PRINCIPLES OF EARTH SCIENCE

EARTHQUAKES & SEISMIC HAZARD

Prof. Gillian R. Foulger

Recommended reading

Books

Bolt, Bruce, *Earthquakes*, W.H. Freeman, 4th edition, ISBN: 071673396X, 320 pp, 1999.
Stein, S. and M. Wysession, Introduction to Seismology, Earthquakes, and Earth Structure, Blackwell Publishing, 2003.
Foulger, G.R., Plates vs. Plumes: a Geological Controversy, Wiley-Blackwell, ISBN: 978-1-4051-6148-0, 2010

Web sites

http://earthquake.usgs.gov/
http://quake.usgs.gov/research/parkfield/index.html
http://www.info-world.com/egypt/
http://www.earth.northwestern.edu/people/seth/Disdef/Teachnm/
http://www.earth.northwestern.edu/people/seth/research/eqrec.html
http://earthobservatory.nasa.gov/NaturalHazards/
http://www.mantleplumes.org/

Introduction

It cannot have escaped the notice of many that there has been a terrible death toll due to earthquakes in recent years. In 2004 some 230,000 people were killed by the Indian Ocean boxing day tsunami, and ~ 315,000 were killed in Haiti in 2010, by a relatively small earthquake which struck weakly built buildings in the capital city, Port-au-Prince. Most recently, over 20,000 people were killed in the extremely well-prepared nation of Japan by the 11th March 2011 Tohoku earthquake, which produced the most damaging tsunami ever to raze human habitations.

What is the outlook for the future? In past centuries there have been relatively few earthquakes that have caused more than a few thousand deaths, and the broader economic impact has been relatively small because humans have traditionally obtained the resources necessary for their food, clothing, shelter and medicine mostly locally. However, the picture is very different today and is changing rapidly as the number of people living in urban areas skyrockets. To make matters worse, a large percentage of the global urban population lives in earthquake-prone areas because humans tend to be coastal dwellers (traditionally for communications and food resources) and this is where most of the world's seismically active subduction zones are. A global economy means that the collapse of a key world economical unit e.g., Tokyo would result in widespread hardship throughout the world. This change has come about over a time period much shorter than the typical inter-event period for large and great earthquakes. That period is one to a few centuries, whereas megacities and the global economy have developed over just the last few decades. Future great earthquakes are thus likely to be much more damaging to humans than past ones.

Earthquakes were first understood on a scientific basis following the devastating 1906 San Francisco, California earthquake. The geologist H.F. Reid studied the ground breaks that extended for hundreds of kilometers across the countryside. He interpreted them as movement on a geological fault, and concluded that sudden slip on that fault had caused the earthquake. This was the first time that the cause of large tectonic earthquakes had been understood. It is now known that faults can be normal, thrust and strike slip, depending on their orientation and the sense of motion in earthquakes. Earthquakes generate P- (primary), S- (secondary) and surface waves, the latter being the strongest and causing by far the most damage.

Most, though not all earthquakes, occur along plate boundaries. Those that occur on transform and subduction type boundaries are the largest and most dangerous. Thus, the “Pacific Ring of Fire” is plagued by killer earthquakes. A catastrophe at a centre of world economic importance e.g., Tokyo, Seattle or San Francisco could be very damaging for the world and not just the local population. The other major earthquake belt on Earth extends from the Alps eastward through the Himalaya.

Environmental effects of earthquakes

Several distinct geological effects of damaging earthquakes may be identified. Ground shaking is strongest during passage of the S- and surface waves and can cause structures to collapse. It is strongest where the substratum is weakest. Liquefaction is a process by which shaking of the ground mobilizes saturated soil and causes it to flow like a fluid. Structures on top of wet ground may be stable before an earthquake but keel over during it. Underground installations such as petrol tanks may rise to the surface during liquefaction and agricultural land may be damaged by the mud volcanoes that occur as a consequence. Ground shaking and cracking may result in landslides which can completely destroy installations and change the layout of the land, leading to confusion over property boundaries. Ground rupturing may occur, but is usually only important in the immediate vicinity of the epicentre. People do not need to fear being swallowed by cracks. This only happens in Indiana Jones movies!

Long sequences of aftershocks follow in the wake of large earthquakes and may cause additional damage to structures weakened by the main shock. They continue for decades following a “great” (i.e. larger than magnitude 9) earthquake. Changes in the water table and the land level may result in flooding, and ground deformation may be permanent and result in installations having to be relocated. The 2004 Boxing Day tsunami in the Indian Ocean, which killed over 230,000 people, and the 2011 Tohoku, Japan tsunami, have highlighted to the world the danger of this remarkable earthquake-induced phenomenon. Tsunamis are much less common in the Indian ocean than in the Pacific ocean, and the reason the death toll was so high was because there was then no tsunami early warning system in place in the Indian ocean as was, at the time, fully installed in the Pacific ocean.

