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Earthquakes of 1999 - Issues for Catastrophe Risk Management

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Abstract

The year 1999 saw an extraordinary number of large damaging earthquakes. Observations derived from these events include:

- The earthquakes came as surprises, yet shouldn't have
- Ground shaking caused 90% of building and equipment damage, with reinforced concrete frames being especially highly variable
- Soil failures (liquefaction, landslides, and settlement) caused extensive damage
- Business interruption can dominate the losses
- Response was poorly managed, and recovery particularly onerous, but shouldn't have been.

A result of several of these events has been the movement toward national catastrophe pools. However, these pools have enormous obstacles to overcome if they are to be effective, including creation of a sustainable financial structure and achieving acceptable quality of building construction and land use planning. An 'ideal" earthquake insurance system is offered as a means of achieving these goals.

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Introduction

The purpose of this paper is to provide a framework for identification and development of mitigation measures intended to manage and reduce global catastrophe risk. The year 1999 saw an extraordinary number of damaging earthquakes, Table 1, which had a number of features in common, and highlighted a number of issues and opportunities for catastrophe risk management. This paper first briefly discusses each event in turn, highlighting particular features of the event, with the purpose of identifying certain commonalties. In addition to the earthquakes of 1999, comparison is made with two other earthquakes – the 1994 Northridge and 1995 Kobe events. Commonalties between these events are explored in order to identify the major contributors to risk. This identification serves as a platform from which major mitigation initiatives can be identified. Implementation of mitigation measures involves regional and culturally specific aspects, which are briefly discussed.

Earthquakes of 1999

This section briefly discusses each of the major earthquakes of 1999.

Armenia, Colombia (Jan. 25 – M 6.2)

This event occurred at 13:19 local time within a system of intraplate faults parallel to the Andes mountains trending northeast. The system is characterized by strike-slip faults, and can generate strong shallow earthquakes (Asfura and Flores, 1999). Most of the structural damage was concentrated in areas of deep layers of volcanic ash or man-made non-engineered fills, with neighborhood estimates of damage ranging to 95%. Most of the damage was to one-and two-story houses and apartment buildings of four to five stories, Figure 1. Approximately 1,200 persons were killed.

Marmara, Turkey (Aug. 17 – M 7.4)

The M_w 7.4 Marmara (Kocaeli, or Izmit) earthquake occurred at 3:10 am local time 17 August 1999 on the east-west trending north strand of the North Anatolian Fault Zone (NAFZ), about 100 km. SE of Istanbul. The 125 km long fault and high damage area follows or is close to the south shore of Izmit Bay, and has predominantly 2.2 m right lateral displacement, from Adapazari in the east to Yalova in the west. Significant vertical fault scarps of as much as 2 m occur at several locations. Peak ground accelerations of approximately 0.4g were recorded near the fault, and liquefaction and subsidence were observed on the shores of Izmit Bay and Lake Sapanca. Several million persons live in the Izmit region, which has experienced rapid growth and heavy industrialization in the last two decades. The predominant building type is mid-rise non-ductile RC frames with hollow clay tile infill, thousands of which collapsed in a ‘pancake’ mode. About 17,000 were killed, with estimates of population requiring short to long-term shelter range from 200,000 to 600,000. Lifelines generally performed well, with the exception of underground piping in the heavily affected areas, where major damage is reported. Electric power, highways, rail and telephone were generally functional within several days following the earthquake, and the Izmit Water Project (the regional water supply and transmission system) was only lightly damaged and fully functional. Fires occurred in a number of collapsed buildings but were generally confined to building of origin. Two fires broke out at the Tupras oil refinery, which burned for several days (Scawthorn, 2000).

This was the most destructive earthquake of 1999, and there are a number of aspects of this earthquake deserving comment:

- The earthquake came as surprise, yet shouldn't have. Figure 2 shows the recent rupture history of the causative fault (North Anatolian Fault Zone, NAFZ). This and historic patterns very clearly demonstrates a characteristic earthquake pattern, which was recognized over 20 years ago (Toksoz et al, 1979), as well as more recently (Stein et al, 1997).
- Ground shaking caused 90% of building and equipment damage, with reinforced concrete frames being especially highly vulnerable.
- Soil failures (liquefaction, landslides, and settlement) caused extensive damage
- Emergency esponse was delayed, and the enormous numbers of collapsed buildings precluded effective search and rescue.

