Session No. 9

Course Title: Earthquake Hazard and Emergency Management

Session Title: Mitigation

Author: James R. Martin, II

Time: 240 minutes

Objectives:

9. 1 Define and discuss earthquake hazard mitigation.

9.2 Describe the costs and benefits of earthquake hazard mitigation.

9.3 Explain the keys to effective hazard mitigation.

9.4 Identify key factors and challenges affecting mitigation.

9.5 Describe a reasonable mitigation goal; that is, to what standard should we mitigate?

9.6 Describe structural mitigation measures.

9.7 Describe building mitigation measures.

9.8 Recognize the purpose of building codes.

9.9 Discuss nonstructural mitigation measures (building contents).

Scope: This session, which focuses on mitigation, is one of the most important and extensive sessions of the entire course. As discussed in earlier sessions, there is a need to shift what has been an emphasis upon emergency response and recovery toward pre-event mitigation measures. Accordingly, this section discusses the need for developing a more proactive stance toward mitigation, and this issue continually is highlighted throughout this session. A number of basic concepts, lessons learned from case histories, and keys for successful mitigation strategies are discussed. The latter half of the session presents specific mitigation techniques that can be used for various cases. A homework assignment (team assignment) that includes in-class presentations by the students is included.

Readings:

Suggested student readings:

Meliti, D. 1999. *Disasters by Design: A Reassessment of Natural Hazards in the United States.* Joseph Henry Press.

FEMA. [No Date]. “Report on the Costs and Benefits of Natural Hazards Mitigation.” *FEMA 294.* Available from http://www.fema.gov/library/lib06c.shtm.

Tierney, K. J. 1993. *Disaster Preparedness and Response: Research Findings and Guidance from the Social Science Literature*. Taipei, Taiwan, ROC: US-ROC Workshop on Natural Disaster Reduction, June, 1993.

Maffei, J. 1998. “Mitigating the Risk: Engineers and Builders.” *Degenkolb Engineers. Earthquake Insurance: Public Policy Perspectives from the Western United States Earthquake Insurance Summit*. Western States Seismic Policy Council. See http://www.wsspc.org/summit/eqiperspectives4.html#maffei).

Required instructor readings:

Meliti, D. 1999. *Disasters by Design: A Reassessment of Natural Hazards in the United States.* Joseph Henry Press.

FEMA. [No Date]. “Report on the Costs and Benefits of Natural Hazards Mitigation.” *FEMA 294.* Available from http://www.fema.gov/library/lib06c.shtm.

Tierney, K. J. 1993. *Disaster Preparedness and Response: Research Findings and Guidance from the Social Science Literature*. Taipei, Taiwan, ROC: US-ROC Workshop on Natural Disaster Reduction, June, 1993.

Maffei, J. 1998. “Mitigating the Risk: Engineers and Builders.” *Degenkolb Engineers. Earthquake Insurance: Public Policy Perspectives from the Western United States Earthquake Insurance Summit*. Western States Seismic Policy Council. See http://www.wsspc.org/summit/eqiperspectives4.html#maffei).

Cowan, H., Falconer, R., and S.Nathan , 2002. “Gaps in the Understanding and Mitigation of Earthquake.” Lower Hutt, New Zealand: Institute of Geological and Nuclear Sciences.. See http://www.nzplanning.co.nz/docs/cowan_etal_v3.doc.

Shah, Haresh C. 2003. “The Last Mile Earthquake Risk Mitigation Assistance in Developing Countries,” Stanford, CA: Stanford University.

Electronic visuals included: [*see Session 9 – Electronic Visuals.ppt*]

9.1 Table 1. Comparison of Major Earthquakes

Handouts Included:

Handout 9.1: Homework Assignment 9.1

General Requirements:

This session is one of the most important sessions of the entire course and is the most extensive in terms of material covered. The instructor should begin with a discussion of the general concepts of mitigation and stress the importance of this activity for reduction of earthquake hazards. The discussion then progresses to specific examples of mitigation strategies for various situations. This session includes a homework assignment that includes in-class presentations by the students as explained further below.

Note that the information in this session will overlap other sessions. For instance, planning is an important aspect of mitigation, as presented briefly in Session 8, where land-use planning was discussed. Planning specially for earthquake disasters will also be covered in Session 14. It is not feasible or desirable to cover all of the various aspects of mitigation in this session alone, as the material is already voluminous. An entire course could easily be presented on this topic alone. The purpose here is to highlight the basic issues and to engender an appreciation of the critical importance of mitigation. **Also, note that there is intentional repetition of the key points as they are re-emphasized in different sections.**

The homework assignment should be distributed at the end of the session and one week is sufficient for this to be completed. Note that this is to be a team assignment for groups of two or three students that will involve brief (5 to 7 minutes) in-class presentations. The instructor should assign each person to two or three-person teams following the completion of the last objective. The students should be given one week to complete the assignment, which involves researching a case history on earthquake mitigation and developing a short three-page report on lessons learned and important aspects of the case. The purpose of this assignment is to foster interaction among the students, provide experience of working in teams, enhance the students' presentation skills, and extend the coverage of the material covered in the lecture (as each student group will present their findings from various case histories in front of the entire class). Two class periods are allotted for the lecture, with two additional periods for the student presentations. The total allotment of time for this session is 240 minutes. Adjustments can be made as needed to the length of the presentations and size of the student groups.

Special instructor note: *Some of the information presented in this section (Objectives 9.6 and 9.8, especially) is technical in nature and instructors with non-engineering backgrounds may require additional background study. In some cases, the instructor may wish to enlist the aid of an outside expert, such as faculty from an engineering department, to teach this material. This is* ***not an engineering course****, and while some instructors may elect to reduce the technical content presented, many of the basic concepts covered will allow a more complete understanding of earthquakes and the nature of the hazard they pose (i.e., non-ductile structures, such as unreinforced masonry buildings, are dangerous) . Therefore, the instructor should cover as much of this material as feasible, and make adaptations where appropriate as the makeup of the class and availability of outside resources dictates.*

Additional Requirements:

Computer and projector for electronic visuals.

Objective 9.1 Define and discuss earthquake hazard mitigation.

Requirements:

The content should be presented as lecture.

Remarks:

I. ***Mitigation is one of the four disaster management phases*** **(preparedness, *mitigation*, response, and recovery), as discussed earlier, in Session 8.**

[***Instructor note:*** *Mention that preparedness, response, and recovery will be covered in detail in Sessions 10 and 11.*]

A. We cannot prevent natural disasters from occurring. However, we can take definite steps to reduce our exposure to the hazards associated with those natural disasters. ***Mitigation*** **is the series of actions or processes by which the degree of exposure to hazards, or the risks, are lessened**. Think about this – if we can take actions to increase our exposure to hazards, such as building in hazardous regions (which unfortunately, we do at increasing rates), **then we certainly should also be able to take steps to reduce the impact of disasters. Again, we design our own disasters in many ways (Meliti, 1999).**

B. **Mitigation is the cornerstone of hazard management.** FEMA's National Mitigation Strategy declares hazard mitigation to be "the cornerstone of the Nation's system of emergency management" (FEMA, 2000). The strategy calls for partnerships between the federal government and other sectors of American society to address five key elements of mitigation: 1) hazard identification and risk assessment; 2) applied research and technology transfer; 3) public awareness, training, and education; 4) incentives and resources; and, 5) leadership and coordination.

C. The government's response to the need for increased emphasis on mitigation prompted the **Mitigation Act of 2000** and the **Earthquake Loss Reduction Act of 2001** as discussed in Session 8.

D. The emphasis on mitigation has increased as the cost of natural disasters is rising dramatically each year, and there is recognition of the many important benefits of such efforts.

E. **If one develops the attitude that there really are no natural disasters, only natural processes and phenomena that must be planned for, this approach takes on new meaning** (Mileti, 1999). **Evidence strongly suggests that much of**

the damage to structures and property (and therefore, cost of replacement) can be prevented in the same way loss of life has been reduced by advances in early warning systems. Thus, hazard identification and risk assessment strategies, as well as mitigation planning, are eclipsing recovery and rebuilding programs in importance.

II. Earthquake hazard mitigation activities fall into three broad categories; ***structural mitigation, nonstructural mitigation and emergency response planning***.

A. Earthquake hazard mitigation consists of actions, practices, and policies that are intended to reduce the impact of an earthquake to people, property, economy, and the environment hazards when it does occur. Mitigation is **long-term in terms of planning and continued activities.**

B. **Typical earthquake hazard mitigation measures include** land-use and zoning regulations (as illustrated in Session 8), application of design and engineering principles to make structures and lifelines more earthquake-resistant, and policies and activities (i.e., education, awareness) to minimize life-safety hazards and social disruption (Tierney, 1993).

C. One of the most important lessons to be learned from many past earthquakes is that **it costs much less to prepare for earthquakes than it does to repair the damage afterwards (FEMA, 274).**

D. Mitigation is especially important in managing earthquake hazards because these events are among the most damaging, pervasive type of disasters. These events tend to affect a widespread region, even if they are moderate in size (NRC, 2003).

E. Consider that the 1994 Northridge, CA earthquake was of only moderate size (M6.7) and occurred in a region of the U.S. where seismic practices and policies are most advanced, yet the Northridge Earthquake is the largest natural disaster in U.S. history in terms of federal expenditures! (NRC, 2003).