The 2004 Boxing Day tsunami in the Indian Ocean occurred as a result of a great earthquake in the underwater subduction zone there. It had a thrust mechanism and the landward side was thrust over the seaward side by up to several metres along a fault hundreds of km long. This huge displacement of the sea floor set up a train of waves that excited the whole Indian ocean basin. Tsunamis have much longer wavelengths than ordinary waves in the ocean.

They travel much faster and when they approach land their amplitude is magnified enormously so they can attain heights of several tens of metres. They comprise not just one wave but a whole train.

Examples of the phenomena listed above are associated with the 1989 Loma Prieta (California) earthquake, which will be studied in the practical class, the 1964 Alaska earthquake, the 1964 Niigata, Japan earthquake, the 2002 Denali, Alaska earthquake, the 1811 New Madrid earthquakes, the 1995 Kobe, Japan earthquake, the 2010 Haiti earthquake and the 2011 Tohoku earthquake and tsunami. Students should study the latter earthquake and tsunami by exploring the voluminous material available on the world wide web.

Effects on human infrastructure

Deaths and damage to human infrastructure (in contrast to environmental effects) can come from several sources. Damage to critical structures such as dams and nuclear power stations is potentially damaging on a huge scale and it is the responsibility of government to safeguard against such disasters. Buildings collapsing is an obvious danger, and there is much truth in the motto “earthquakes don’t kill – buildings do”. Particularly unfortunate may be damage to vital emergency services and community buildings such as hospitals, fire stations and schools, and it is particularly important to make such buildings safe in earthquake-prone areas. Flying objects may do a lot of damage, raining down on people fleeing from shaking buildings and blocking roads so emergency vehicles cannot access fires and injured people. The outbreak of fires can do more damage than the actual earthquake. San Francisco was virtually completely destroyed by fire after the 1906 earthquake. Kobe, Japan suffered great damage by fires that raged out of control in the aftermath of the 1995 earthquake, when debris in the streets prevented access by fire fighting services. The severing of communications e.g., roads and bridges can also hamper crisis management, rescue and recovery, as can the destruction of industrial infrastructure. In recent years, the main tolls of death and destruction have come from tsunamis, which devastate coastal regions where the majority of the world’s population lives.

Earthquake hazard mitigation

Seismologists, engineers, government and individual citizens can all contribute to earthquake hazard mitigation. Seismologists make earthquake forecasts, using the past history of earthquake activity to estimate the probability of future large events occurring within various time windows. This at least gives engineers some numbers on which to base building codes, and although forecasts have been little tested to date, anything that results in buildings being made to higher standards in earthquake-prone regions must be a step in the right direction. Tsunamis take several hours to cross ocean basins and warnings can be issued to coastal areas well in advance of arrival of the waves. A system is in place in the Pacific ocean and has saved thousands of lives over the last few decades. The construction of a similar system in the Indian ocean was urgently undertaken after the 2004 Boxing Day tsunami.

Engineers can contribute to hazard mitigation by designing building codes and earthquake proofing buildings. Techniques include earthquake-proof building design, diagonal bracing, retrofitting and incorporating flexible sections in oil and gas pipelines where they cross fault lines. This measure prevented the Alaska oil pipeline from breaking during the 2004 magnitude 7.9 Denali earthquake.

PRINCIPLES OF EARTH SCIENCE

EARTHQUAKES & SEISMIC HAZARD PRACTICAL

THE LOMA PRIETA EARTHQUAKE, CALIFORNIA, 1989

1. You are provided with a map of the San Francisco bay area, showing faults of the San Andreas system (Figure 1). Felt intensities, estimated on the Mercalli scale, and reported by citizens, are also shown.

As part of your self-study, familiarize yourself with the Mercalli scale.

The coordinates of the Loma Prieta earthquake epicentre are 37˚ N 01.98', 121˚ W 53.14'. Plot this epicentre on Figure 1. Note 1: There are 60 minutes in each degree.

2. The segment of the San Andreas fault that slipped in the Loma Prieta earthquake was 40 km long and it had a strike of N 40˚ W. Assuming that the earthquake epicenter lay in the centre, plot the segment that slipped on Figure 1.

3. Contour the felt intensities at intervals of 1 intensity unit. Note 2: Your contour lines should fall between the dots, and not pass through them, *i.e.*, draw lines that separate the 6's from the 7's and the 7' from the 8's etc. Note 3: Do not "invent data" by continuing your contour lines for long distances outside the area where there are observations.

Does the intensity decrease smoothly with distance?