Athens, Greece (Sept. 7 – M 5.9)

This event occurred at15:00 local time, affecting primarily the Northern Athens District of Menidi (also called Aharnes). It was felt strongly in Thrace-Macedoni and Metamorphosi (Figure 3). Confirmed deaths are 124, with approximately 100,000 homeless. Total costs for the event are estimated at $600 Million, and unemployment is expected to rise to 30,000 in the affected areas.

The majority of the residential housing in this area of Athens consists of 3-to 5-story reinforced concrete apartments. The ground floor is usually left open to act as a garage. This particular area of Athens has seen a large amount of (initially) unauthorized development and construction of houses by their owners. The level of engineering design and control that has been exercised is highly variable. There have been a number of collapses, which have resulted in loss of one or two stories, and at least four complete collapses. In addition, there were many structures, which were badly damaged. This was the result of clear breeches in good design practice coupled with poor detailing especially of steel confinement. The failures observed were as a result of the following:

- Short column effects

- Anisometric stiffness, resulting in torsional behaviour
- Pounding of adjacent structures Poor arrangement of the lateral load-resisting system
- Lack of adequate confinement to the major load resisting elements

Chichi, Taiwan (Sept. 21, - M 7.6)

The ChiChi earthquake at 1:47 a.m. on September 21, 1999. The epicenter was approximately 7 km NW of Chichi, a small town bordering a mountainous resort area, located 155 km from Taipei, the capital. The duration of severe ground shaking was about 40 seconds. The earthquake was felt over the entire island. In the 5 days following the earthquake, there were many aftershocks, several from M6.0 to M6.8. This earthquake is of particular importance for a number of reasons including the extraordinary number of strong motion records obtained, and because of its impact on the high-tech facilities that are a crucial part of the supply chain to the worldwide computer manufacturing industry. Business interruption in these facilities has repercussions for major computer companies in Silicon Valley and elsewhere.

Well over 10,000 buildings collapsed or were severely damaged. The collapsed buildings were predominately of reinforced concrete framing, with infill masonry walls or reinforced concrete walls, and ranged from older, smaller buildings to modern high-rises. At distances more than about 5 km from the fault line, it was repeatedly observed that the older buildings performed well, but many of the modern structures over six stories tall performed poorly. This can be attributed to faulty design and construction, and improper enforcement of seismic design provisions in the building code - even though the building code used in Taiwan is comparable to those used in Japan and in California.

Hsinchu is located about 110 km from the epicenter and is the site of the Science Based Industrial Park, a major development where about 30 companies provide a significant percentage of the world’s semiconductor manufacturing and silicon processing. Even though the facilities were a long distance away from the epicenter, there was still a major business interruption consequence from this earthquake for this key industry. The overwhelming problem caused by the earthquake was loss of electrical power. Almost all of the Science Park was down for several days, resulting in business interruption costs of about $50 million to $100 million per day. Earthquake damage to distant 345 kV transmission towers and a switching station made it impossible for the park to receive power from the usual steady supply from the South of Taiwan. Power was slowly restored to major users in the area by rationing residential and small commercial customers in other parts of the country, including Taipei. Some facilities were able to maintain emergency power through the use of generators with varying success. One wafer fabrication company sustained a large loss when the generators burnt up after running continuously for 40 hours after the earthquake. With loss of the standby power, this facility went completely black, and lost power to fans that maintain the clean room environment. The large business interruption costs due to this power failure clearly demonstrate the need to consider the risk not just to the facility, but also to the surrounding infrastructure. The ground shaking intensity in the Science Park area was low, with ground accelerations of less than 0.15g. As such, damage to buildings in the Science Park was limited to minor breakage of windows and small cracks in concrete walls. Some facilities sustained partial failure of raised floors and dropped ceilings. Had the earthquake ground motion been more intense, the business interruption as a result of structural failure would have been worse. The buildings in the Science Park can be categorized according to age: mid-80s, late 80s to early 90s, and mid-to-late 90s. There are significant differences between the building codes for these three periods. Heavy concrete was used in most of the buildings, some with and some without special shear walls. Some buildings, mainly those that are newer and taller, were built with structural steel. With more intense shaking, there could have been widespread business interruption caused by structural damage to the mid-to-late 80s and early 90s buildings.