III. Mitigation measures may be adopted without going through the steps of risk assessment, although this may result in inappropriate measures, which are not designed for the correct level of protection for a given situation, or not applied to priority areas and critical facilities, vulnerable groups, or vital economic assets, being taken.

IV. While risk assessment is complex and costly, it is an important task in resource management decisions of all responsible governments, thus emphasizing *the need for vulnerability assessment and hazard identification so that appropriate mitigation strategies can be developed.*

V. **Loss estimation tools (such as hazard maps, and GIS systems such as HAZUS, to be discussed later in Session 14) should be used as the basis for *mitigation planning* to establish the cost-effectiveness of different mitigation strategies.**

Damage functions and building inventories can be adjusted to reflect changes in building codes, or the impact of planned retrofit programs. Loss estimation tools allow the user to forecast future benefits by simulating a sequence of events over some time period and examining the expected losses with and without mitigation measures (FEMA 274). Similar results can be obtained by incorporating probabilistic seismic hazard analysis procedures.

Objective 9.2 Describe the costs and benefits of earthquake hazard mitigation.

Requirements:

The content should be presented as lecture. The lecture will be enhanced if the instructor presents electronic slides or overheads of the figures below. The instructor is cued as to when the accompanying electronic visual files should be presented.

Electronic Visuals Included:

Electronic Visual 9.1a	Table 1 – Comparison of Major Earthquakes
Electronic Visual 9.2	Failed column during the 1989 LPE and mitigation by wrapping with steel jackets
Electronic Visual 9.3	Steel jacket. Carbon fiber jacket.
Electronic Visual 9.4	Collapsed Murrah Federal Building

Remarks:

I. **Upgrading existing vulnerable structures, using better designs in new construction, and increasing preparedness in all areas appear to be the most cost-effective ways to reduce loss and achieve recovery from earthquakes (FEMA 294).**

A. Results from recent earthquakes suggest a huge payoff from mitigation efforts (CSSC, 2001; FEMA 294). **Alternatively, time and time again, experience shows that one of the principal causes of the soaring costs of disasters is that there is a distinct absence of proactive programs and activities to reduce the vulnerability of at-risk people and communities** (Maffei, 1998**).**

B. New quantitative data are being developed (i.e., from FEMA 227, 255, 256 , 288, and 294,) that show mitigation for natural hazards, including earthquakes, is cost-effective. Post-earthquake investigations show that mitigation works, but there is still the question of cost. Although we are beginning to collect hard data, further studies are needed (Tierney, 1993).

C. The obvious and tacit assumption is that action taken to reduce the loss from earthquakes produces better results than inaction. That is, if a facility is built to higher performance standards, it will suffer less damage than one not constructed to those higher standards. **But the questions are often asked: "How much better? "Is it cost-effective?" "Has it been proven in an actual event?"**

II. As directed by Congress, FEMA currently is sponsoring an extensive effort, managed by the Multi-Hazard Mitigation Council of the National Institute of Building Sciences and being conducted by the Applied Technology Council, to analyze the befits of mitigation, both in terms of direct and indirect benefits using quantitative and qualitative loss criteria. This probably will be a landmark study because such comprehensive studies, especially for earthquakes, can be challenging to perform.

A. Difficulty in performing quantitative cost-benefit analyses for earthquake mitigation is attributed to the following points: 1) placing a dollar value on life itself has not reached universal acceptance (although the FAA and EPA have been issuing reports that include this controversial topic); 2) placing a dollar value on the speculation of damage and disruption is still an inexact process; 3) predicting when and how earthquakes will impact any particular building cannot be done accurately; and, 4) real-life testing before and after mitigation is not possible (California Seismic Safety Commission, 2003).

B. Based on the issues above, the benefits can be difficult to quantify; however, the benefits are becoming more apparent with each major earthquake. In a simple qualitative comparison between seismic performance of buildings in **California compared to other seismically active areas of the world with lower building standards, the benefits are obvious.** As shown in Table 1, the magnitude of losses in recent earthquakes in Turkey, Taiwan, El Salvador, India, and Iran show that, when compared to recent U.S. earthquakes in California, the use of sound design and construction practices is making a difference in controlling losses and especially, **saving lives**: [*Electronic Visual 9.1*]

[***Instructor note****: Point out in table that the most dramatic effect of building codes is* ***saving lives – this is the primary focus of building codes, as will be discussed later.***]

Table 9-1 Comparison of Major Earthquakes

Earthquake	Loma Prieta 1989	Northridge, 1994	Kobe, Japan 1995	Kocaeli, Turkey 1999	Chi-Chi, Taiwan 1999	El Salvador 2001	Bhuj, India 2001	Bam, Iran 2004
Magnitude	7.0	6.7	7.1	7.4	7.6	7.6	7.7	6.6
Mitigation effort	moderate	moderate	low	v. low	low	Nil	nil	nil
Deaths	63	57	5,400	18,000	2,000	1,200	20,000	40,000+
Severely Damaged Buildings	5,700	1,000	150,000	115,000	80,000+	250,000+	1,120,000	>60% of structures collapsed

Visual 9.1 – Comparision of Major Earthquakes. Data source: USGS and California Earthquake Loss Reduction Plan (2002-2006)

C. Although the data in the table above demonstrate that mitigation is effective, e**specially for saving lives**, the 1994 Northridge Earthquake suggests there is still need for improvements to reduce earthquake-related losses, even in California. (Considering the fact that this was the largest U.S. natural disaster, in terms of federal expenditures, although a relatively moderate event located on the fringes of Los Angeles)

D. The geological risk in the central and eastern U.S. (CEUS) by comparison may seem lower than the western U.S. (WUS), but several damaging earthquakes have occurred in this region during historical times. It is a challenge to plan for such low-probability/high-consequence events.

E. What do the effects from the 1994 Northridge Earthquake imply for the eastern and central US?

*[**Instructor note**: Consider prompting an informal class discussion here to stress the fact that if such damage can occur in a relatively small earthquake located on the fringes of a region where mitigation practices are more advanced, then the outlook for much of the central and eastern U.S. is alarming].*

III. Mitigation has both external and internal benefits – that is the "external" benefits of mitigation extended beyond the specific facility or lifeline being mitigated.

For example, if a large neighborhood fire breaks out after an earthquake due to a poorly secured water heater, the homeowner and his neighbors will suffer the direct losses in their homes. In addition to this damage, the costs of the fire department's response, the damage to any public infrastructure, communication or utility lines, as well as other damage could occur. All of this damage could be avoided with proper mitigation. *(Tierney et al, 2001)*

Other social or external benefits resulting from individuals undertaking earthquake mitigation measures include a reduction in emergency response expenses (fire, police), disaster relief and recovery expenses, and economic loss from business disruption. Not only will such measures benefit earthquake disasters, but also will offer significant improvement in addressing other natural and human-induced hazards, such as hurricanes, as well.

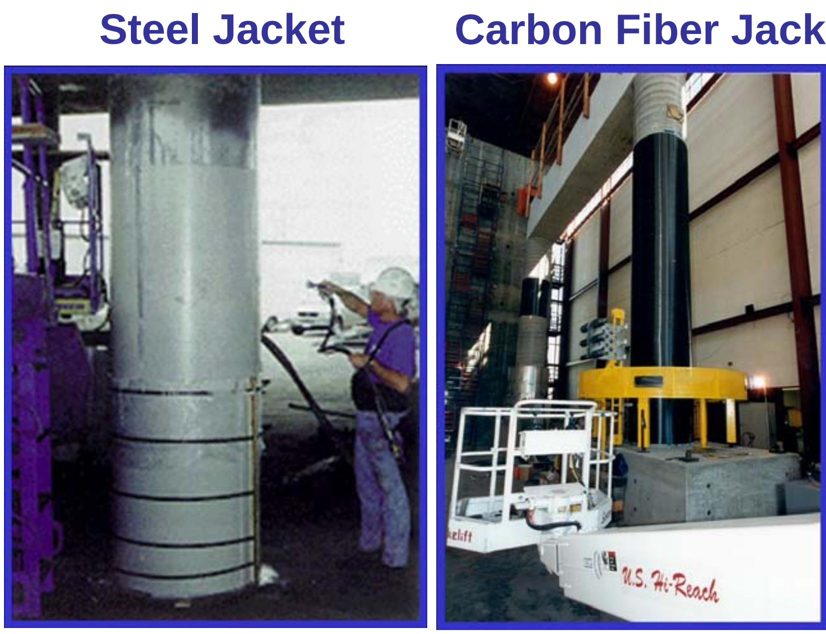
IV. In short, earthquake hazard mitigation offers many benefits:

A. **Saves lives and property –** A community can save lives and reduce property damage from all hazards through earthquake mitigation actions, as more disaster resilience is introduced.

B. **Reduces vulnerability to future hazards, including those other than earthquakes –** By having a mitigation strategy in place, an entity is prepared to take steps that will permanently reduce the risk of future losses from other hazards. In fact, many of the structural mitigation procedures for increasing resilience to earthquakes also are used to increase protection from terrorist-related activities such as bomb blasts. [*Electronic Visual 9.2*].

