its obligation under a fire insurance policy to cover the losses of a fire which is caused by or follows an earthquake.

California courts use the doctrine of Efficient Proximate Cause (EPC) to determine included and excluded losses. “Efficient” meaning the predominate or most important cause which is not necessarily the “moving” or “triggering” cause.

Example of EPC found in *Brian Chuchua’s Jeep, Inc v. Farmers Ins. Co* whereby the insured’s gasoline tank lines were ruptured by an earthquake causing pollution. The insured had earthquake cover with an absolute pollution exclusion but the court ruled that the pollution was covered as the earthquake was the EPC.

Types of liability claim following a seismic event:

1. Bad faith claims against loss adjusters. (Seen after Northridge, when some adjusters kept losses below deductibles).
2. Pollution Liability on petrochemical companies. Strict liability applies.
3. Construction defect claims – water intrusion if building skin insufficiently flexible or building codes breached.
4. Contractors – not meeting design standards.



Models

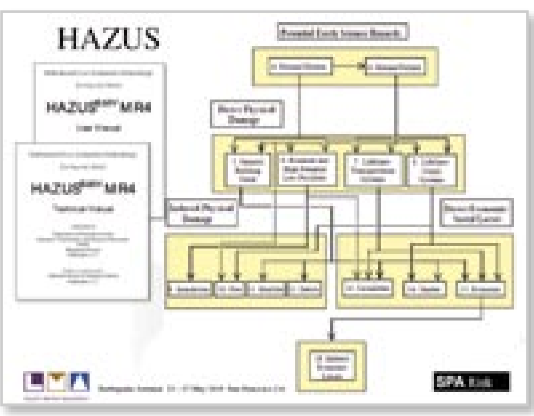
The first loss estimation software emerged in the late 1960s / early 1970s. Key developers were:

- Travelers Insurance for USA hurricane and earthquake (Friedman).
- Steinbrugge (earthquake).
- Wiggins, Petak et al (USA wind, earthquake and other hazards).
- Scawthorn (Japan earthquake and SF Fire Following in 1980s).

Commercial models emerged in the 1980s:

- **AIR** Applied Insurance Research (Karen Clark).
- **EQE** International (Scawthorn, Yanev, Fraser).
- **RMS** Risk Management Solutions (Shah, Dong).

There was a slow uptake by the insurance industry until 1989 (Hurricane Hugo and Loma Prieta Earthquake) which was accelerating by 1992 – 1994 (Hurricane Andrew and Northridge Earthquake).



The first real-time loss estimation was during the Northridge Earthquake. Thereafter, FEMA initiated the development of **HAZUS**, the open-source software model:

- HAZUS Earthquake 1993 – 1998
- HAZUS Flood 1998 – 2003
- HAZUS Hurricane (1998 ongoing)

HAZUS has been emulated in Turkey, Taiwan and analogous software has been developed in Turkey, New Zealand and Australia. China is currently undertaking development of HAZUS-like software.

HAZUS is available free, contains its own broad level buildings inventory (which can be updated with an insurance portfolio) and its vulnerability functions can be changed. HAZUS can “generate a ground up loss”, although it has more uncertainty than a proprietary model. Its probabilistic loss estimate is only approximate and its current Fire Following model is limited in value.

Other models or initiatives:

The **Alliance for Global Open Risk Analysis (AGORA)** was founded in 2007 to encourage the use of Open Data with improved methods and tools. AGORA was derived from a risk management process and can be used as the engine to produce a model using a variety of software such as Open Seismic Hazard Analysis and Opensees (Open Source Structural Earthquake Engineering Software).

ROVER (Rapid Observation of Vulnerability and Estimation of Risk) was designed for FEMA and represents end-to-end data building software to collect seismic attributes of buildings. It is available from a paper form to a smart phone application. It can collect information such as: location, name, use, photographic imaging as well as additional information such as soil, falling hazard and a risk scoring system. Its data can be incorporated in the USGS shake maps, so that when an earthquake occurs the affected region can be seen on a map with basic predictions of damage – it also employs a traffic light system (RAG) to indicate severity.

