Session No. 7

Course Title: Earthquake Hazard and Emergency Management

Session Title: Nature and Effects of Earthquake Hazards

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Time: 120 minutes

Objectives:

7.1. Describe the nature of earthquake hazards, and especially, how these hazards differ from other hazards.

7.2. Describe the effects of earthquakes upon infrastructure (buildings, lifelines, etc.).

7.3. What are the general effects of earthquakes upon people and what is the nature of the casualties from earthquakes?

7.4. Describe the general effects of earthquakes upon the economy and the nature of earthquake losses.

Scope:

In this session, the students will learn about the general nature of earthquake hazards, specifically how earthquake hazards differ from other natural hazards, and the special challenges they pose. This section addresses a variety of effects of earthquakes and specifically the factors that produce damage and losses. The session covers the effects on people, the economy, and infrastructure. This section is closely linked with Section 9 in which mitigation will be discussed. This section is important because it provides a better understanding of earthquake hazards, and fosters improved communication with scientists, engineers, policy makers, the public, etc.

Readings:

Suggested student reading:

Commission on Engineering and Technical Systems. 1990. “The Economic Consequences of a Catastrophic Earthquake,” *Proceedings of a Forum, August 1 and 2, 1990, Overview of Economic Research on Earthquake Consequences*, National Academies Press.

http://books.nap.edu/catalog/2027.html.

Shah, Haresh. 1995. "Natural Hazards Observer, an Invited Comment." *Scientific Profiles of 'The Big One,'* November 1995. available from: http://www.colorado.edu/hazards/dr/dr189.htm.l

Required instructor reading:

Commission on Engineering and Technical Systems. 1990. "The Economic Consequences of a Catastrophic Earthquake," *Proceedings of a Forum, August 1 and 2, 1990, Overview of Economic Research on Earthquake Consequences*, National Academies Press. http://books.nap.edu/catalog/2027.html.

Shah, Haresh. 1995. "Natural Hazards Observer, an Invited Comment," *Scientific Profiles of 'The Big One,'* November 1995. available from: http://www.colorado.edu/hazards/dr/dr189.html.

Sugimoto, M. 2000. *Earthquake Preparedness for EOS370 Students*. available from http://fumbling.com/academic/eq-talk.html.

Meliti, D. 1999. *Disasters by Design: A Reassessment of Natural Hazards in the United State.s* Joseph Henry Press. Chapter 3, pp. 65-104.

Electronic visuals included: [*see Session 7 – Electronic Visuals.ppt*]

7.1 Moderate Failure Severe Disruption (Oakland Bay Bridge)
7.2 Time Required for Lifeline Restoration
7.3 Influence of geology upon shaking levels during the 1989 LPE
7.4 Stronger shaking on softer sites
7.5 Influence of soft sediments
7.6 Ground shakes erratically
7.7 Liquefaction damages infrastructure
7.8 Liquefaction and Lateral Spreading at Port
7.9 Effect of 1995 Kobe Japan EQ on Trade at Port of Kobe
7.10 Soil being densified to avoid liquefaction
7.11 Slope failure during 1989 LPE
7.12 Lateral ground shifting due to fault
7.13 Breech of dam during 1999 Chi-Chi EQ
7.14 Broken gas line due to ground movements during 1994 Northridge Earthquake
7.15 Death or injury can be caused by contents
7.16 Collapse of Cypress Freeway during 1989 LPE
7.17 Effect of 1923 Japan EQ on that economy

Handouts Included:

Handout 7.1: Homework Assignment 7.1

General Requirements:

Some of the information presented in this section is technical in nature and additional background study will be required by instructors with non-scientific backgrounds. Accordingly, the instructor should thoroughly review the recommended reading material for this session. In some cases, the instructor may wish to enlist the aid of an outside expert, such as faculty from a geological sciences or engineering department, to teach this material. While some instructors may elect to reduce the technical content presented, the concepts are important for a complete understanding of earthquakes and the nature of the hazard they pose. Therefore, the instructor should cover as much of this material as feasible, and to make adaptations where appropriate as the makeup of the class and availability of outside resources dictates.

Major points to be emphasized strongly are that earthquake disasters are among the most dangerous and life-threatening disasters mainly because they occur without warning, and they tend to be cascading-type disasters. It also is important for students to understand basic issues about the specific effects of earthquakes, such as the fact that areas of poor, soft soils tend to produce stronger shaking effects and are where greatest damages are concentrated.

The lecture format will be mostly conventional lecture with the use of visual aids in the form of electronic visuals. A homework assignment is included in the attached handout. This assignment should be distributed at the end of the session and one week is sufficient for completion. Electronic visual images presented in these notes are included in the accompanying file: Session 7 Electronic Visuals.ppt.

Additional Requirements:

Computer and projector for electronic visuals.

Objective 7.1 Describe the nature of earthquake hazards, and especially, how these hazards differ from other hazards.

Requirements:

The content should be presented as lecture.

Electronic Visuals Included:

Electronic Visual 7.1 Moderate Failure, Severe Disruption

Electronic Visual 7.2 Time Required for Lifeline Restoration Following the 1995 Kobe, Japan EQ

Remarks:

I. The nature of earthquake disasters.

A. Earthquakes are one of the most dangerous and destructive forms of natural hazards.

1. Earthquake risk is widespread. As discussed in Session 3, earthquakes occur in most regions of the U.S. and throughout the world.

2. There are 45 states and territories in the United States at moderate to very high risk from earthquakes, and they are located in every region of the country.

3. On a yearly basis, 70 to 75 damaging earthquakes occur throughout the world (USGS). Many of the world's urban centers are located in seismically active regions (as discussed in Session 3).

B. Earthquakes are fast-developing disasters that usually strike with sudden impact and little warning (although regions where seismicity is most likely to occur are generally well defined).

1. Earthquakes can occur at any time of the year and at any time of the day or night.

2. There is no "earthquake season," such as for hurricanes.

3. Earthquakes do not appear on weather radar. We cannot yet reliably predict earthquakes, as discussed in Session 7.

C. Because there typically is no warning, earthquakes, given their occurrence, usually pose the largest immediate threat to loss of life relative to other natural hazards. Unlike with other disasters such as hurricanes, people at risk from earthquakes are not able to retreat to a safer region (although early warning systems may at least allow enough warning (seconds) for quick relocation to a safer area within a structure, such as beneath a sturdy table, before the heart of the strong earthquake shaking begins).