Comparative Analysis

The earthquakes of 1999 briefly reviewed above, and two other major earthquakes of the 1990’s, have a significant number of commonalties, which are briefly compared in Table 2. What emerges is:

- All these areas are regions of high active seismicity
- In most of the events, reinforced concrete building collapse is the major cause of deaths and loss. Exceptions were the Kobe event, where numerous reinforced concrete buildings collapsed but the traditional Japanese wooden house was also a major contributor, and the Northridge event, where wood house damage was not a killer, but was a major source of financial loss.
- Soft soils played a major factor in the Armenia, Marmara and Kobe events
- Pre-event, active earthquake risk mitigation via (a) microzonation of poor soils, (b) retrofitting of high-risk structures, and (c) a national or regional proactive earthquake insurance scheme, was largely lacking.
- Post-event, retrofitting of structures has increased and, in general, public earthquake insurance is created or enhanced.

Catastrophe Risk Management

As noted in the previous section, post-event most of the affected regions see increased mitigation, and the creation or enhancement of a public earthquake insurance system. Table 3 summarizes the three major public earthquake insurance systems currently in existence, in California, Japan and New Zealand. The Japanese system existed prior to the Kobe earthquake, but had policy limits and modest market penetration such that it provided only limited protection. California was afforded significant protection prior to the Northridge event (note the relatively large insurance payments), but had to create a public Earthquake Authority after the Northridge event, due to the revealed inability of the private sector to insure a very large California earthquake. New Zealand's system has been in existence for quite some time, but has not seen a major test (but is carefully managed, and can probably meet a test). As Table 3 indicates, only the New Zealand EQC links insurance with an active mitigation program. Two other national natural hazards schemes, not summarized here but worth noting, are the US national flood insurance program (NFIP) and France's Caisse Centrale de Reassurance (CCR) – both of these strongly link mitigation to insurance, and are government funded.

Turkey, Taiwan and Mexico are currently studying options for financing public earthquake or natural hazards insurance schemes. All three of these countries sustained damaging earthquakes in 1999, so that their consideration of insurance schemes is no coincidence. Other countries, whether or they have recently sustained damaging earthquakes, should also probably be studying how to mount an effective insurance scheme. These countries, in no particular order, include Italy, Greece, Bulgaria, Romania, Iran, selected Central Asian states, parts of Canada, China, Peru, Chile, and various Caribbean states.

Consideration of the commonalties among the several earthquakes reviewed above, and the several public earthquake insurance systems currently in place, leads to the following observations, for an 'ideal' earthquake insurance scheme:

- Earthquake insurance needs to be mandatory in selected high risk regions, otherwise a form of Gresham's Law[2] penalizes responsible property owners.

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[2] in economics, the principle that when depreciated or debased currency is in circulation along with coins that have full value in terms of precious metal, the latter tend to disappear. In other words, "bad money drives out good".