By way of illustration, AIR is currently offering modelling capabilities for the following:

Risk Assessment
Data quality and improvement
Loss analysis
Risk transfer analysis
Securitization
Modelling Outsourcing
Renewal periods
Broker placements
Aggregates
Process Improvement
Managing data
System performance
Training
Quality controls
Documentation and standards
Model Development
Life, Personal Accident and Disability
New regions – China
New capabilities – Vulnerability enhancements
Underwriting Enhancement
Underwriting metrics
Concentration management
Deterministic analysis
Pricing Accuracy
Zonal or territory definition
Ratemaking studies
Deductible studies
Mitigation credits
Regulatory support
Portfolio Management
Capital allocation and reserving
Optimization and growth
Rating agency

Some of the models include a time dependency feature. Even within a model some regions can include time dependency whereas others don't (based on how often earthquakes occur in the region and the accuracy of the science in the region). If time dependency is included, the event rates will alter after an event has occurred which can cause issues from an underwriting point of view (e.g. pricing will be based on what has just happened and not on a long term burning cost).

A range of users employ such models: primary insurers, reinsurers, capital markets, rating agencies, regulators and relief pools.

The **Global Earthquake Model (GEM)** was initiated in 2008. Soil distribution for the whole world has been mapped by the USGS and they have contributed to GEM – the Global Earthquake Model, whose mission is: "GEM will add sustainable social and economic development by providing free, reliable and uniform information on seismic risk and the impact of earthquakes around the world".

See: www.globalquakemodel.org

Observations from Models Demonstrated

Numerous insurance-specific catastrophe models now exist, either commercially produced and marketed or developed in-house. They aim to generate loss estimates using demonstrable science, e.g. NGA equations. Models are available for multiple regions and multiple perils. Models either have a stochastic or historical event set or both. The models either use an event set or a simulated years approach.

The models take into account a range of factors e.g. the soil type and the effect of basins, and can include elements such as Fire Following and sprinkler leakage.

The main modelling companies also produce a range of tools:

- Underwriting desktop modelling
- Portfolio modelling and optimisation
- Reinsurance purchasing
- Data validation against industry exposures
- Post event loss estimation
- Reporting tools
- Accumulation management

Great Expectations

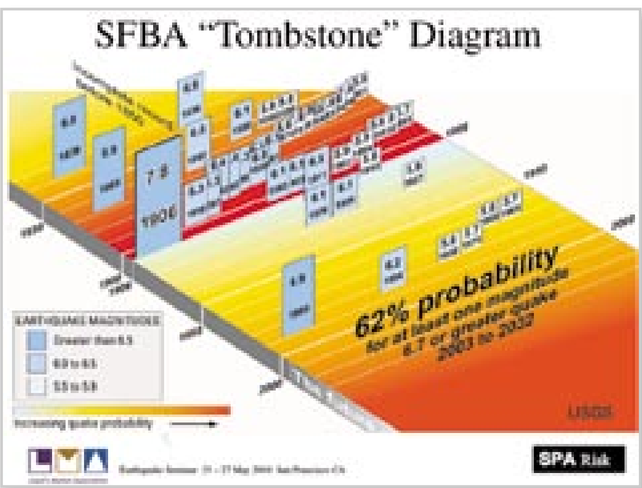
3

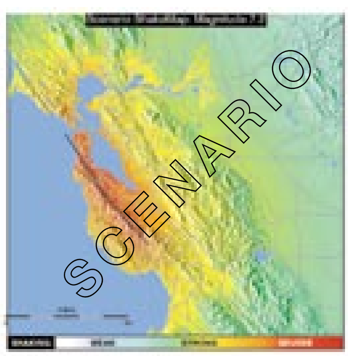
Loss Expectancy – the Numbers

A repeat of the 1906 San Francisco Earthquake today would produce an estimated total economic loss of the order of US$ 150 billion – including property damage, business interruption, payments for death and injury and infrastructure losses (utilities, roads, bridges and transportation systems). Not all economic damage will be insured. Estimates vary but, depending on commercial business interruption coverage, between 50% and 65% of this total might be insured, which in turn will be extensively reinsured.

The current “prediction” of the Southern San Andreas Fault “participating” in an earthquake of magnitude 6.7 or greater within the next 30 years is about 60%. All the major faults in California are past their “return period”.

These forecasts are detailed in:
http://pubs.usgs.gov/fs/2008/3027





Earthquake planning scenario shake map for an M 7.2 event on the San Andreas Fault.

Next “Big One” in San Francisco

- 62% chance of a 7.5 Magnitude or greater earthquake in the Bay Area by 2030.
- 7,000 to 18,000 buildings destroyed from shake and Fire Following.
- Total value of San Francisco private buildings is US$ 53.3 billion.
- Total San Francisco Bay Area property exposure estimated at US$ 104.2 billion.