D. The probability of the event occurring during nonworking hours is better than 3:1. This means that people will tend to be concentrated in their residences, increasing the likelihood of death and injury.

II. Earthquakes are both physically and emotionally devastating to communities:

A. They can wreck the physical infrastructure, including critical facilities and lifelines (gas, electrical, communications lines, transportation systems) on which we are so dependent upon, especially for response and recovery.

B. They can reduce buildings to a pile of rubble in seconds, killing and injuring their inhabitants. An earthquake can devastate an entire city or a region of hundreds of square miles.

C. The regional, and state (and sometimes national) economies can be decimated.

D. Thousands of people can be left homeless or in temporary, makeshift shelters

III. Earthquake hazards tend to be "cascading" type disasters. Although strong ground shaking is the predominant effect, the ground shaking can produce other secondary effects that, in turn, can cause “secondary disasters.”

A. For example, ground shaking can cause liquefaction and ground movement that rupture utility lines, including gas and water mains.

B. The broken gas mains cause fires and the broken water mains impede the progress of firefighters to extinguish the fires.

C. Thus, as this scenario depicts, there are a number of **smaller secondary disasters within the main disaster.** In fact, much of the city San Francisco nearly burned by fire during the 1906 earthquake, and this was a real threat in the 1989 Loma Prieta Earthquake.

IV. Even a relatively moderate-sized earthquake can produce widespread damage.

A. Earthquakes pose a major threat to our densely populated urban areas, as demonstrated by **moderately** large earthquakes in 1989 in the San Francisco Bay Area (Loma Prieta Earthquake, magnitude 7.1), and in 1994 in the Los Angeles metropolitan area (Northridge Earthquake, magnitude 6.7).

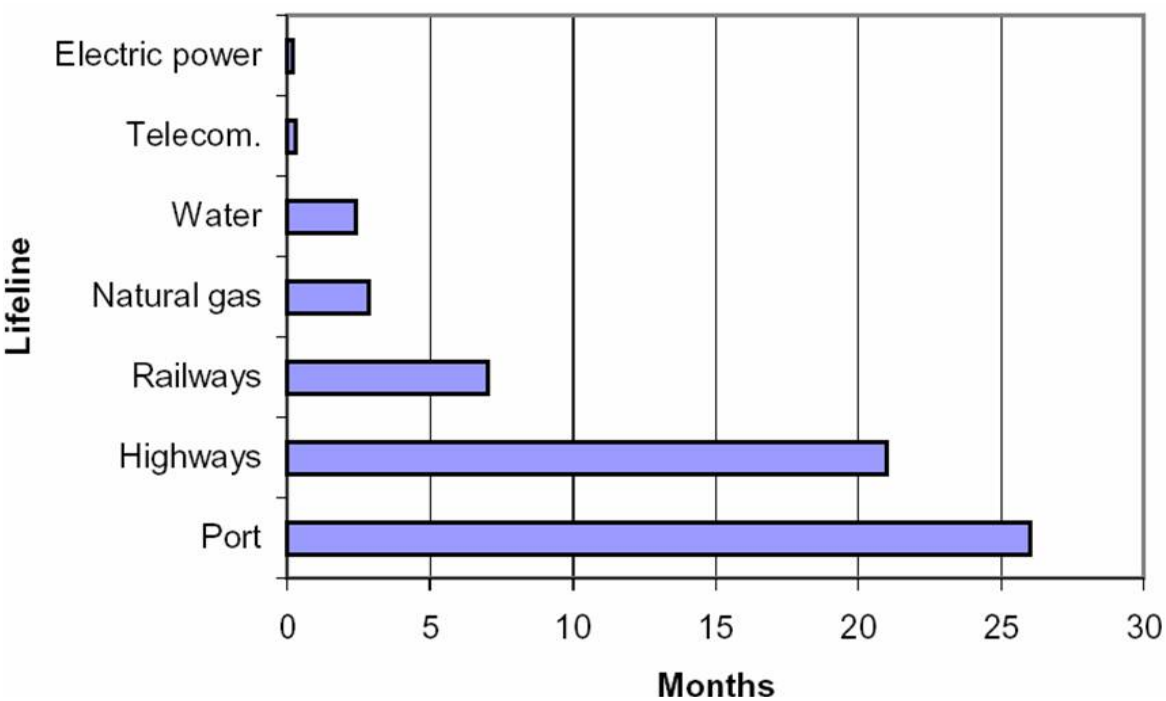
B. Although **the epicenters of these two earthquakes were on the fringe of urban areas, and their magnitudes were only moderate** (much lower than the largest expected earthquakes for these two cities), total economic loss for both events exceeded $50 billion dollars with nearly one hundred lives lost (NRC, 2003).

C. As these two recent experiences demonstrate, our densely populated cities in seismic zones are exposed to very high risk of loss of life, property and business interruption.

D. **A major source of economic loss and societal disruption during earthquakes is due to the loss of critical transportation facilities, such as major bridges.** The **loss of key transportation facilities is made more significant due to the fact that they require so much more time to repair relative to other lifelines**. The relatively modest structural failure of one portion of the Oakland Bay Bridge linking San Francisco and Oakland crippled the flow of traffic in the region for months. **[***Electronic Visuals 7.1, 7.2***]**

[*Note: Mention that the importance of transportation facilities in response and recovery will also be discussed in Session 11***].**

Visual 7.1 – Photo of upper deck of Oakland Bay Bridge that slipped off its bearing seat during the 1989 Loma Prieta EQ. This was a moderate structural failure (inadequate beam seat width), but the disruption in the Bay area was severe. More than one month was required for repair. Photo credit: CalTrans.



Visual 7.2 – Graph illustrating time required for repair of lifelines following the 1995 Kobe Japan Earthquake. Note that the transportation facilities required much longer repair times. Visual from Chang (2000).

V. Unlike most other natural hazards, the danger is not over in an earthquake when the initial events occurs (the main shock).