In fact, it has been shown that the Murrah Federal Building, struck by the 1995 Oklahoma City bombing, probably would not have collapsed had it been designed for even moderate earthquake shaking (FEMA277, 1996).

Visual 9.2 – Failed column during the 1989 Loma Prieta Earthquake (left). Mitigation measures, such as wrapping with carbon fiber or steel jackets (right), are effective in preventing this type of failure. Also, similar methods are used to provide increased blast resistance to columns. (Photo credit: CalTrans).



Visual 9.3 – Steel jackst and carbon fiber jacket. Left: Steel jackets installed on highway columns in Los Angeles, CA; Right: Proof test about to be performed on carbon fiber-jacketed column.

Visual 9.4 – Photo of the collapsed Murrah Federal Building in Oklahoma City following the 1995 bombing. This building would not have collapsed if it had been designed for even moderate earthquake shaking (FEMA277, 1996). Credit: FEMA.

C. **Indirectly benefits response and recovery –** By developing an earthquake mitigation strategy, an entity can identify post-disaster mitigation opportunities in advance of the disaster. By having this strategy thought out in advance, an entity such as a community will be more ready to respond quickly after a disaster and recover faster.

Objective 9.3 Explain the keys to effective hazard mitigation.

Requirements:

The content should be presented as lecture.

Remarks:

I. ***Effective mitigation involves four basic steps*: 1) hazard assessment; 2) creating cost-effective design and construction solutions; 3) setting priorities; and 4) committing the necessary resources.**

II. **Summary of Key Steps for Emergency Managers (***adapted from NHO, 1995 and UN, 2004***):**

A. **Unless and until the entities involved fully understand the risks they face and what they can do to reduce their exposure, comprehend the significant benefits of mitigation, and appreciate the severe consequences and enormous costs of inaction**. In other words, mitigation will fully take hold only when an *informed* public is convinced that it is necessary and feasible; that it is cost-effective and reaps large, long-term dividends; and, that failing to mitigate is both unaffordable and unacceptable. Then, and only then, will America begin to break the vicious, costly, and destructive disaster-rebuild-disaster cycle.

B. **Create a culture of prevention:** As Kofi Annan, Secretary General of the United Nations, stated in 1999, “Building a culture of prevention is not easy. While the costs of prevention have to be paid in the present, its benefits lie in a distant future. Moreover, the benefits are not tangible; they are the disasters that did not happen” (UN, 2004).

C. Earthquake mitigation options should be assessed in terms of their **sustainability**. It is important that earthquake mitigation options reduce the risk to the community from earthquakes, however, it also is important that this is not at the expense of the natural and physical resources or the social, economic, and cultural well-being of communities (Mileti, 1999).

D. **Make natural disaster reduction a public value**. The single key to success is to transform the current national psychology that disasters are somehow unavoidable, or a matter of emergency response alone, to one where every individual assumes responsibility for his/her personal and family safety in the face of inevitable natural extremes.

1. **Shift the emphasis from emergency response and recovery to pre-event mitigation measures.** Recent and ongoing detailed cost-benefit studies suggest very high returns on mitigation investments (i.e., FEMA 294).

2. **Improve early-warning systems.** As mentioned in Session 6, earthquakes cannot yet be predicted, but systems designed to automatically sense ground shaking and shut down critical systems such as subways and gas lines would result in a reduced scale of earthquake disasters.

3. **Promote the adoption and enforcement of technically sound and economically feasible codes, standards, and procedures for the design and construction of new structures and additions to existing structures.**

4. Identify existing structures, **especially critical facilities**, susceptible to earthquake damage and develop methods to reduce such damage. Encourage studies of critical structures and lifeline vulnerability.

5. Perform both structural and non-structural mitigation, especially **for critical facilities such as hospitals, schools, etc.**

6. Support educational, regulatory, legislative, or market-based efforts to promote insurer ability to respond to seismic catastrophes

7. A successful earthquake risk mitigation program will require the combined efforts of the engineering, construction, and insurance professions, as well as federal and local governments (Maffei, 1998). The Loma Prieta, Northridge, and Kobe, Japan Earthquakes were just a glimpse of the risks to life and property that exist for major metropolitan centers – consider regions such as Istanbul, Turkey or Dhaka, Bangladesh.

8. **To dramatically reduce this risk, the value of a building in a seismically active region must reflect the earthquake resistance capability of its structure.** Additionally, incentives must be introduced to encourage building owners to implement earthquake risk mitigation programs (Maffei, 1998).

Objective 9.4 Identify key factors and challenges affecting mitigation.

Requirements:

The content should be presented as lecture.

Remarks:

I. **History has shown that earthquake risk mitigation will not occur widely without incentives or mandates** (Maffei, 1998).

II. **The insurance industry might have the potential for having a dramatic effect on earthquake risk mitigation by the introduction of mitigation incentives**.

If insurance policies required an evaluation of the expected seismic performance of the structure, insurance premiums will reflect the expected seismic risk posed by the structure. It has been suggested that the result would be a strong incentive for mitigation by building owners (Maffei, 1998).

III. **Perception of risk is an important key**.

As will be discussed in Sessions 10 and 11, risk perception is an important factor that determines whether individuals or entities will take mitigation actions (Tierney, et al., 2001). Without the society's understanding of the type and level of risk, it is more difficult to develop and implement strategies for earthquake risk reduction. The first and foremost requirement for a developing society to implement needed risk reduction strategies is to understand the earthquake risk and how it relates to other human-induced or natural risks.

IV. **There are many competing demands on available resources, and it is not always clear how to balance the risk/reward equation**.

What level of resources needs to be spent to achieve an acceptable level of safety is a complex problem. The answer to such a complex question can be especially difficult in less affluent regions and/or developing countries. Consider again the issue of seismic risk in the central and eastern U.S. The risk is significant in this region, but the cost/benefit picture becomes cloudier in such low-probability, high-consequence regions. **It must be decided if the further investment in engineering analysis and construction costs will bear fruit – and this issue is compounded further in cases where the funding for the project is difficult to begin with.** Again, recent studies are starting to demonstrate the cost-effectiveness of mitigation so that these decisions will be more common place (FEMA 294).

V. Political issues are always at play. The costs of mitigation are immediate, while the benefits are uncertain, typically do not occur during the tenure of current elected officials, and are not visible like roads or a new building. **And the costs of land acquisition and hazard-zone mapping for mitigation sometimes can be enormously expensive and exceed the ability of local governments** (NHO, 1995; Tierney et al., 2001).

Communities that are less "public-minded," more individualistic, and more concerned with protection of property rights tend to give little support to hazard mitigation. So, few local governments are willing to reduce natural hazards by managing development. Hazard mitigation can take a back seat to more pressing local concerns like unemployment, crime, housing, and education (Mileti, 1999; NHO, 1995).

[***Instructor note****: You may wish to prompt a discussion here regarding the political issues associated with mitigation actions of local governments, etc.]*.

VI. There often is a perception that the steps required to mitigate earthquake risks have a high cost in the immediate or short term.

The technical community mainly has propagated this perception. The message has been that earthquake-resistant structures require specialized knowledge, and that to build earthquake-resistant structures or to upgrade existing structures to some acceptable level of performance, requires considerable costl. This may be true, but such messages impact on the ability of a community to carry out non-capital intensive actions such as awareness drive, self-help solutions, community-based retrofitting, financial risk management options, disaster management plans, non-structural mitigation, etc. (NRC, 2003; NHO, 1995).

VII. The time between the generation of knowledge from recent earthquake and its implementation on the ground can be long (Mileti, 1999; NHO, 1995).

[***Instructor note***: *Tie in this point with Session 6, stressing the importance of research data and programs such as NEHRP, which have relevance for developing and developed countries. This point also relates to the vulnerability issues that will be discussed in Session 12*].

VIII. Legal-taking claim property rights lobbies are growing stronger.

Legally, local governments need to consider claims that they have reduced the value of private property, and hence must compensate the owner. Thus, to avoid being subject to claim of taking, hazard-related land use regulations should clearly serve a legitimate public interest and be supported by scientific data demonstrating a connection between the regulation and the public interest (Mileti, 1999; NHO, 1995).

[***Instructor note***: *This point can be linked to land-use planning discussed in Session 8 and planning in general discussed in Session 14]*.

IX. The science of identifying hazards designing to reduce their adverse impact is typically beyond the ability of most local governments.

Few planning programs provide detailed instruction in hazard mitigation. Many enforcement personnel have insufficient knowledge to enforce hazards-related code provisions effectively. **Sometimes natural hazards do not respect political boundaries, so hazard mitigation cannot be effective without cooperative intergovernmental coordination.** [See Association of Bay Area Governments (ABAG) as an example of an intergovernmental effort to coordinate hazard mitigation the Bay area of northern California from website at: http://www.abag.ca.gov/bayarea/eqmaps/eqmaps.html].

X. The principal obstacles to greater use of hazard assessment include limited knowledge of the probabilities, magnitudes, and locations of some types of extreme natural events; lack of parcel-specific data on relevant attributes of land uses such as the type, design, and construction of buildings; lack of professional expertise to incorporate risk analysis models into land use decision-making; and lack of understanding and confidence in these models by appointed and elected officials (NAS, 1998)**.**

Objective 9.5 Describe a reasonable mitigation goal, that is, to what standard should we mitigate?