- Earthquake insurance needs to be strongly linked to mitigation, via:
  - High risk areas need to be accurately identified – this mandates a regional microzonation or soils and fault mapping program. In California, Special Studies Zones about 500 m. each side of known faults have been in existence since the 1970's. If a building is planned within these areas, special studies are required so that the building is not placed directly on an active fault. The wisdom of this was clear in Turkey, where many buildings directly on faults collapsed. The analogy of this mapping exists in the US NFIP, where NFIP insurance premiums are used to pay for flood mapping (Scawthorn, 1999)
  - High risk structures, such as reinforced concrete buildings, need to be carefully designed and constructed for earthquake. The Marmara region's rapid development for example prevented effective code enforcement, even though Turkish academic earthquake knowledge is quite high level. Again, the US NFIP offers an effective model – communities cannot get flood insurance unless they demonstrate effective land use and building code enforcement (NFIP employs a *Community Rating System* for this purpose).
  - Existing high-risk structures need to be strengthened, as a condition of getting earthquake insurance. Since earthquake insurance is mandatory, enforcement requires that the buildings be vacated if not strengthened within a reasonable period.
- Earthquake insurance needs to have high credibility of payment. Therefore, it needs to have some linkage to government funding. However, to avoid corruption or laxity of enforcement, the earthquake agency needs to be semi-autonomous and independent. New Zealand's EQC is perhaps a good model for this. The publicly linked insurance authority may also need to derive the ability to promote mitigation via (among other means) the police power of the state.

Concluding Remarks

The year 1999 saw an extraordinary number of damaging earthquakes. Unless proactive national mitigation schemes are initiated, however, future years will see similar catastrophic earthquakes. The damaging events of 1999 have initiated examination of how national earthquake insurance schemes might be developed. Unless these national earthquake insurance schemes are strongly linked with an integrated program of earthquake risk identification, quantification and mitigation, the insurance schemes will only prolong the problem, and ultimately fail. This paper has drawn some insights from existing programs and based on this, laid out some (certainly not all) elements of what an 'ideal' earthquake insurance scheme should be. No scheme currently in place for earthquake meets these criteria, although New Zealand's EQC comes closes, and the US NFIP and French CCR offer excellent flood-related analogies.

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Table 1 – Earthquakes of 1999

Earthquake	Date	Magnitude	Fatalities
Armenia, Colombia	Jan. 25	M6.2	~1,200
Western Washington	July 2	M5.9	nil
Marmara, Turkey	Aug. 17	M7.4	~17,000
Athens, Greece	Sept. 7	M5.9	~125
Chichi, Taiwan	Sept. 21	M7.6	2,333
Puerto Escondido, Mexico	Sept. 30	M7.5	30
Mojave Desert, California	Oct. 16	M7.1	nil
Duzce, Turkey	Nov. 12	M7.2	~600

Table 2 – Comparative Analysis

	Armenia, Colombia	Marmara, Turkey	Athens, Greece	Chichi, Taiwan	Northridge 1994 (M 6.7)	Kobe 1995 (M 7.1)
Deaths	~1,200	~17,000	~125	2,333	~67	~6,000
Approx. $ Loss (USD Billions)	?	$10	$0.6	?	$40	$100
Primary Loss Contributor	Concrete Building collapse	Concrete Building collapse	Concrete Building collapse	Concrete Building collapse	Wood house damage	Wood house collapse
Other Loss Contributors	Soft soils	Industrial, Faulting Subsidence		Industrial, Faulting		Lifelines / Industrial Soft Soils
Insurance Paid ($ Billions)	?	~ $1	?	?	$14	< $5
Pre-event Mitigation	?	nil	?	?	active	nil
Post-event Mitigation	?	active	?	active	active	active
Pre-event Public Insurance ?	?	No (Minor Private Sector)	?	No	No (Private sector)	Limited
Post-event Public Insurance ?	?	Under Study		Under Study	CEA created	Enhanced

Table 3 – Public Earthquake Insurance Schemes

(after Guy Carpenter, 1999)

	USA	Japan	New Zealand
	Calif. Earthquake Authority CEA	**Japan Earthquake Reinsurance Company (JER)**	**Earthquake Commission EQC**
Created Year	1996, as a result of 1994 Northridge earthquake	1966	1994 (replaced prior EQ and War Dmg. Commission, 1944)
Covered Perils	EQ for residences	Earthquake, tsunami and volcano, for residences	Earthquake, tsunami, landslides, volcanic eruption and geothermal activity for personal property
Reinsurance / Primary	Primary	Reinsurance	Primary
Purchase of Reinsurance Primary Carriers?	N/A	Mandatory	N/A
Mitigation	No	No	Awareness campaigns and strict code enforcement
Government Funded	No	No	No