A. There is still a significant risk to further damage **– aftershocks are expected!** Aftershocks are smaller earthquakes that follow the main shock and can cause further damage to weakened buildings.

B. In many cases, heavily damaged buildings collapse during the aftershocks causing loss of life (especially from occupants retrieving valuables, etc.).

C. These events also can cause considerable unease among the public. Aftershocks can occur in the first hours, days, weeks, or even months after the quake. Be aware that some **earthquakes are actually foreshocks, and a larger earthquake might occur**.

VI. ***Infrastructure and lifelines above and below ground (tunnels, utilities, etc.) can be affected* due to strong shaking as well as ground displacements, especially due to soil liquefaction (as discussed later).**

A. Thus, lifelines, including transportation routes, communications and utilities are typically greatly affected during significant earthquakes.

B. Hurricanes and other natural disasters often are not as pervasive in their destruction of lifelines, especially buried utilities. **Lifelines are vital for both response and recovery (NRC, 2003)**.

C. For instance, damage to sensitive telecommunications systems, even if only temporary after a moderate earthquake, will interfere with response management.

VII. Earthquake are less frequent (relative to many other disasters), but high-consequence events, meaning that *we have less experience with earthquakes than with most other disasters. That is, earthquakes are not relatively common in populated areas (compared to other disasters), but earthquakes are high-consequence hazards*.

A. That is, we have more experience with hurricanes, floods, etc. **Therefore, earthquake hazards are often the most difficult to visualize in terms of really understanding what to expect during such a disaster.**

B. It is difficult to assess and prioritize for mitigation precisely because they are perceived by the public to be infrequent events that may not occur within a human lifetime. For instance, communities may accept expenditure of $50 million on flood control for a 100-year flood event, but would not consider spending a small percentage of that on earthquake monitoring or mitigation, even though the earthquake risk may in fact be comparable or greater for a given timeframe (Cowan et al., 2002).

C. Some of the differences in risk perception are because the public sees floods more frequently than they experience large earthquakes. This means that there is currently a larger amount of human inertia to counter in providing mitigation strategies and preparedness. Also, because these types of disasters are relatively infrequent, emergency response and recovery operations tend to be less familiar and rehearsed by those responsible (Cowan et al., 2002).

VIII. *Fortunately, much of the damage in earthquakes is predictable and preventable*. All must work together in a unified fashion to apply our knowledge to building codes, retrofitting programs, hazard hunts, and neighborhood and family emergency plans (Mileti, 1999).

Objective 7.2 Describe the effects of earthquakes upon infrastructure (buildings, lifelines, etc.).

Requirements:

The content should be presented as lecture, supplemented with electronic visuals. The instructor is cued as to when the graphics from the accompanying electronic visual files should be presented.

Electronic Visuals Included:

Electronic Visual 7.3	Influence of Geology upon shaking levels during the 1989 LPE
Electronic Visual 7.4	Stronger shaking on softer sites
Electronic Visual 7.5	Influence of soft sediments
Electronic Visual 7.6	Ground shakes erratically
Electronic Visual 7.7	Liquefaction damages infrastructure
Electronic Visual 7.8	Liquefaction and Lateral Spreading at Port 1995 Kobe, Japan Earthquake
Electronic Visual 7.9	Effect of 1995 Kobe Japan EQ on Trade at Port of Kobe
Electronic Visual 7.10	Soil being densified to avoid liquefaction
Electronic Visual 7.11	Slope failure during 1989 LPE
Electronic Visual 7.12	Lateral ground shifting due to fault
Electronic Visual 7.13	Breech of Dam during the 1999 Chi-Chi Earthquake
Electronic Visual 7.14	Broken gas line due to ground movements during 1994 Northridge Earthquake

Remarks:

I. Effects on infrastructure (buildings and lifelines).

A. The effects of earthquake can be broadly categorized into: **primary effects and secondary effects**

B. ***Primary effects*** include the primary mechanism involved in earthquakes—namely strong ground shaking due to fault rupture. **The primary way in which earthquakes cause damage is by strong ground shaking**

C. ***Secondary effects*** are those indirect consequences that result from strong ground shaking, and in many cases, create hazards themselves. **Typical secondary effects include ground failures (landslides, liquefaction, subsidence), tsunamis (seismic ocean waves) and seiches (rhythmic movements of inland bodies of water), floods, and fires.**

II. Primary Effects: Strong Ground Shaking

A. The primary earthquake hazard is the **effect of strong ground shaking**. Structures can be damaged by the shaking itself, especially unreinforced masonry structures.

B. When strong earthquake shaking occurs, a building is thrown mostly from side to side, and also up and down. That is, while the ground is violently moving from side to side, taking the building foundation with it, the building structure tends to stay at rest, similar to a passenger standing on a bus that accelerates quickly. Once the building starts moving, it tends to continue in the same direction, but the ground moves back in the opposite direction (as if the bus driver first accelerated quickly, then suddenly braked). Thus the building gets thrown back and forth by the motion of the ground, with some parts of the building lagging behind the foundation movement, and then moving in the opposite direction.

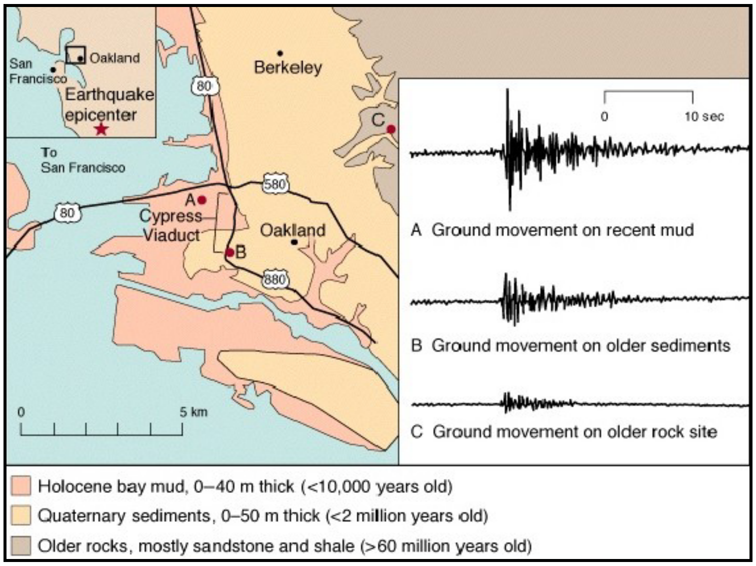
C. The factors that primarily determine ground shaking intensity are:

1. Magnitude (a big earthquake shakes more intensely than from a small one) As discussed in Session 5, big earthquakes also release their energy over a larger area and for a longer period of time. In most cases, only 10-15 seconds of shaking that originate from the part of the fault nearest will be very strong (USGS).