Requirements:

The content should be presented as lecture. The lecture will be enhanced if the instructor presents electronic slides or overheads of the figures below. The instructor is cued as to when the accompanying electronic visual files should be presented.

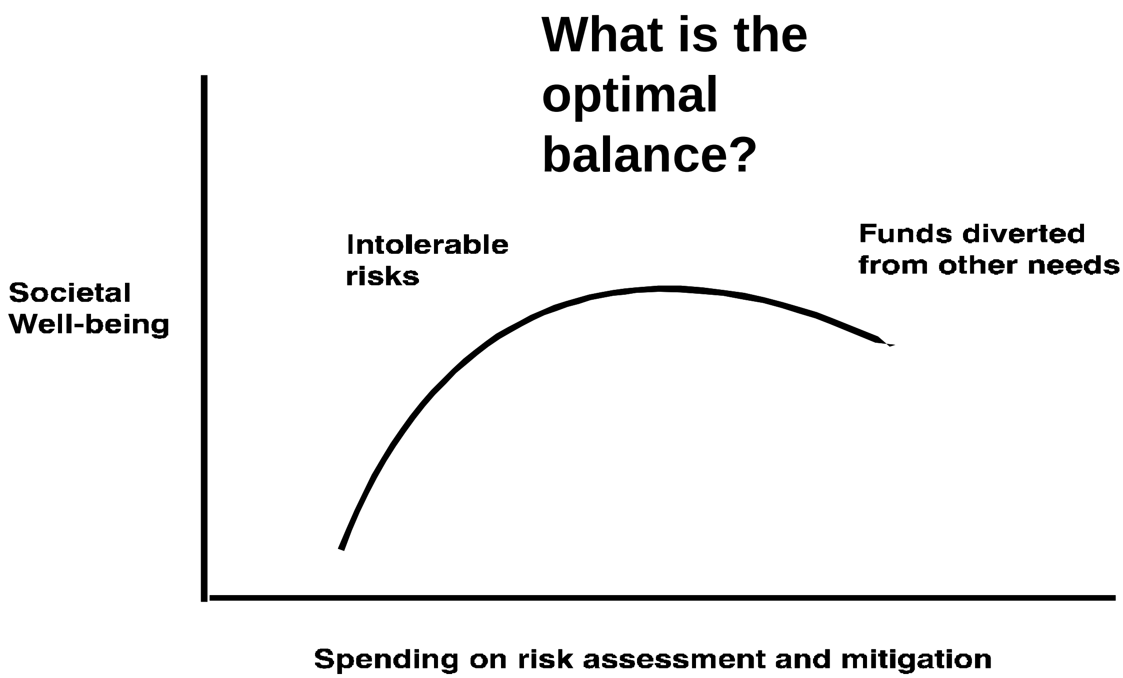
Electronic Visuals Included:

Electronic Visual 9.5 Expenditure on mitigation involves making judgments

Remarks:

I. As mentioned earlier, there are limited resources for mitigation actions, and there is always a tradeoff between the resources that can be allocated to mitigation and to other needs.

Priorities, strategies, and standards provide the foundation for coordination of resources and regulation in a stable society. Decision-making for general management of resources is about value judgments based on incomplete information and imperfect predictions. Inevitably, there are tradeoffs between available resources to mitigate risk and the cultural perceptions and tolerance of those risks (Cowan et al., 2002). We reach a point of diminishing returns, as the relationship might look like: [*Electronic Visual 9.5*]



Visual 9.5 – Expenditure on mitigation involves making judgments of losses weighed against competing priorities for overall societal well-being. Deciding upon the right balance can be a difficult task, especially in less affluent regions (Visual adapted from Cowan et al., 2002).

II. We must ask ourselves "To what standard should we mitigate?"

[***Instructor note***: *Conduct informal classroom discussion by asking the students to answer the question "To what standard should we mitigate*?**"** *Allow an informal discussion to develop and then proceed to present some possibilities below*].

A. **Mitigation should not just occur for the sake of mitigating**. Mitigation needs to make financial sense and needs to be implemented on a case-by-case basis. Incentives that distort the benefit-cost calculations for mitigating need to be avoided.

B. We should focus first on life safety issue, then examine cost-effectiveness. One philosophy is that **we should not seek to eliminate or minimize future earthquake losses –** the costs associated with such a program would greatly exceed the benefit to be gained (Hamburger, 2002).

C. Instead, perhaps **we should seek to develop and implement policies and design and construction technologies that can balance the marginal present-value cost of improving earthquake resistance against the marginal present-value reduction in future earthquake losses (Hamburger, 2002).**

D. For example, when an individual or business is considering undertaking mitigating measures, typically only the marginal private benefits are considered. For example, retrofitting a brick chimney to prevent collapse during an earthquake may cost a certain amount of retrofit dollars ($RD). If the homeowner assigns a probability of that chimney falling during an earthquake (P) and the cost of damage due to the chimney's collapse ($DD), then the homeowner, if risk neutral, will only mitigate if $RD is less than P times $DD. Using proxy numbers, if it costs $500 to retrofit, but the homeowner thought the chance of the chimney falling was 5% and the cost of repairing any chimney damage was estimated to be less than $10,000, the homeowner would not mitigate. Clearly the biggest problem with decisions like these for property owners is assigning correct probabilities for damage. The higher the perceived probabilities are, the more likely the owner will mitigate. However, inaccurate probabilities will result in **too much** or **too little** mitigation (Maeffi, 1998).

E. The techniques now becoming available for analyzing and quantifying risk can prevent or minimize disasters, can improve safety, and can markedly reduce societal disruption following disasters (Helm, 1996). ***Risk assessment*** **is the fundamental basis for the process of** ***risk management*** **and requires adequate knowledge of the phenomenon (hazard) and the ability to evaluate trends. Without such insight, the risk management process has no adequate basis. Again, illustrate the importance of research studies mentioned in Session 6 to form the basis for probabilities.**

III. Mitigation can be incorporated into the design of a new structure; the process usually includes retrofitting via repairs or modifications to an existing structure.

A. Provisions to mitigate seismic damages to new structures are incorporated into building codes.

B. Facilities constructed under the current provisions of regional building codes require that they be built to resist a specified minimum level of force that might be generated by an earthquake. **This minimum level of protection basically is designed to prevent collapse and loss of life, not to minimize damage.** Buildings built prior to the adoption and enforcement of these relatively recent requirements almost never have the desired earthquake resistance. **However, buildings constructed with this minimum level of resistance still could experience considerable structural and nonstructural damage.** This is especially true considering that ground shaking exceeding the building code anticipated level may occur resulting in increased damage to all structures.

C. Existing buildings **in seismically-prone regions constitute the primary source of seismic risk and concern. In the western U.S., buildings constructed prior to mid-1970s are of concern; in other regions of the country, most buildings**

(including fairly recent construction) have little to no seismic protection and are of major concern (MCEER, 2000).

D. In addition to the structure itself, **the contents of buildings and/or their mechanical systems also represent a significant threat to life safety and financial losses**. In many cases, the contents of buildings are more valuable than the building itself. Also, the cost of loss of operation due to damages to either the building or its contents can quickly outweigh the cost of the loss of the buildings itself.

[Instructor note: *This issue is very important to emphasize – the fact that the building contents and/or the loss of operation often are much more significant than the structural losses, as explained more below**].***

E. Thus, the mitigation of constructed facilities and lifelines and their subsystems are categorized into two categories: **structural and nonstructural mitigation.**

1. **Structural mitigation** involves modifying the frame or skeleton of a structure to better withstand the earthquake to which it is exposed.

2. **Nonstructural mitigation** relates to measures designed to reduce damage to a building's architectural elements (ceilings, walls, lights) and mechanical and electrical systems, furniture and equipment, computer installations, machinery and process lines (in industrial environments), utilities and lifelines, and communications. Nonstructural elements can be the major source of loss.

Objective 9.6 Describe structural mitigation measures.

Requirements:

The content should be presented as lecture. The lecture will be enhanced if the instructor presents electronic slides or overheads of the figures below. The instructor is cued as to when the accompanying electronic visual files should be presented.