San Francisco Scenario damage estimates vary with the seismic release of energy (for shaking damage only, not including Fire Following or infrastructure):

San Andreas M 7.9 event
Building damage: US$ 29.0 billion
Total Economic Loss: US$ 39.7 billion

San Andreas M 7.2 event
Building damage: US$ 18.6 billion
Total Economic Loss: US$ 25.7 billion

San Andreas M 6.5 event
Building damage: US$ 11.8 billion
Total Economic Loss: US$ 16.4 billion

Hayward M 6.9 event
Building damage: US$ 8.5 billion
Total Economic Loss: US$ 12.1 billion

The **Applied Technology Council (ATC)** is a non-profit, tax-exempt corporation established in 1973 through the efforts of the Structural Engineers Association of California. ATC’s mission is to develop and promote state-of-the-art, user-friendly engineering resources and applications for use in mitigating the effects of natural and other hazards on the built environment.

In ATC’s view ... “An earthquake with PGA (Peak Ground Acceleration) of 0.7 (highest experienced in Kobe and Northridge and highest that would be expected in most earthquakes) would cause all but the most well engineered buildings to collapse.”

Even from space, smoke generated by brush fires in Southern California is clearly visible.

Special Considerations for San Francisco

San Francisco is built on a combination of rock and reclaimed land, which is susceptible at low levels to liquefaction and basin effects (especially in the Marina district).

Great Expectations

Fire Following

In the **ShakeOut** scenario, the estimated 1,600 ignitions predicted could completely overwhelm the local Fire Department.

San Francisco Fire Fighting Capabilities

The **San Francisco Fire Department (SFFD)** was founded on 25 December, 1849 and pioneered several innovations in fire fighting such as the ladder truck.

Fire services were overwhelmed in 1906 as water pressure failed, gas mains ruptured and ignited, cisterns proved inadequate and major hydrants and water supplies were so badly damaged as to be of little value.

Fires in the Marina district of San Francisco, following the 1989 Loma Prieta Earthquake, reminded citizens of the ever-present danger of conflagration, especially as minimal separation between buildings is a feature of many fashionable urban areas.

Conflagrations from brands and burning debris can be so difficult to contain, especially if such post-earthquake fires occur when the ferocious Santa Ana and Diablo winds blow in Southern and Northern California respectively.

As with retrofitting, similar considerations apply to Fire Following earthquake exposures. Sprinklers, drenchers and adequate fire fighting facilities are, in many senses, easier and cheaper to install and maintain but they depend upon adequate water resources and systems that will operate after a major earthquake shock.

Fire Following is, therefore, a very significant issue – 90% of residential buildings are wood frame.

SFFD constructed the **Auxiliary Water Supply System (AWSS)** after the city ran dry during the Fire Following the 1906 Earthquake. A proposal to expand the AWSS was voted on in June 2010.

High pressure is held in the Twin Peaks reservoir, with lower tanks at Ashbury and Jones. Total capacity of the reservoir and the two tanks is 11.5m gallons.

Saltwater pumping stations are available in San Francisco bay. Two fireboats can add saltwater to the system by pumping water from fireboat manifolds. Fireboats add 3,600 gallons per minute.

Neighbourhood Emergency Response Teams comprise volunteer auxiliaries.

The fireboat *Guardian* was purchased with the help of two generous donors from the Marina district, shortly after the Loma Prieta Earthquake in 1989, in recognition of the contribution made by the fireboat *Phoenix* in controlling the Fire Following in the Marina district. *Guardian* had previously been in service in Vancouver BC, Canada.

Appendix

Alcatraz

At the start of the Earthquake Seminar, all attendees embarked on a visit to Alcatraz, one of the most famous landmarks of San Francisco.

The aim of the visit was twofold:

- From an excellent vantage point, the seminar attendees were able to orientate themselves, first hand, with the topography of the San Francisco Bay Area and gain a greater insight into the risk in its own locality as a region renowned for its fault lines and the high potential for earthquake and Fire Following earthquake.

- To provide the attendees with their first real opportunity to network together as a peer group which was regarded as a key part of the learning process.

Alcatraz, the former US State Penitentiary, affectionately known as "The Rock" was once home to the United States' most notorious criminals. It has the ability to captivate its visitors through the sheer impressiveness of its history, and, in particular, by the fact that, officially, no prisoner has ever succeeded in escaping from the island alive.

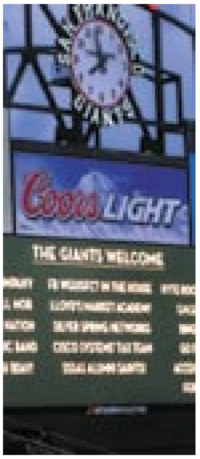
Famous Alcatraz inmates included George "Machine Gun" Kelly, Al Capone and Robert Stroud the "Birdman of Alcatraz". However, being famous did not mean any privileges were gained, and inmates had to abide by a strict set of rules and regulations which included good conduct.