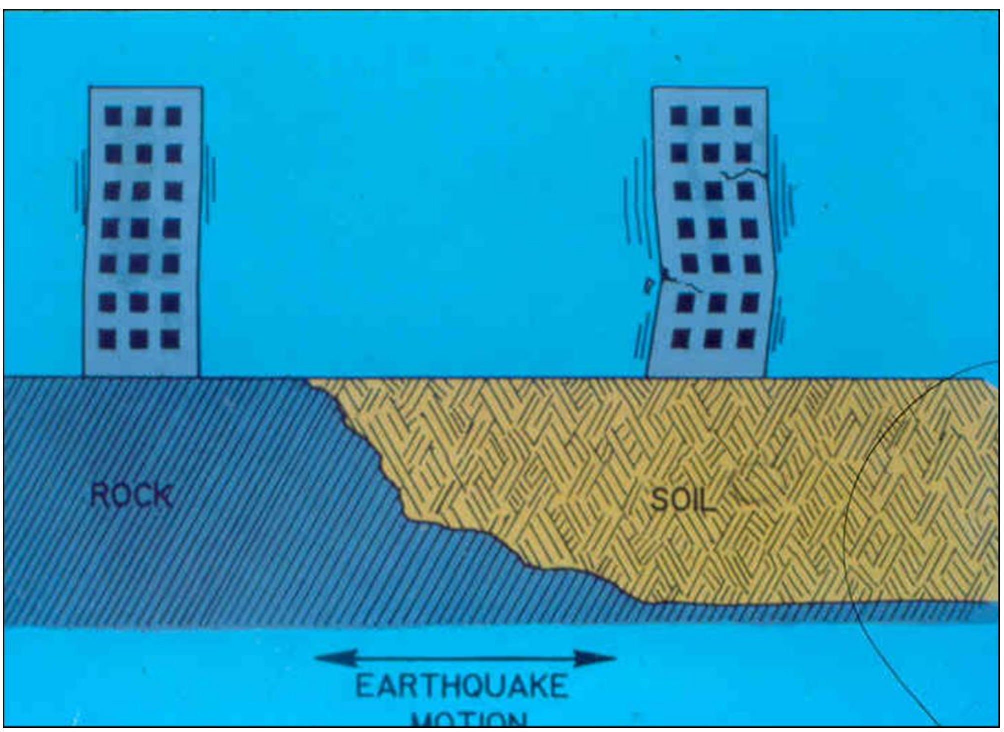
2. Distance from the fault (earthquake energy dissipates (**attenuates**) as the waves travel through the earth, so shaking becomes less intense farther from the fault.

3. Local soil conditions (certain soils greatly amplify the shaking in an earthquake). Seismic waves travel at different speeds in different types of rocks. Passing from rock to soil, the waves slow down but get bigger. Poor soils amplify motion and change their character such that shaking is more intense and more damaging for buildings. Thus, damage from shaking can be aggravated by geological and soil conditions. **A soft/loose soil will typically shake more intensely than hard rock at the same distance from the same earthquake**. The looser and thicker the soil is, the greater the amplification typically will be (e.g., Loma Prieta EQ damage area of Oakland and Marina [SF] were 100 km (60 mi.); most of the Bay Area escaped serious damage). **Consequently, all things being equal, stiff soils and rock are generally much less damaging than softer deposits.** [*Electronic Visuals 7.3, 7.4*]

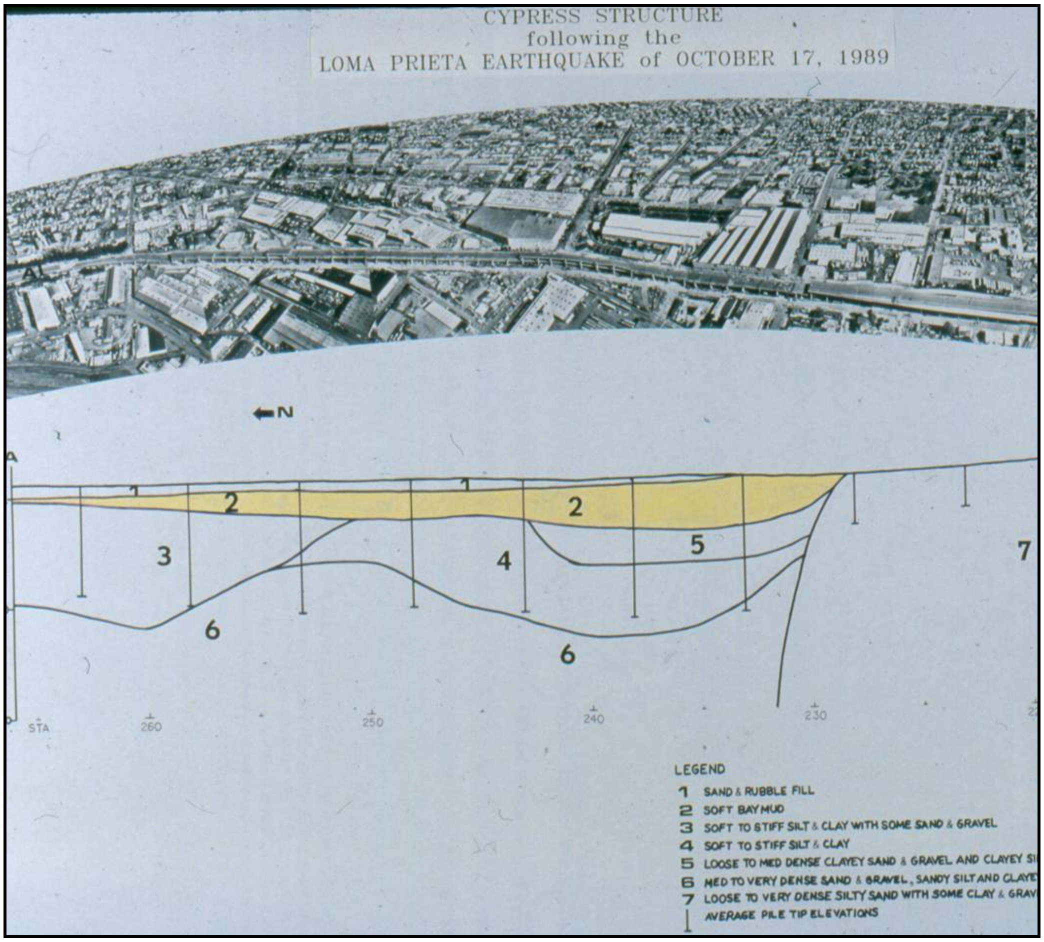
   Although the failure of the double-decked Cypress Freeway in Oakland, California during the 1989 Loma Prieta Earthquake was related primarily to its inadequate, non-ductile seismic design, the section of the roadway system that collapsed was underlain by soft sediments, as shown in Visual 7.5 [*Electronic Visual 7.5*].