Electronic Visuals Included:

Electronic Visual 9.6	Soft first-story failure of unreinforced masonry structure
Electronic Visual 9.7	Steel bracing to avoid soft first-story failure
Electronic Visual 9.8	Photograph showing mitigation with bracing
Electronic Visual 9.9	Infilling openings to avoid soft first-story failure
Electronic Visual 9.10	Photo of infilling openings to avoid soft first-story failure
Electronic Visual 9.11	Separation joint filled with elastic material to prevent pounding
Electronic Visual 9.12	Bolting sill plate to foundation
Electronic Visual 9.13	Steel cross-bracing added to steel-framed building

Electronic Visual 9.14 Column wrapped with carbon fiber
Electronic Visual 9.15 Failure of an unreinforced masonry structure
Electronic Visual 9.16 Wall strengthened using a fiber-reinforced sheet
Electronic Visual 9.17 Dampers added to reduce shaking of building
Electronic Visual 9.18 Dampers being installed in San Francisco building
Electronic Visual 9.19 Base isolator bearings installed to support building columns

Remarks:

I. Buildings:

[***Instructor note:*** *Much of the following is adapted from FEMA, 2000. Note that it is impractical (if not impossible) to attempt a discussion that completely covers of all conceivable mitigation strategies for all types of buildings in this session. Moreover, such a discussion would be beyond the scope of this course.* ***Therefore, only <u>some</u> of the most common problems and possible mitigation strategies are discussed under this objective. The list of issues and corresponding strategies will necessarily be incomplete.***]

A. Buildings are the most commonly damaged public facility in earthquakes.

B. **The seismic performance (degree of damage) of a structure is sensitive to** the design and construction detailing, structural material, configuration of the structure, and the type of foundation. Although strength is important, the parameter of primary concern in seismic engineering is **system ductility**[1]**—**the ductility of the system must be greater than the ductility demand on the structure. Proper seismic detailing (i.e., spiral wrapping of reinforced concrete columns, adequate reinforcement of connections/joints), is the key to ensuring adequate system ductility. An example of a non-ductile failure is provided in Visual 9.30 with the collapse of the Cypress Freeway (to be discussed later).

C. A building's repair and upgrade needs are dependent on numerous factors, such as the underlying soil conditions, structural type, architectural design, and contents. Determining the most appropriate measures for a building commonly requires an engineer trained in earthquake design with experience with the type of original construction involved.

D. Unreinforced masonry structures perhaps are the most vulnerable, especially if located on weak or liquefiable soils. Also, some early non-ductile reinforced concrete frames are of great concern (the Cypress Freeway in Oakland that collapsed in a non-ductile fashion during the 1989 Loma Prieta Earthquake was constructed in 1957).

[1] Ductility in a simple sense, refers to the system's ability to strain and yield without collapsing. The more ductility, the greater the ability to dissipate energy without collapse. Seismic detailing is the key to ensuring adequate system ductility.

E. As will be discussed and illustrated later, **one of the basic guidelines or principles in the seismic-resistant design and construction of structures is that the whole structure-foundation system should work as a unit, and that the superstructure be tied or anchored properly to the foundation.**

F. **Damage can be due either to structural members (beams and columns) being overloaded or to differential movements between different parts of the structure.** If the structure is sufficiently strong to resist these forces or differential movements, little damage will result. If the structure cannot resist these forces or differential movements, structural members will be damaged, and partial or complete collapse may occur.

G. **Building damage is related to the characteristics of the building, and the duration and severity of the ground shaking.** Larger earthquakes tend to shake longer and harder, and therefore cause more damage to structures. Earthquakes with magnitudes of less than 5 rarely cause significant damage to buildings, since acceleration levels (except when the site is on the fault) are relatively small and the durations of shaking for these earthquakes are relatively short. In addition to damage caused by ground shaking, damage can be caused by indirect earthquake hazards such as buildings pounding against one another, ground failure that undermines the building foundation, landslides, fires, and tsunamis.

II. General Mitigation Techniques and Vulnerabilities: Structures constructed of all types of materials including wood, steel, masonry, and concrete generally can be susceptible to certain modes of failure and damages.

A. **Problem: “Soft first-story” failures –** A common source of damage is attributed to buildings with open areas and little lateral bracing on the first story (i.e., spaces used for open lobbies or garages) that allows collapse under relatively low levels of shaking. Failure or damage due to this mechanism is referred to as a soft or “weak first-story” failure. A soft first-story failure during the 1989 Loma Prieta earthquake is shown below: [*Electronic Visual 9.6*]

Visual 9.6 – Example of soft first-story failure of wooden structure in the Marina District during the 1989 Loma Prieta Earthquake; a garage was located on the first floor. Photo credit: J. Martin.

1. **Common mitigation strategy: reinforce building with steel bracing.**

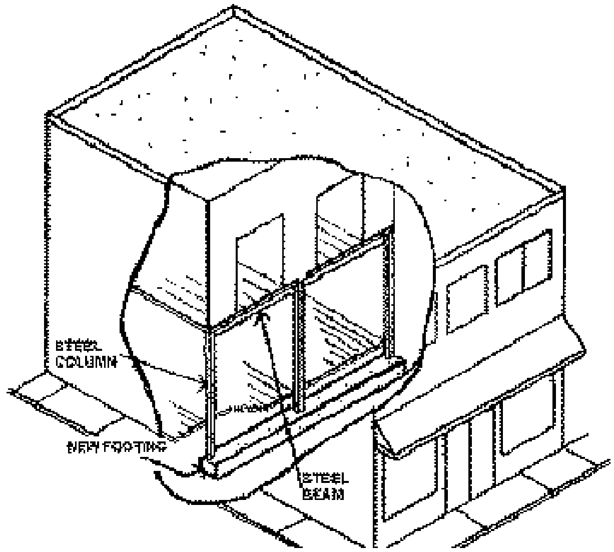
   a. Lateral bracing can be employed through the use of a steel moment frame that allows the open space to be maintained and eliminates the need for infilling openings or additional crosswalls[2]. A steel moment frame is composed of beams and columns welded at their joints and connected to the floor above the open area as shown in the sketch below: [*Electronic Visual 9.7*]

   b. **Effectiveness of this approach**:

      1) Very effective.

      2). Consider crosswalls for maximum effectiveness.

[2] A crosswall is a light-framed wall (i.e., wood framed) sheathed with new or existing materials. Crosswalls function as energy dissipaters and act similar to "shear" walls to the extent that they diminish the displacement of a floor or roof relative to the building base, but are not true shear walls as their in-plane stiffness is not comparable to shear walls of masonry, concrete, or lateral load-resisting elements of structural steel.



Visual 9.7 – Example of steel bracing added to avoid soft first-story failure. Credit: FEMA (2000).

c. Limitations of this approach:

1) Steel moment frame must be adequately connected to the new footing and to the structure.

2) Field welding of the frame components is necessary and a new footing for the frame must be added. [*Electronic Visual 9.8*]

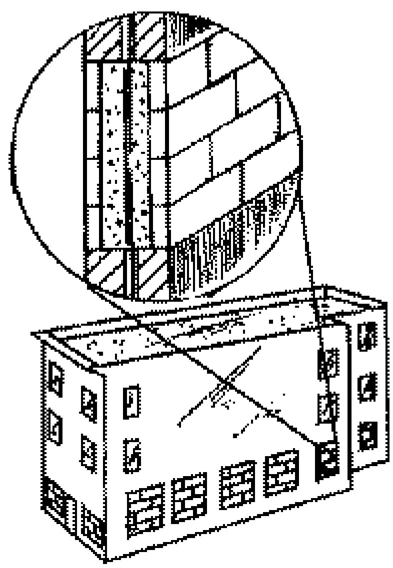
Visual 9.8 – Photograph showing mitigation with wood bracing installed in the garage of a Marina District home following the 1989 earthquake. The bracing was intended to provide lateral support and prevent a future soft first-story failure. Photo credit: G. Clough.

2. **Common mitigation strategy: enclosing or infilling the openings to increase lateral resistance.**

   a. Enclosing or infilling window and door openings increases lateral resistance, increases seismic strength, and reduces the stresses on the walls. Windows and door openings typically are filled with reinforced concrete or reinforced masonry, which is connected to the existing wall using steel dowels. *[Electronic Visuals 9.9, 9.10]*

   b. Effectiveness: Generally very effective.

   c. Limitations: May have significant impact on form and function of the building.



Visual 9.9 – Infilling openings to avoid soft first-story failure. Credit: FEMA (2000).

Visual 9.10 - Photo of infilling openings to avoid soft first-story failure. Credit: NOAA (1999).

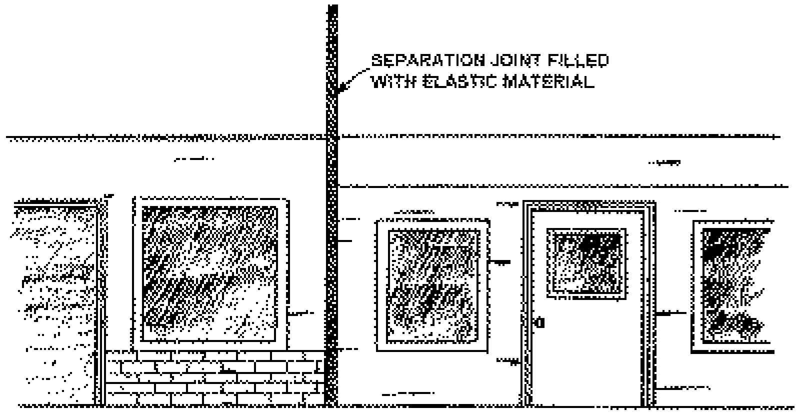
B. **Problem: "Pounding:"** Sometimes different structures are combined within (or immediately adjacent to) one building. For example, a tall, unreinforced masonry structure may be combined with a low-rise, modern, steel-framed addition. These two structures will behave very differently in an earthquake, which can lead to the transfer of damaging impact forces between the two structures and cause either damage or collapse.