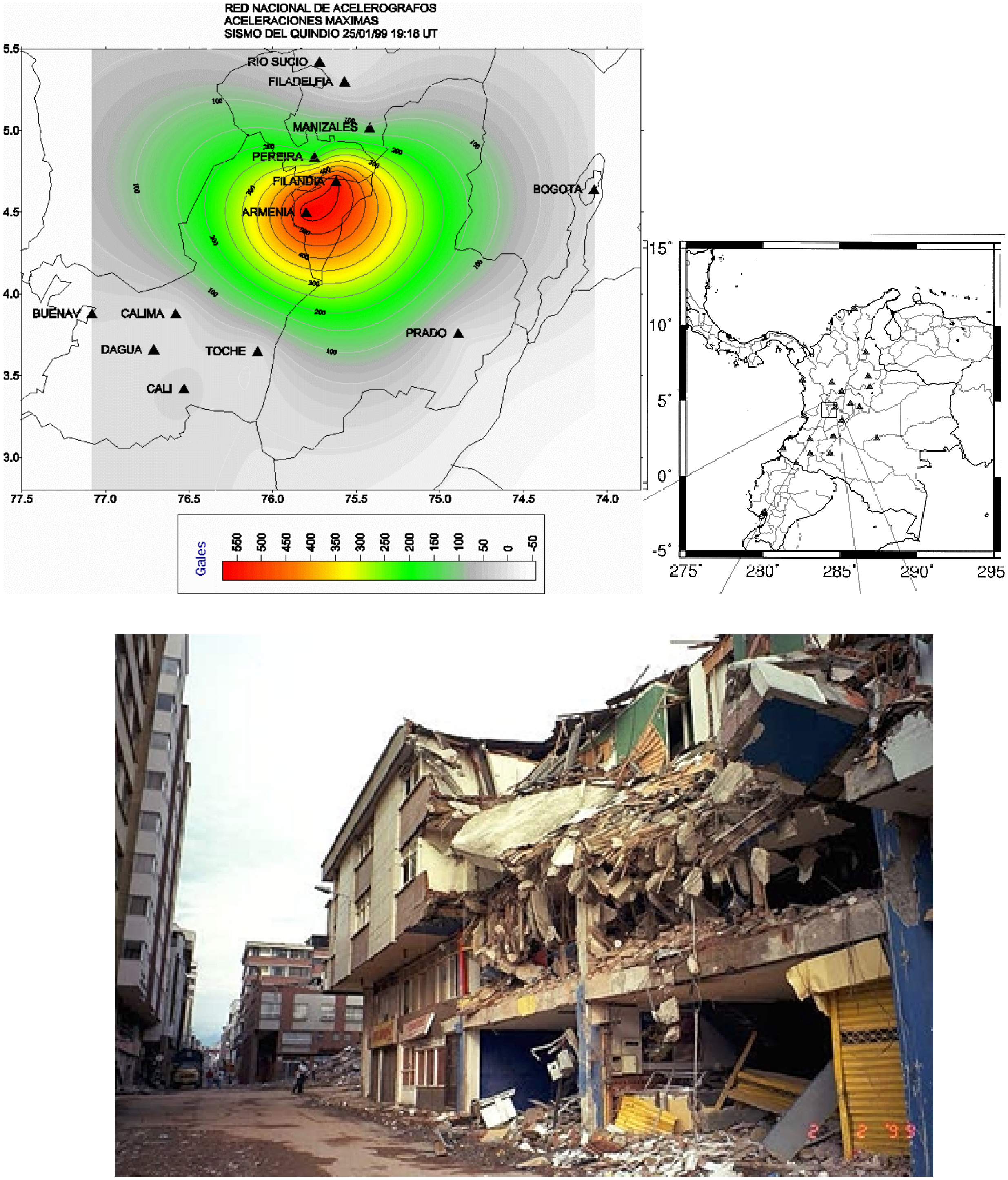

Figure 1 – Armenia Colombia earthquake – accelerations and example of damage.