Visual 7.3 – Map showing geology of the San Francisco Bay region and the relative levels of ground shaking recorded during the 1989 LPE. The shaking was stronger and of longer duration on sites with softer, geologically younger soils (soil amplification). Credit: USGS.

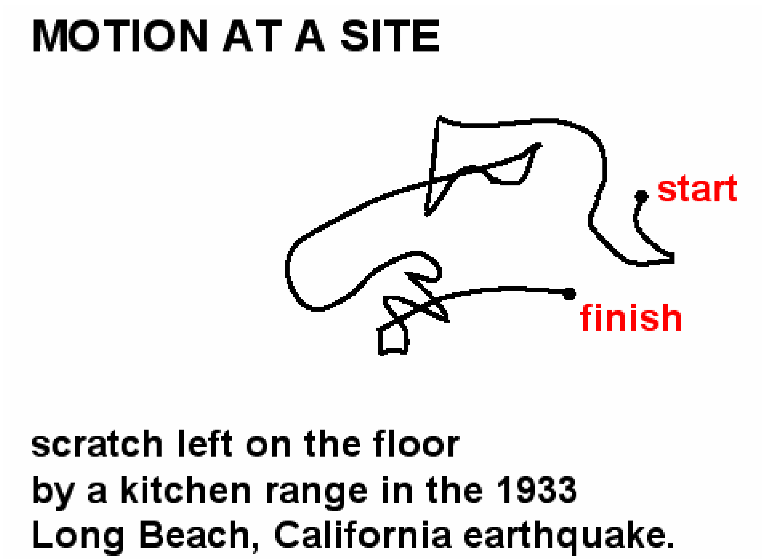


Visual 7.4 – Sketch depicting the tendency for stronger, more damaging shaking on soil relative to stiff sites.



Visual 7.5 – Panoramic photograph (top half) of the failed section of the Cypress Freeway and a sketch of the underlying soil profile (bottom half). It can be seen that the portion of the freeway that collapsed was underlain by soft soils (Young Bay Mud) that caused amplification of the shaking in this location. Credit I. Idriss.

D. The nature of the ground shaking typically is erratic, although predominantly horizontal (as opposed to vertical), and often exaggerated in one direction. The erratic nature of the shaking is depicted in the visual below: [*Electronic Visual 7.6*]



Visual 7.6 – This figure depicts the "herky-jerky" erratic nature of the ground shaking during an earthquake (adapted from BSSC, 2000).

E. As will be discussed more in Session 9, unreinforced masonry structures are non-ductile and extremely vulnerable to damage from ground shaking.

1. Such structures are serious problems for the U.S. Not only do we have a significant inventory of non-ductile concrete buildings in California, but we have a very significant inventory of non-ductile buildings in the central and eastern U.S.

2. This places a substantial portion of the U.S. building stock at risk from high impact, low recurrence earthquakes. It also places a considerable number of buildings at risk of catastrophic collapse in high impact, high recurrence earthquake zones.

3. It is not just high occupancy apartment, commercial, and industrial buildings that are at risk. Critical lifelines, such as bridges, also are vulnerable, especially outside California.

4. Finally, many of these buildings and lifelines are located atop deposits of soft sediment that will amplify the ground motions and damage potential.

III. Secondary Effects.

Ground failures caused by earthquakes include settlement, liquefaction, ground cracking, slumps, landslides, rockfalls uplift and subsidence.

A In addition to the strong ground shaking, structures can be damaged by the ground beneath them settling to a different level than it was before the earthquake (**settlement** or **subsidence**).

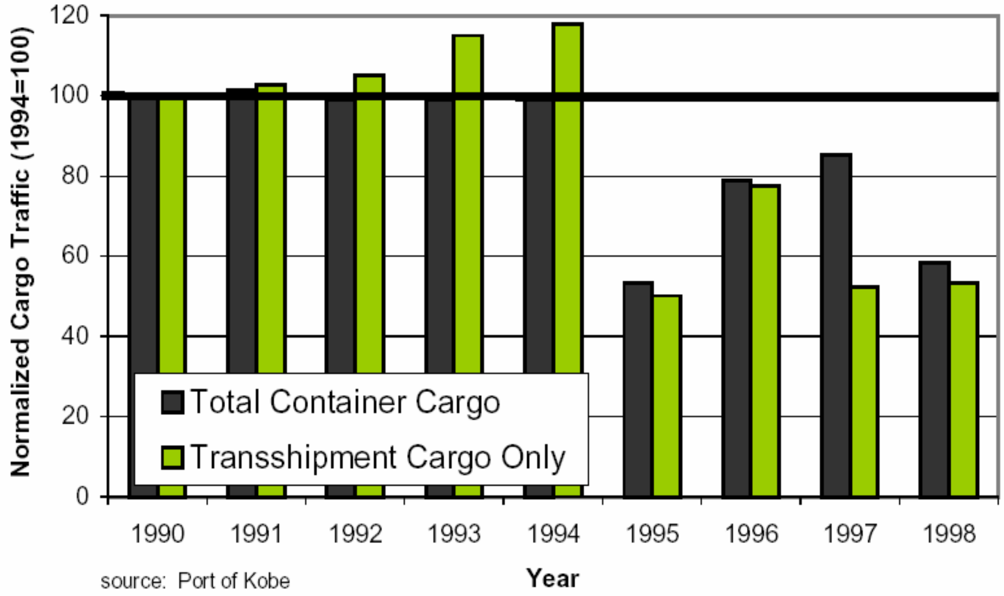
B. **Liquefaction** occurs when loose water-saturated sands, silts or gravels are shaken so violently (in moderate to strong earthquakes) that the grains lose their points of contact and rearrange themselves, squeezing the water out of the shrinking pores and causing it to flow outward forming sand “boils” or causing lateral spreading of overlying layers. When the water and soil are mixed, the ground becomes very soft and acts similar to quicksand. Liquefaction typically occurs within the upper 40 ft. (12 meters) of the soil profile.