The authentic audio presentation, narrated by former prison wardens and prisoners, provided a haunting insight into what life on The Rock was really like.

Programme
Academic Outline and Presenters

	Topic / Module	Speaker
Monday 24 May 2010 **Fundamentals of Earthquake Risk**	Earthquake Risk Management – Overview	Professor Charles Scawthorn and Professor Keith Porter (SPA Risk LLC)
	Global and California Seismotectonics	Charles Scawthorn
	Earthquake Hazards and their Analysis	Charles Scawthorn and Keith Porter
	Earthquakes and Damage	Charles Scawthorn and Keith Porter
	Insurance Aspects (California History, Coverages, Underwriting Practice)	Lindsey Frase (Willis) and Tim Richison (CFO – California Earthquake Authority)
	Dinner speaker: Presentation on San Francisco Earthquake and Fire, based on his novel “1906”.	Author James Dalessandro
Tuesday 25 May 2010 **Earthquake Risk Management**	Overview US Earthquake Community	Charles Scawthorn
	US Seismic Hazards Research	Dr Lucy Jones (USGS)
	Earthquake Policy in California	Richard McCarthy (Seismic Safety Comm.)
	Legal Issues	Bill Enger (Wilson Elser)
	Earthquake Claims Adjusting	Gene Hensley (Vale Training West)
	San Francisco and its Risks	Charles Scawthorn
	Tour San Francisco Fire Department Jones Street Tank	Captain Tom Doudiet (SFFD)
Wednesday 26 May 2010 **Field trip – University of California, Berkeley Campus**	Overview of PEER; NGA Programme; Housing and Wood Building Performance in CA; UC Berkeley retrofit programme	Dr Yousef Bozorgnia, Professor Stephen Mahin and Professor Mary Comerio (PEER Faculty)
	Walking Tour of UC Berkeley Campus Retrofits	Mary Comerio
	UC Berkeley Seismology laboratory	Dr Peggy Hellweg
	Richmond Field Station – NISEE (National Information Service for Earthquake Engineering) and Test Facilities (Shake Table)	Stephen Mahin
Thursday 27 May 2010 **Earthquake Modelling**	Earthquake Models – Overview	Charles Scawthorn and Keith Porter
	Modeller 1 Demonstration	Kate Stillwell (EQECAT)
	Modeller 2 Demonstration	Paolo Bazzurro (AIR)

Attendees



Name	Lloyd's Managing Agency
Frank Chu	AEGIS
Michaela Bradshaw	Amlin Bermuda
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Sophie Buckingham	Amlin
Lauren O'Rourke	Argo
Nick Pozzebon	Ascot
William Steinberg	Beazley
Sam Ashard	Catlin
Jamie Martin	Catlin
Steve Jackson	Chaucer
Matt Town	Hardy
Peter Parsons	Hiscox
Carl Diprose	Kiln
Alex Dugand	Kiln
Graham Clark	Liberty
Neil Elliott	Liberty
Lewis Wicks	Talbot
Richard Shiel	Travelers

Facilitators

in addition to speakers and presenters

Debbie Babcock	Katie School of Insurance and Financial Services / Illinois State University
Tony Joseph	Lloyd's America Inc.
Terry Hayday	Lloyd's Market Association

Links to Other Materials

Links to the LMA Website

A 331 page pdf version of all the PowerPoint slides that were shown during the seminar is available on the LMA website:

www.lmalloyds.com

To access this information please:

- Click on the **Publications** section on the horizontal menu on the Homepage
- Click on **Other LMA Publications** on the drop-down menu
- Look under the heading **Reports on Seminars and Conferences**
- Select **Lloyd's Market Academy Earthquake Seminar**

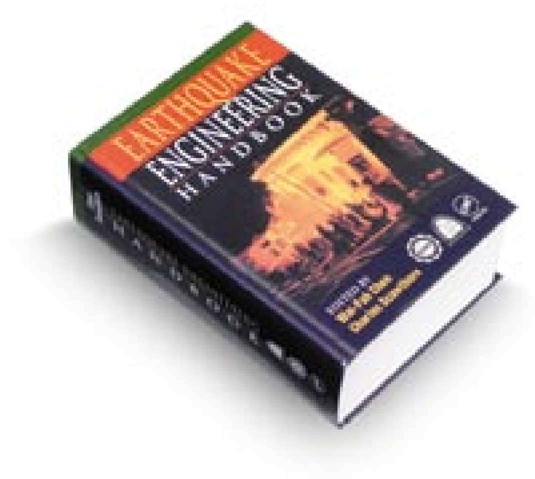
Other useful websites are shown opposite.