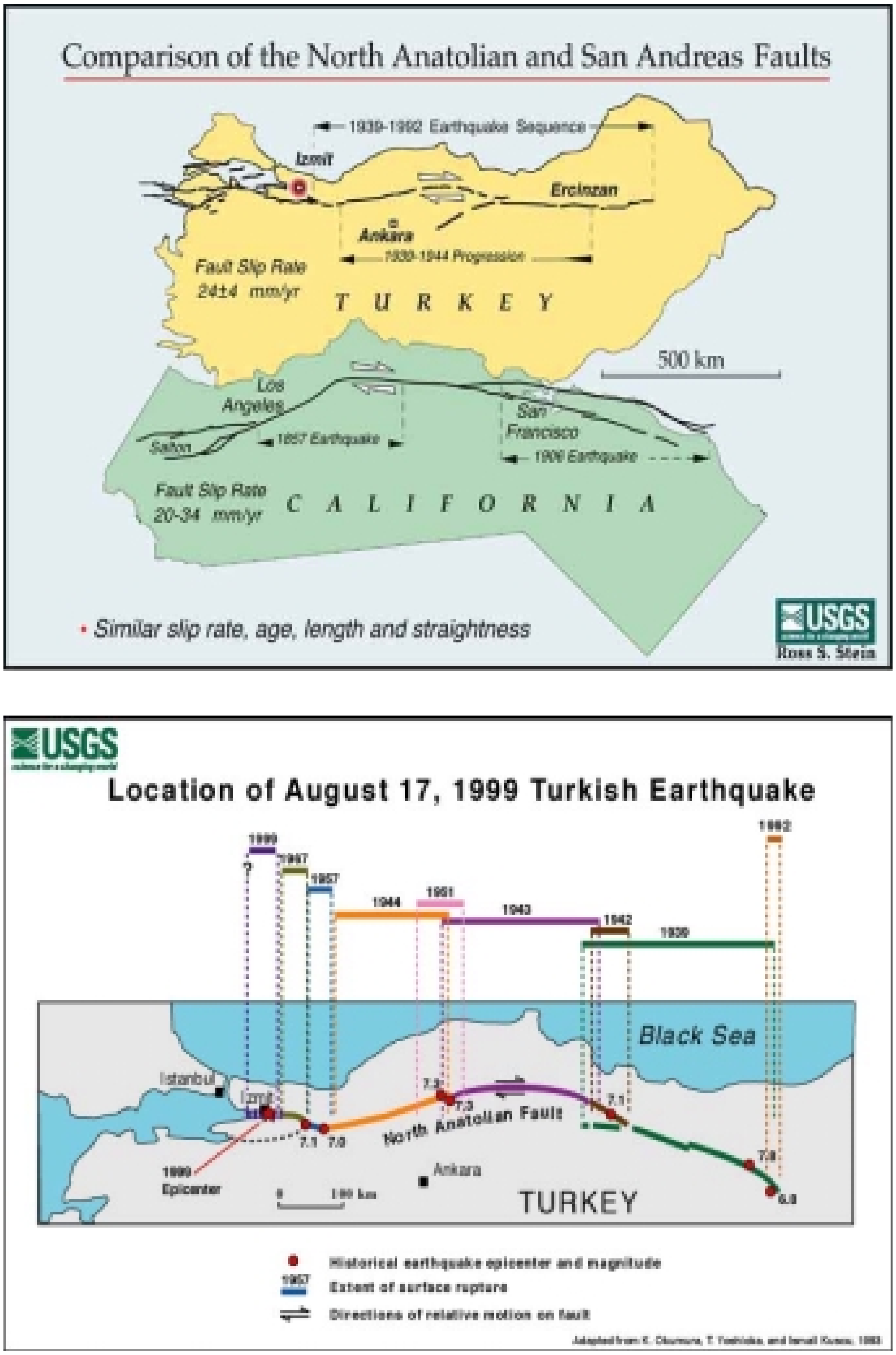

Figure 2 (a) Comparison of the North Anatolian and San Andreas faults, and (b) recent history of ruptures, NAFZ. (figures, courtesy USGS).

Figure 3 – examples of damage, Marmara Turkey earthquake.