Liquefaction causes loss of bearing strength under structures, triggers slides, and floats low-density structures, such as fuel tanks, under a moderate or strong earthquake. If liquefaction occurs under a building, it may start to lean, tip over, or sink several feet [*Electronic Visual 7.7*]. In the Northridge Earthquake, homes damaged by liquefaction or ground failure were 30 times more likely to require demolition than those homes only damaged by ground shaking (ABAG, 2004).

Liquefaction also is a primary cause of damage to lifelines, including underground utilities. Liquefaction is a hazard in areas that have groundwater near the surface and sandy soil, such as stream and ocean deposits. When the ground is non-level, liquefaction allows **lateral spreading,** where large chunks of soil move laterally for up to several meters, to occur. Lateral spreading is one of the most pervasive forms of damage associated with earthquakes, and is especially damaging to lifelines [*Visual 7.8*]. The Port of Kobe, Japan handles more than 10 times the cargo of Oakland. Liquefaction caused major damage in a 1995 earthquake. After 10 years, 10-15% of business has still not returned to the Port of Kobe (NRC, 2003). [*Visual 7.9*]

Visual 7.7 – Buildings overturned due to loss of bearing support from liquefaction of the foundation soils during the 1964 Niigata, Japan Earthquake. Credit: Japan National Committee on Earthquake Engineering.

Visual 7.8 – Liquefaction-induced lateral spreading at port, 1995 Kobe, Japan Earthquake. This mechanism was a major cause of severe port damage in Kobe. Photo credit: Gifu University Researchers.



Visual 7.9 – This figure indicates the reduction in port cargo due to damage from the 1995 Kobe Earthquake. Much of the damage was due to liquefaction. The effects on port trade are lingering as shown. Visual from Chang (2000).

Engineers have now learned to predict, reasonably well, the occurrence of liquefaction for a given earthquake scenario. Tests typically are conducted in the field to provide a basis for estimating liquefaction resistance of a soil deposit under a given level of earthquake shaking. Dense soils are not susceptible to liquefaction. Thus, a loose deposit can be made more resistant liquefaction if it is densified. If liquefaction is judged to be likely, the ground can be made more resistant by a variety of soil improvement methods, such as densification or grouting. [*Electronic Visual 7.10*]

C. **Slope failures** also are a concern as they can be triggered by earthquakes, as shown in Visual 7.11 [*Electronic Visual 7.11*]

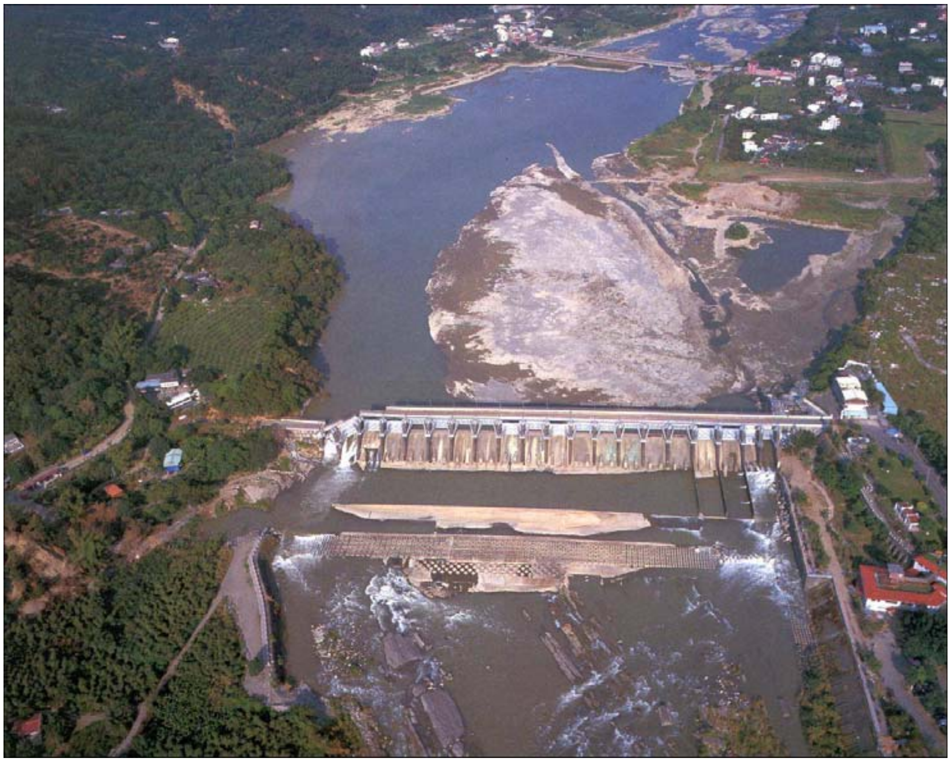
Visual 7.10 – Soil deposit in northern California being densified using a vibroflot, a large electrical vibratory probe that densifies the sand to prevent liquefaction. Credit: J. Mitchell.

Visual 7.11 – Slope failure during the 1989 Loma Prieta Earthquake. Note the housing development atop the slope that nearly became part of the view. Photo credit: J. Martin.