1. **Common mitigation strategy:** Using separation joints between structures.

    a. Using separation joints between the structures will allow each structure to behave independently. Exterior joints between the two structures should be filled with elastic materials and then weatherproofed. All separation joints should be wide enough to accommodate differences in lateral movement between the two structures *[Electronic Visual 9.11]*.

    b. Effectiveness: Very effective.

    c. Limitations: The seismic strength of the structures is not increased by the separation joints.

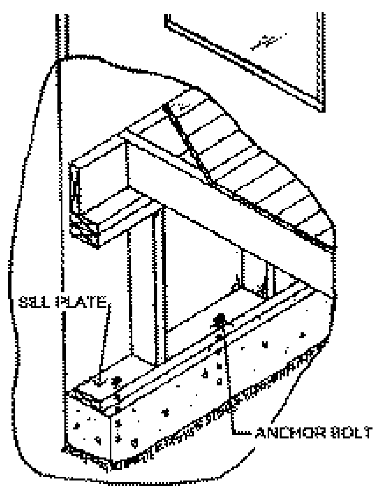


Visual 9.11 – Separation joint filled with elastic material to prevent pounding (FEMA, 2000).

II. Mitigation Techniques for Wooden Structures: Well-designed wood structures have generally performed well in earthquakes due to their light weight and flexibility. Failures often are due to lack of foundation anchorage or unbraced crawlspace (cripple) walls (FEMA, 2000).

A. **Problem:** During an earthquake, a building can shift on the foundation if its sill plate is not anchored to the foundation.

1. **Mitigation strategy**: Anchor sill plate to foundation. Sill plates should be bolted or otherwise anchored to the building foundation. Bolts long enough to pass through the sill plate and penetrate several inches into the foundation should be installed every few feet along the exterior walls. [*Electronic Visual 9.12*]



Visual 9.12 – Example of bolting sill plate to foundation. Credit: FEMA (2000).

a. Effectiveness:

1) Very effective.

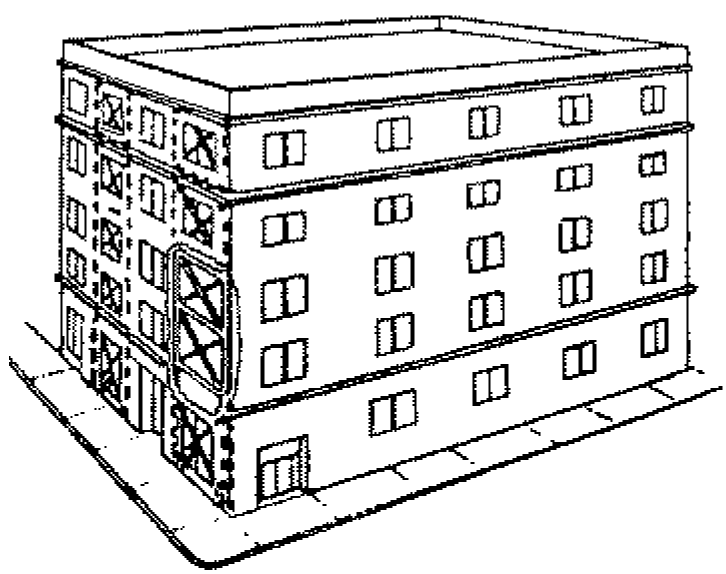
2) Bracing cripple walls can increase effectiveness.

b. Limitations: May require that portions of the walls or floor be temporarily cut away.

III. *Steel Buildings*: Steel structures generally perform well relative to most other structure types. Steel has very favorable strength-to-weight properties.

A. The Problem: Steel moment frame structures may have damage to primary members, distress at connections, and broken or buckled braces and brace connections. Excessive movement between floor levels (story drift) can cause nonstructural damage

1. **Common mitigation strategy:** Reinforce building with cross bracing**.** Full-height, steel cross bracing can increase a building's capacity to withstand seismic forces. Cross bracing can be exterior or interior and is secured to the building at floor level. (*Note: Other techniques such as infill shear walls, doubler plates, replacement or overly welds, stronger bracing and energy dissipaters are other common techniques used but are not presented here for brevity purposes*.)
[*Electronic Visual 9.13*]



Visual 9.13 – Example of steel cross bracing added to increase seismic resistance of steel-framed building. Credit: FEMA (2000).

a. Effectiveness:

1) Somewhat to very effective, depending on pre-disaster building condition and the extent of cross bracing.

2) Increase effectiveness by tying exterior walls to the floors.

b. Limitations:

1) Foundation must be able to support bracing.

2) Restricts useable space, blocks exterior vision and use.

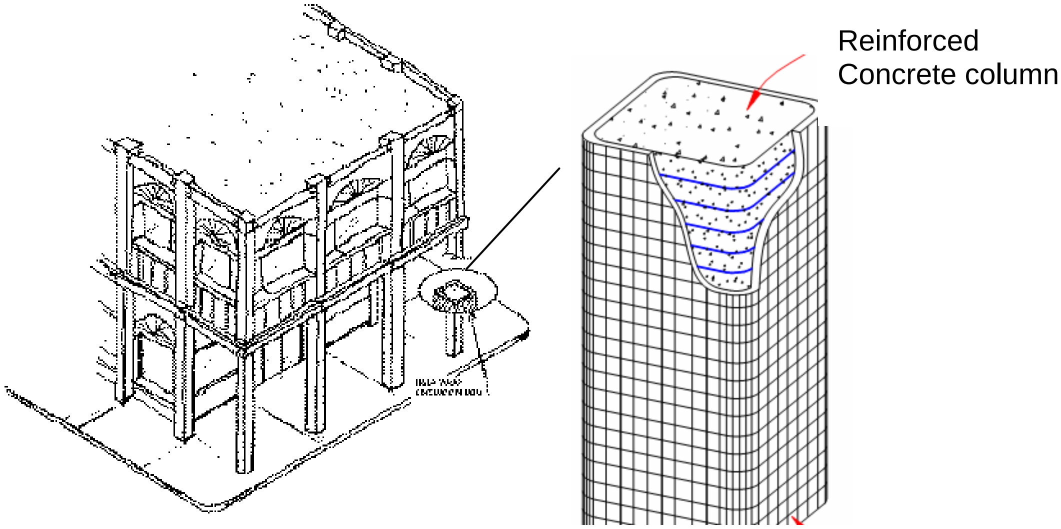
2) Multi-story cross bracing is less effective than cross bracing at each floor level.

V. Reinforced Concrete Buildings. Well-designed reinforced concrete buildings, with adequate system ductility, behave well during earthquake.

A. Problem: Most reinforced concrete buildings are cast-in-place structures that can be damaged to the point of collapse, if the **system ductility is inadequate**. The most vulnerable buildings are those constructed as frame structures without shear walls, and with minimal **ductility** in the beam/column intersections, and inadequate ties in the columns. Usually such vulnerable buildings were constructed after architectural styles favored open office or shop plans with exterior light-weight metal and glass curtain walls, and before building codes were altered to require ductile detailing.

1. **Common mitigation strategy**: Confine columns with steel or carbon fiber wraps.

a. Earthquake forces can buckle reinforced steel within concrete and masonry columns. A fiberglass or carbon fiber wrap around columns will strengthen them and may prevent such failures. The high strength of the fiber wrap confines reinforcing steel in the column and significantly increases the ultimate strength of the column. [*Electronic Visual 9.14*]



Visual 9.14 – Example of column wrapped with carbon fiber in a reinforced concrete building. Credit: FEMA (2000). Closeup, expanded view of the carbon wrap around the concrete column is shown on the right.

b. Effectiveness: Very effective. Technique also provides protection from terrorist activities, such as bomb blasts.

VI. Unreinforced Masonry Buildings (URMs). There are two kinds of masonry construction: unreinforced and reinforced.

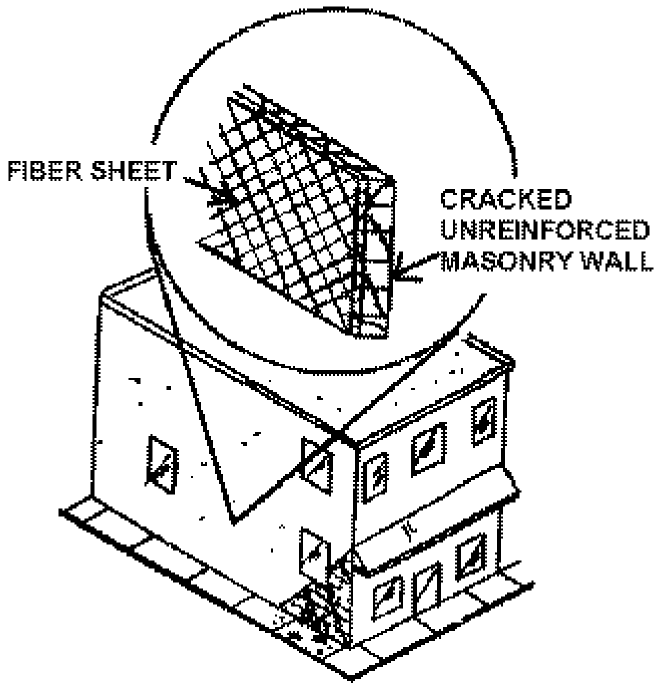
A. Problem: Unreinforced masonry structures, particularly bearing walls, are the form of construction most vulnerable to earthquake damages. Floors and walls of these structures often are not tied together or, when tied together, are only weakly connected. Some older structures have mortar that has deteriorated. Long, unreinforced masonry wall sections, unsupported by intersecting cross-walls, are particularly prone to severe cracking or failure due to the lack of bracing or reinforcing steel. Chimneys in older buildings commonly are damaged or destroyed, creating falling hazards. [*Electronic Visual 9.15*]

Visual 9.15 – Failure of an unreinforced masonry structure during the 1989 Loma Prieta Earthquake – a typical and unfortunate example of non-ductile behavior. Unfortunately, five people were killed at this site as the fourth-floor wall collapsed onto occupied cars waiting alongside the building. Photo credit: J. Martin

1. **Common mitigation strategy:** Reinforce walls with fiber materials.

   a. Earthquake forces may cause extensive crack damage in unreinforced masonry-bearing walls, which can weaken the building. Walls can be strengthened in-place using fiberglass or carbon fiber sheets. The fiber sheeting is secured to the exterior walls using a chemical adhesive and protected with a weather-resistant barrier or other exterior finish. [*Electronic Visual 9.16*]

      [*Note that there are other strategies, such as constructing a steel frame to carry the loads, or even demolishing the building, but for brevity purposes only one possible approach is discussed here*].