Figure 3 Location of Athens Earthquake , and typical damage
(http://www.itsak.gr/report.html)

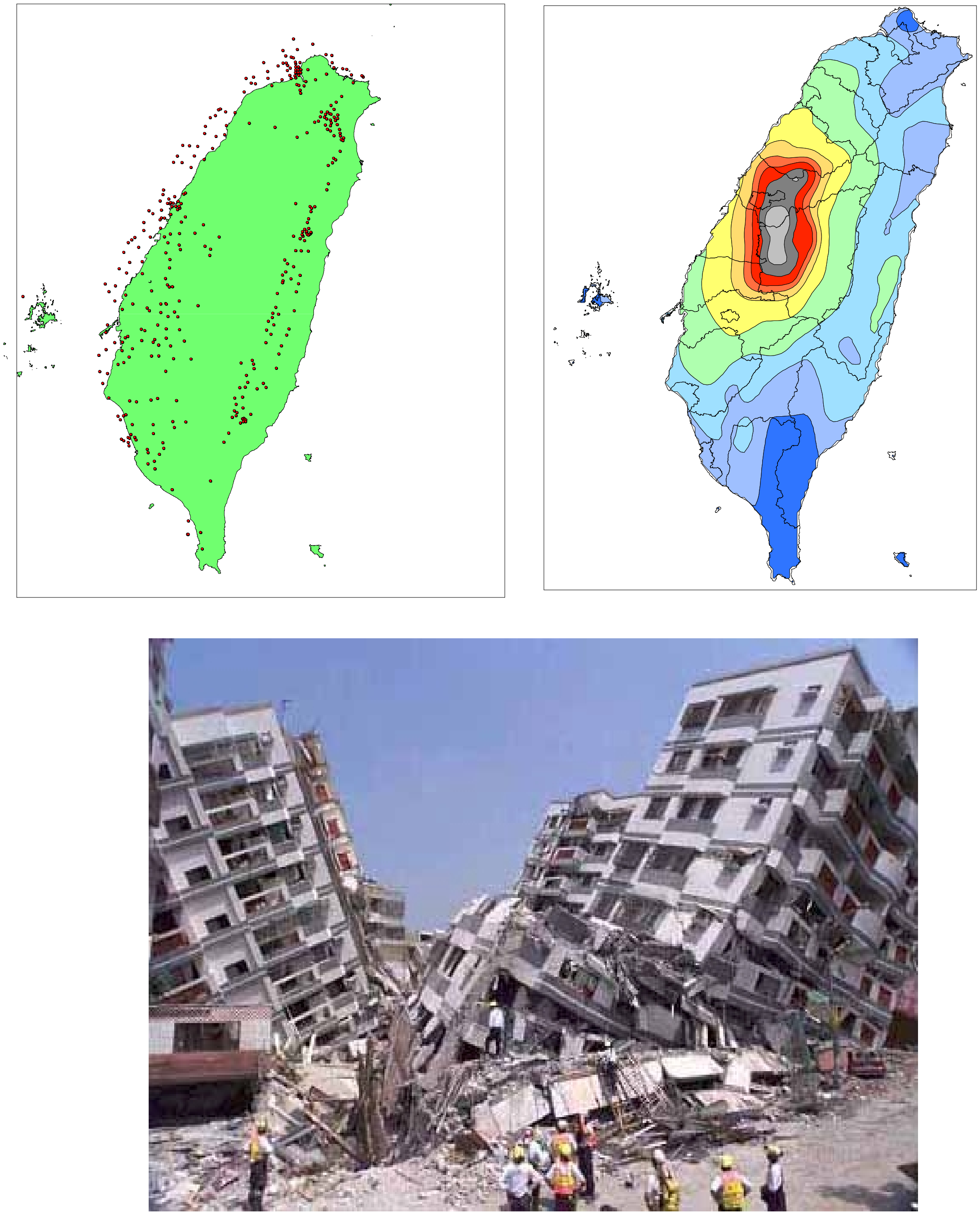

Figure 4 – Strong Motion instrument sites, isoseismal intensity patterns, and example of building damage, Taiwan earthquake.