III. Another secondary hazard is *ground displacement* (ground movement) *along a fault*. If a structure (a building, road, etc.) is built across a fault, the ground displacement during an earthquake could seriously damage or rip apart that structure. [*Electronic Visual 7.12*]

Visual 7.12 – Offset due to surficial fault rupture. The road was connected prior to the event. Photo credit: G. W. Clough.

IV. A third secondary-type hazard is *flooding.* An earthquake can *rupture* (break) dams or levees along a river. The water from the river or the reservoir would then flood the area, damaging buildings and maybe sweeping away or drowning people. [*Electronic Visual 7.13*]



Visual 7.13 – Photograph showing failure of the Shih-Kang Dam during the 1999 Chi-Chi (Taiwan) Earthquake. The thrust fault broke right through it. In this picture taken on its downstream side, you can see where the right hand side of the dam rose 10 meters (35 ft.) compared to the left side. Photo credit: R. Boulanger.

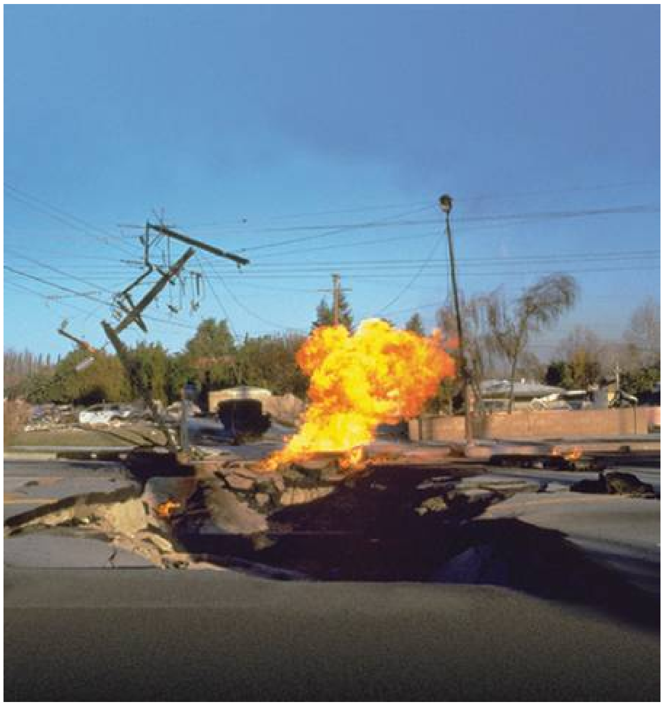
V. ***Tsunamis* and *seiches* also can cause a great deal of damage.**

A. A **tsunami** is a huge wave caused by an earthquake under the ocean. Tsunamis can be tens of feet high when they hit the shore and can do enormous damage to the coastline.

B. **Seiches** are like small tsunamis. They occur on lakes that are shaken by the earthquake and are usually only a few feet high, but they can still flood or knock down houses, and tip over trees.

VI. **A common secondary earthquake hazard is *fire*.**

Fires can be started by broken gas lines and power lines, or tipped over wood or coal stoves. They can be a serious problem, especially if the water lines that feed the fire hydrants are broken, too. For example, after the Great San Francisco Earthquake in 1906, the city burned for three days. Most of the city was destroyed and 250,000 people were left homeless (USGS). This fire was the result of rupture gas lines and ruptured water mains (to extinguish the fires) A large fire also occurred during the 1989 Loma Prieta Earthquake in the Marina District triggered in the same fashion. Even the smaller 1994 Northridge Earthquake caused fires as shown in the visual. [*Electronic Visual 7.14*]



Visual 7.14 – Fire from a broken gas line due to ground movements at Balboa Boulevard, Los Angeles, California, 1994 Northridge earthquake (Credit: USGS Circular, 1242; Photograph by M. Rymer)

Objective 7.3 What are the general effects of earthquakes upon people and what is the nature of the casualties from earthquakes?

Requirements:

The content should be presented as lecture, supplemented with electronic visuals. The instructor is cued as to when the graphics from the accompanying electronic visual files should be presented.

Electronic Visuals Included:

Electronic Visual 7.15	Death or injury can be caused by contents
Electronic Visual 7.16	Collapse of Cypress Freeway during 1989 LPE

Remarks:

I. Earthquakes really pose little direct danger to a person. People cannot be shaken to death by an earthquake. *Thus, ground shaking during an earthquake is seldom the direct cause of death or injury.*

A. Most earthquake-related injuries result from collapsing walls, flying glass, and falling objects due to the ground shaking. That is, ***falling things (that we have built or placed in our living and work spaces) injure and kill people in an earthquake***, not the ground shaking itself. Thus, **we essentially "design our own disasters**" (as per the tile of the popular book by Mileti, 1999). This also means that **much of the damage in earthquakes is predictable and preventable.** [*Electronic Visual 7.15*]

*Visual 7.15 – Damage from the Livermore Earthquake of January 24, 1980. There was considerable damage to facilities at the Lawrence Livermore Lab. These overturned bookcases in the library are typical of the damage that occurred within the buildings. Light fixtures, acoustic tiles, electronic equipment, lamps, planters and blackboards also were damaged. **Consider the potential injury to occupants, even though the building was undamaged**. Photo credit: U.S. Geological Survey*

B. As stated earlier, progress is being made ***in the U.S.*** for death prevention due to earthquakes. We are fortunate that the loss of life due to earthquakes since 1971 has been less than 140 (Mileti, 1999).

II. Casualties due to earthquakes generally are categorized as follows (as adapted from Sugimoto, 2002):

A. **Primary casualties:** those killed/injured by collapse, fire, physical hazards.

B. **Secondary casualties:** those injured by physical hazards who die because of insufficient resources.

C. **Tertiary casualties:** those with preexisting medical conditions exacerbated because of disaster environment.

D. **Quaternary casualties:** those who suffer psychological/emotional problems brought on by stress, grief, and loss.

III. *Primary casualties* are those who are injured directly or killed due to the earthquake itself – by fire, by structural collapse, and other physical hazards related to the actual shaking.

A. Primary casualties essentially are unsalvageable because of the critical nature of their injuries and the delays inherent in providing help, or because they died instantly.