Key Source

The primary **textbook** (selected chapters) for the entire seminar is:

Chen, W.-F., and Scawthorn, C. (2003) "**Earthquake Engineering Handbook**"

CRC Press. 1,512pp. Co-published by the International Conference of Building Officials and co-sponsored by the National Council of the Structural Engineers Association, Boca Raton, Fla.



Key Websites

Association of Bay Area Governments (ABAG)
http://quake.abag.ca.gov/faults/

California Earthquake Authority (CEA)
http://www.earthquakeauthority.com/

CEA / UCERF 3
http://www.earthquakeauthority.com%5CuserFiles%5Cfile%5C06-25-2009_GB_Attachments%5CAI9_B.pdf

California Emergency Management Agency (CalEMA)
http://www.seismic.ca.gov/pub/CSSC_2007-02_CELRP.pdf

California Geological Survey
http://www.conservation.ca.gov/CGS/Pages/Index.aspx

California Integrated Seismic Network (CISN)
http://www.cisn.org/

California Seismic Safety Commission (CSSC)
http://www.seismic.ca.gov/pub/CSSC_2005-01_HOG.pdf

CSSC / Commercial
http://www.seismic.ca.gov/pub/CSSC_2006-02_COG.pdf

Earthquake Engineering Research Institute
http://www.eeri.org/site/

Global Earthquake Model (GEM)
www.globalquakemodel.org

Governor's Office of Emergency Services – California
http://www.oes.ca.gov/

HAZUS (FEMA)
http://www.fema.gov/plan/prevent/hazus/index.shtm

Lloyd's Market Association (LMA)
www.lmalloyds.com

National Information Service for Earthquake Engineering (NISEE)
http://nisee.berkeley.edu/

Preparedness
http://www.prepare.org/home/

Quake Information
http://quakeinfo.org/

San Francisco Office of Emergency Services and Homeland Security
http://sanfrancisco.about.com/od/livinginsanfrancisc1/a/emergencylist.htm

Seismological Society of America
http://www.seismosoc.org/

Southern California Earthquake Center
http://www.scec.org/

SPA Risk LLC (Scawthorn Porter Associates)
http://www.sparisk.com/

Structural Engineers Association of Northern California
http://www.seaonc.org/

University of California, Berkeley
http://berkeley.edu/

US Department of Homeland Security, Federal Emergency Management Agency
http://www.fema.gov/

US Geological Survey: USGS
http://www.usgs.gov/

USGS / ANSS
http://earthquake.usgs.gov/monitoring/anss/

USGS / Hazards
http://earthquake.usgs.gov/hazards/

USGS / Notification
https://sslearthquake.usgs.gov/ens/

USGS / Pager
http://earthquake.usgs.gov/earthquakes/pager/

USGS / Shake Map
http://earthquake.usgs.gov/earthquakes/shakemap/

USGS / Step
http://earthquake.usgs.gov/earthquakes/step/

USGS / UCERF
http://pubs.usgs.gov/of/2007/1437/

Endpiece

Derived from on the spot sketches and painted on a 5ft x 10ft window blind salvaged from a wrecked building, William A. Coulter's *San Francisco Fire, 1906* shows the destruction of downtown San Francisco. It now hangs in the Headquarters of the San Francisco Fire Department.

Over 4,000 troops saw service during the 1906 emergency. They aided the fire department in dynamiting buildings in the path of the fires, and became responsible for feeding, sheltering and clothing the tens of thousands of displaced residents of the city.

Front and back covers: details from USGS National Seismic Hazard (NSH) ratio maps, comparing earthquake ground motion probabilities for California over a period of time.

Page 1: detail from NSH map showing ground motion probability levels for California.

Inside front cover: NASA image taken by astronauts aboard the International Space Station.

Opposite: NASA image of San Francisco, captured from the space shuttle *Endeavour* by imaging radar. Densely populated urban areas appear pink.

Picture Credits
Seminar slides: courtesy SPA Risk LLC. Many of the images in this report appeared in the seminar slide presentations: Hearst Memorial Mining Building retrofit photos, p 11, W. Godden and J. Kelly, Earthquake Engineering Online Archive; pp 22, 23, California Seismic Safety Commission.
Earthquake damage photos: courtesy US Geological Survey.
Shake maps and hazard maps: courtesy US Geological Survey.
1906 Earthquake photos, pp 1, 6, 24, 30, 34: courtesy US Library of Congress.
Additional photography: Debbie Babcock, Sophie Buckingham, Penny Jones, Lauren O'Rourke.

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