Visual 9.16 – Example of wall strengthened in an unreinforced masonry structure using a fiber-reinforced sheet. Credit: FEMA (2000).

b. Effectiveness:

1) Very effective for cracks that threaten structural integrity.

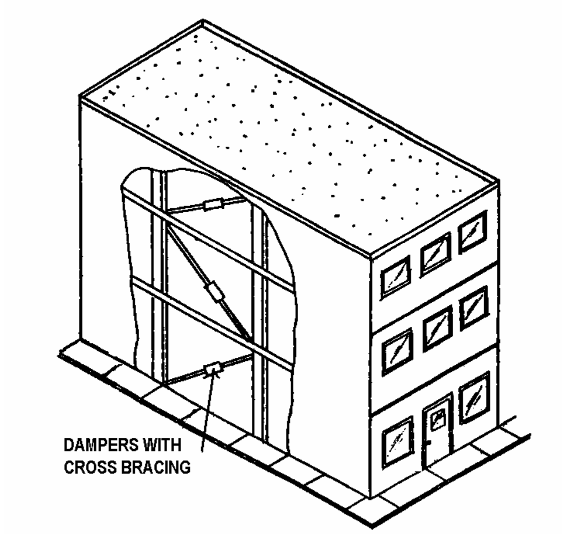
2) Place sheeting on both sides of the walls to increase effectiveness.

c. Limitations: The wall may not be returned to pre-disaster strength if cracking is too severe.

VII. *Alternative Concepts Applicable to All Buildings*: Mechanical damping and base isolation are two approaches that can be used to reduce earthquake damages in buildings.

A. Common mitigation strategy: **Install dampers** [*Electronic Visual 9.17*]

1. **Dampers** can be installed to help absorb movement and increase a building's earthquake resistance. The dampers act similarly to automobile shock absorbers and can be integrated into cross-bracing throughout the building frame. [*Electronic Visual 9.18*]



Visual 9.17 – Example of dampers added to reduce shaking of building during earthquake. Credit: FEMA (2000).

a. Effectiveness: Somewhat to very effective.

b. Limitations: Effectiveness depends on existing building behavior and location of dampers. Steel frames typically are needed to carry the dampers.

Visual 9.18 – Dampers (four large diagonal "shock absorbers") being installed in a new building in San Francisco. Credit: MBDSI (2003).

B. Common mitigation strategy: Base-isolate building with isolation bearings

1. Rigid and brittle buildings can suffer extensive earthquake damage. This damage can be greatly reduced by **isolation bearings**. Vibration isolation bearings are designed to dampen earthquake ground movements before they reach the building and help the building move as a unit. [*Electronic Visual 9.19*]

Visual 9.19 – Base isolation bearings installed to support building columns. Photo credit: G. W. Clough.

a. Effectiveness: Very effective when properly installed.

b. Limitations: Can be relatively expensive.

Objective 9.7 Describe non-building mitigation measures (lifelines).

Requirements:

The content should be presented as lecture. The lecture will be enhanced if the instructor presents electronic slides or overheads of the figures below. The instructor is cued as to when the accompanying electronic visual files should be presented.

Electronic Visuals Included:

Electronic Visual 9.20 Transformer at substation damaged during 1994 Northridge, EQ
Electronic Visual 9.21 Anchorage of transformers for increased seismic resistance
Electronic Visual 9.22 Fire in 1906 and 1989 San Francisco EQs

Electronic Visual 9.23 Broken gas line due to ground movements
Electronic Visual 9.24 Illustration of flexible joints connection to tank
Electronic Visual 9.25 Use of high strength steel pipe improves performance (not shown in text)
Electronic Visual 9.26 The Alaskan oil pipeline is designed to withstand seismic forces
Electronic Visual 9.27 Tank damage (bulging at the bottom) following earthquake.
Electronic Visual 9.28 Tank damage (bulging at the bottom) following earthquake.
Electronic Visual 9.29 Illustration of damaged tank (left) and stiffening of tank walls (right)
Electronic Visual 9.30 Collapse of the Cypress Overpass during the 1989 LPE
Electronic Visual 9.31 Steel jackets installed on highway columns in Los Angeles, CA
Electronic Visual 9.32 Critical areas where the weak, liquefiable soil is threatening to bridges
Electronic Visual 9.33 Soil being densified to prevent liquefaction
Electronic Visual 9.34 Failure of upstream embankment of the Van Norman Dam
Electronic Visual 9.35 Schematic showing berm to increase dam stability

Remarks:

I. In many high and moderate seismic risk areas, earthquakes not only pose a major threat to buildings, but also to *lifelines*.

A. **Lifelines** are those systems, such as power, water, and infrastructure systems, that are **necessary for human life and urban function**, and without which large urban regions cannot exist **– lifelines are essentially the arteries and veins of our communities**.

B. Lifelines basically convey water, fuel, energy, information, and other materials necessary for human existence from the production areas to the consuming urban areas. Seismic disruption of lifelines would lead inevitably to major economic losses and deteriorated public health.

C. **Lifelines** are either ***utility services***, such as water, wastewater, power, gas, and telecommunications, or ***transportation networks*** including roads, rail, ports, and airports.

D. **Utility services and transportation networks can be restored rapidly if mitigation measures are well established and robust recovery plans are already in place.**

E. To mitigate the seismic impact on lifelines, preparation against damage is required by establishing and using seismic design criteria.

F. **Lifelines account for roughly 22% of the total built environment (FEMA, 2000).**

G. **Rapid restoration of lifelines after a disaster is a key factor in how quickly an affected community can recover**.

II. **Utilities [***Note: much of the information in this section is adapted from FEMA, 2000***].**

A. **Utilities include water, wastewater, fuel, electricity, gas, and telecommunications systems.**

1. The basic components of utilities include supply and storage equipment, transmission lines, and the connections between these components.

2. Utility components may be located above ground or underground, and rely on poles, grade level foundations, or soils for support.

B. **Utilities commonly suffer earthquake damage for two reasons**:

1. **Above ground** utility equipment, tanks, pipelines, and connections often are inadequately braced or inadequately secured to their foundation structures.

   a. Like buildings and other facilities, utilities tend to be designed only for vertical gravity loads.

   b. As a result, the equipment anchorage and pipeline bracing may not be strong enough to carry the large lateral forces associated with earthquakes.

2. **Underground utility** pipelines and connections often are too weak or inflexible to withstand earthquake ground movements and differential settlements, causing them to crack or fail. Ground movements are especially a problem for utilities that cross faults or that are located in regions where landslides or liquefaction occurs.

C. **Typical types of utility damage are described below:**

1. **Supply Equipment.** Supply equipment, such as electrical transformers, pumps, or generators, typically is located on grade level foundations or elevated support structures.

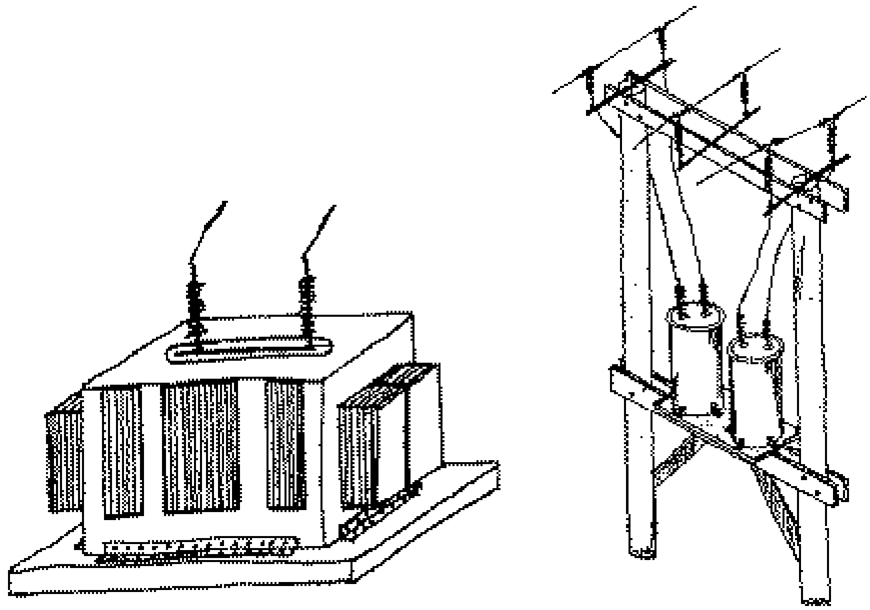
2. **The Problem:** When this equipment is not supported or anchored properly, it may topple or fall from its supports during an earthquake. Supply equipment mounted on separate foundations also can be damaged by differential settlements or relative movements between the foundations. Porcelain components of electrical transformers are brittle and can break during an earthquake. [*Electronic Visual 9.20*]

Visual 9.20 – Damaged transformer at power substation during the 1994 Northridge, EQ (2003, MBDSI).