B. Examples of primary casualties in the 1989 Loma Prieta earthquake include the people killed when the upper deck of the Cypress structure collapsed, trapping them underneath. [*Electronic Visual 7.16*]

Visual 7.16 – Collapsed upper deck of the Cypress Freeway due to 1989 Loma Prieta Earthquake. Unfortunately, 42 people were killed at this site, the majority of deaths experienced in the earthquake (63 total deaths). The casualties from this site would be considered primary casualties. Photo credit: CalTrans.

IV. ***Secondary casualties* are people who survive the initial incident, but are injured during the process, and who die because of exposure, insufficient resources, or the inability to access effective and immediate emergency medical care. An example of a secondary casualty would be a person who sustained an injury such as a severely broken leg, but died of shock as a result of internal bleeding.**

V. ***Tertiary casualties* are people who suffer from preexisting medical conditions aggravated by the earthquake.**

A. Such conditions normally would be survivable, but because the medical system is overwhelmed with traumatically-injured patients, they will die because of an inability to access the system.

B. Typically, this group might include those with chronic disorders such as heart conditions, severe asthma, etc. This group also includes those who become sick as a result of the post-disaster environment, primarily through communicable diseases, and who may or may not die as a result.

VI. ***Quaternary casualties* constitute perhaps the largest and unquantifiable group of casualties, since it involves those who suffer lasting effects from their involvement in the incident. The psychological impact of an earthquake, the stress of surviving and the grief at having lost loved ones, and the loss of property almost certainly will result in suicidal deaths. *When* these deaths occur is enigmatic, as little research has been conducted on this issue. Thus, it is difficult to identify these future deaths that would probably be attributed to other, more natural causes.**

Objective 7.4 Describe the general effects of earthquakes upon the economy and the nature of earthquake losses

Requirements:

The content should be presented as lecture, supplemented with electronic visuals. The instructor is cued as to when the graphics from the accompanying electronic visual files should be presented. Handout 7.1 (Homework assignment 7.1) should be handed out at the end of this session and one week should be allowed for completion.

Electronic Visuals Included:

Electronic Visual 7.17 Effect of 1923 Japan EQ on that economy

Handouts Included:

Handout: 7.1: Homework Assignment

Remarks:

I. Nature of Losses Due to Earthquake Disasters:

A. A strong damaging earthquake anywhere in the U.S. could have huge economic and social consequences throughout the nation. Earthquakes pose a particularly major threat to our densely populated urban areas.

B. The costs to society from future earthquakes include two primary components (NRC, 2003):

1. Resources invested today to harden our built environment to avoid future losses from earthquakes include: a) cost of developing earthquake resistant construction technologies; and b) cost of implementing earthquake-resistant construction technologies.

2. Actual losses that occur as a result of future earthquakes.

C. Although casualties have dramatically reduced in recent U.S. earthquakes, the dollar loses of widespread non-life threatening damage are enormous (Mileti, 1999; NRC, 2003).

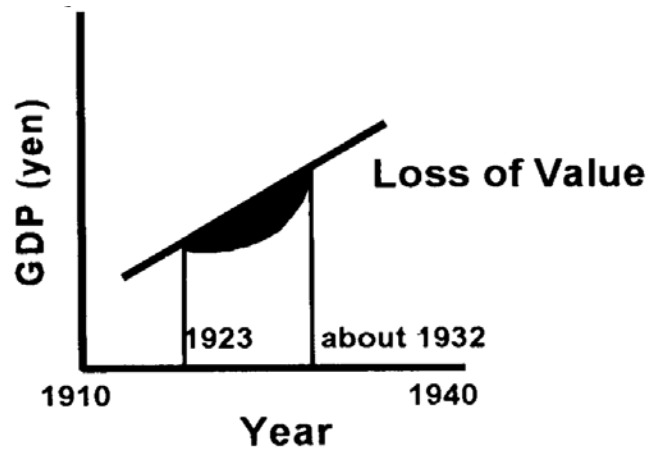
D. Recent estimates of earthquake risk in the United States alone project current average annual financial loss exposure on the order of $4 billion in building stock alone; including losses due to damage to infrastructure and indirect losses would give total annualized losses of about $10 billion (EERI, 2002).

E. **The characterization of losses from disasters, often presented on an annualized basis, is misleading because the losses from a strong, damaging earthquake will be sudden and** huge, leading to business interruption, loss of housing, insurance instability, loss of jobs, etc.

II. A better understanding of the potential impact to an *economy* can be gained by plotting the growth of the Gross Domestic Product (GDP) for a region or for a country versus time and noting the dip in the curve compared to an extrapolated version.

A. The curve shown below provides insight as to the total losses (or loss of value) incurred after the great 1923 earthquake in Japan. This figure suggests that immediately following the earthquake, Japan's GDP dropped, as depicted by the bottom of the dark area. However, after 10 years, the GDP returned to the same rate of growth that was occurring prior to the earthquake. [*Electronic Visual 7.13*]

B. The ***GDP*** is defined as: The total market value of all the goods and services produced within the borders of a nation during a specified period.



Visual 7.17 – Plot showing dip in Japan's gross domestic product following the 1923 Japan Earthquake. Visual adapted from Natural Hazards Observer (1995).

III. Estimates of losses to the built and human environment from a single large metropolitan earthquake in the U.S. approach $200 billion (NRC, 2003), several times that experienced in the 1994 Northridge earthquake, the most costly domestic earthquake to date (Mileti, 1999).

A. This economic loss is of the same order as that caused by the terrorist attacks of September 11, 2001 on the twin towers of the World Trade Center in New York and on the Pentagon in Virginia (NRC, 2003).

B. A repeat of the 1906 San Francisco earthquake potentially can cause $1 trillion in direct and losses affecting cities along the northern coast of California, about 100 km south of San Francisco almost north to Eureka (NRC, 2003).

C. Consider this: at the time of the 1906 event there were only 0.5 million people in the region, and now there are more than 5 million in the immediate vicinity

IV. Thus, while casualties have dramatically dropped in recent U.S. earthquakes, the dollar loses of widespread non-life threatening damage are unacceptably large. Thus, our codes and design and construction practices are only partially successful; as stated in Mileti (1999): "if the war against death is almost won, the war against destruction is far from over."

[*Instructor distribute Handout 7.1: Homework Assignment 7.1*]

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