4. Describing scientific results accurately and without bias is a rare but vital scientific skill. Practice it by writing two or three sentences describing your results.

What is the explanation for the strange observation that the intensity of ground shaking was greatest a long way away from the epicenter? San Francisco bay used to be much larger than it is today. This is because hydraulic mining during the 19th Century gold rush blasted vast quantities of sediment out of river banks, and this was washed down into the bay by rivers, causing it to partially silt up. Much of the land around the edges of the bay, that is now built on, is thus comprised of poorly consolidated muds.

Write two or three sentences proposing an explanation for the strong ground shaking a long way away from the epicentre.

Briefly write down how would you test your theory using independent observations.

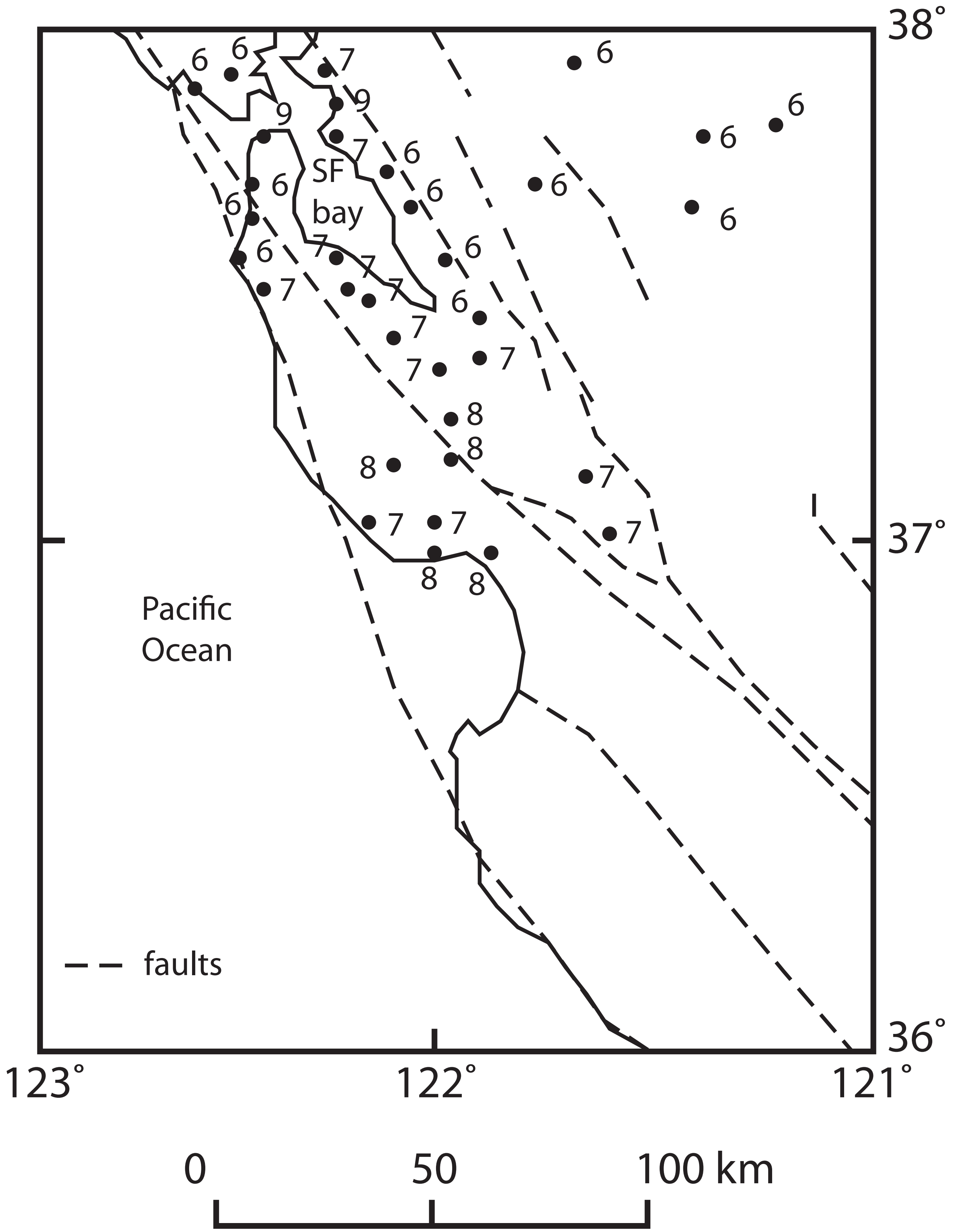

Figure 1. Map of the San Francisco bay area showing tectonic faults and intensities of ground shaking during the 1989 Mw 6.9 Loma Prieta earthquake.