D. **Common mitigation strategy:** Anchor electrical transformers [*Electronic Visual 9.21*]

1. Ground motions during an earthquake can cause inadequately anchored, pole-mounted transformers to fall, and slab-mounted transformers to slide or topple. Damage caused by the movement of these transformers can be mitigated relatively inexpensively by properly anchoring the transformers to utility poles and the equipment to foundation slabs. Connections to the transformers should be flexible enough to help isolate the forces from other sources. Unanchored electrical and instrumentation cabinets and motor control centers also should be anchored to prevent sliding or toppling.

2. Effectiveness: Very effective.



Visual 9.21 – Anchorage of transformers for increased seismic resistance. Credit: FEMA (2000).

III. Utility Transmission Lines.

A. Utility transmission lines include pipes for water, wastewater, fuel, gas, and electrical conduits that run underground or above grade level.

1. Damage to above-ground transmission lines typically occurs along unsupported line sections when lines crack, leak, or fail.

2. Damage to underground transmission lines usually occurs in areas of soil failure where the line sections cannot withstand soil movements or differential settlements.

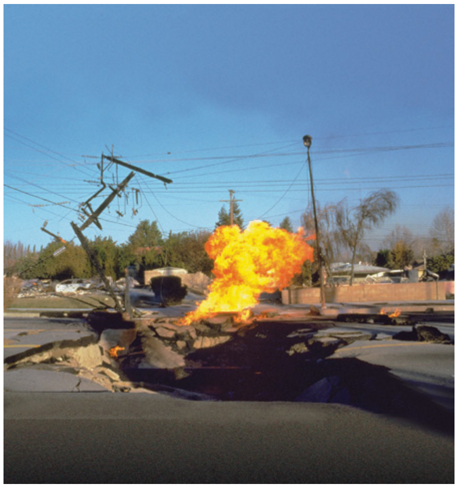
3. In addition to the types of damage listed above, **damage to utilities can trigger secondary damages that affect the community at large. Leaking or broken utilities can cause water damage, fire, or explosion.** Fire is a problem when gas mains rupture and cause fires, and especially when nearby water mains also rupture. There is insufficient water pressure to extinguish the flames.

4. Damage to connections between utility pipeline sections and/or between utility transmission lines and equipment occur where the connections can not withstand soil movements or differential movement.

B. **Almost every major earthquake in an urban region has experienced fire as a secondary effect**, mostly due to ruptured gas mains and electrical fires. During the 1989 Loma Prieta earthquake for instance, gas and water mains in the Marina District ruptured due to ground movements from liquefaction causing fires. Ruptured water mains greatly lessened the ability to extinguish the fires. Similar behavior occurred during the 1906 San Francisco Earthquake in which nearly the entire city burned. [*Electronic Visual 9.22*]

Visual 9.22 – Fires during the 1906 (left) and 1989 (right) earthquake in the San Francisco area. In both events, broken gas mains led to major fires, and broken water lines reduced the capacity to fight the fires. The bottom left photo shows a broken water line from 1906 and the bottom right photo shows a ruptured gas line from 1989. Credit: USGS.

C. **The Problem:** Underground utility transmission lines and connections often are not strong enough to withstand soil movements or differential settlement triggered by earthquakes. Utility pipelines and connections located above ground may not be properly braced against earthquake forces and movements. As a result, transmission lines and their connections can crack, leak, or fail, even damaging other facilities. [*Electronic Visual 9.23*]



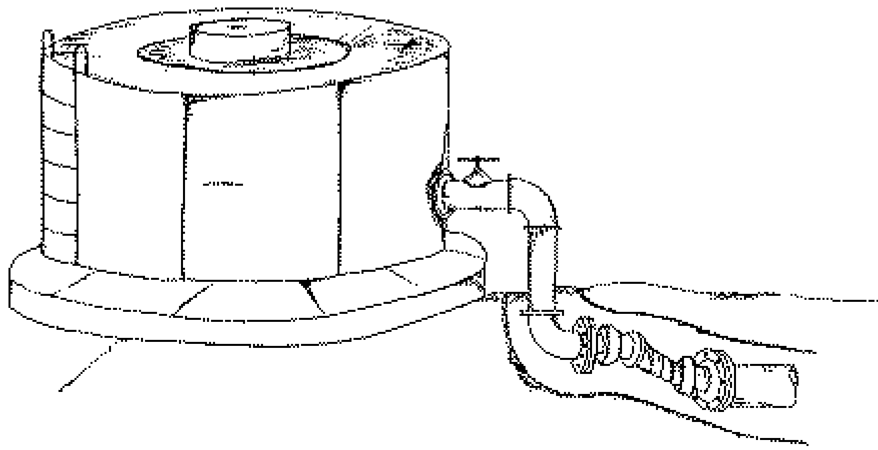
Visual 9.23 – Broken gas and water lines due to ground movements at Balboa Boulevard, Los Angeles, California, 1994 Northridge Earthquake (Credit: USGS Circular, 1242; Photograph by M. Rymer)

1. **Common mitigation strategy:** Install flexible expansion joints [*Electronic Visual 9.24*]

   a. During earthquakes, ground motion can cause transmission lines to leak, crack, or break. Expansion joints can be added to allow some movement. There are a variety of expansion joint configurations and materials available, from flexible, single-layer joints to complex, multilayer composite constructions. Expansion joints are installed as flexible connections at various points along duct and pipe systems to withstand earthquake forces, soil movements and differential settlements.

   b. Effectiveness: Somewhat to very effective.

   c. Limitations: Qualified professionals should design and install expansion joints.



Visual 9.24 – Illustration of flexible joint being used for connection to tank. Credit: FEMA (2000).

2. **Common mitigation strategy:** Install high-strength steel pipes [*Electronic Visuals 9.25(not shown in text), 9.26*].

   a. The performance of underground piping in earthquakes largely is dependent upon the construction material for the pipe. Pipes made of brittle materials, such as cast iron, are particularly vulnerable to breakage during an earthquake. Replacement of pipe made of brittle materials with pipe made of more flexible, ductile materials like steel, ductile iron, copper, and some plastics can mitigate pipe damage from an earthquake.

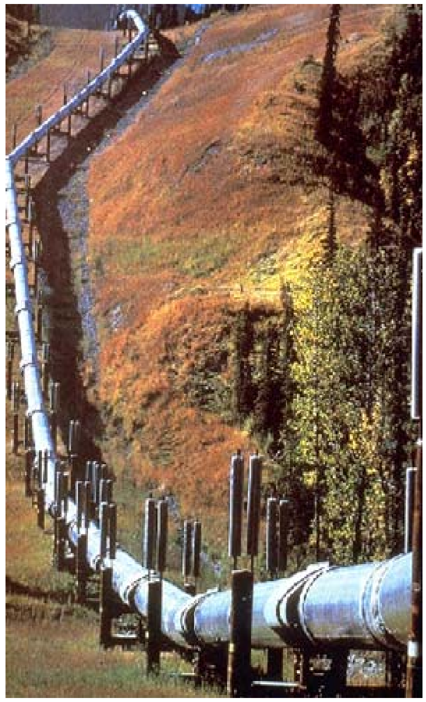
   b. Effectiveness:

      1) Somewhat to very effective, depending on ground displacement.

      2) Strengthening ductile pipe by increasing the pipe wall thickness also can improve the viability of the pipeline.

      3) Corrosion protection measures for buried pipelines in corrosive soils can maintain the pipe strength.

   c. Limitations: May not be cost effective for undamaged underground lines.



Visual 9.26 – The Alaskan oil pipeline had to be designed to withstand seismic force and ground movements. The pipeline consists of flexible supports so the pipeline can undergo relative movement with no damage. This design proved very successful during the magnitude 6.7 Denali Earthquake in 2002. Credit: USGS.

IV. Tanks.

A. Tank structures may be oriented vertically, horizontally, at grade, or elevated. Tall vertical tank structures or standpipes often are damaged by a combination of the structure's reactions to ground shaking and dynamic forces generated by water sloshing inside the tank. Tank foundation supports fail, and buckling of thin tank wall sections often result. The most serious type of vertical tank damage occurs when the tank walls buckle near the base, triggering tank leakage or collapse. Horizontal tanks often are damaged when tanks are not securely anchored to the foundations. Elevated tank structures may be damaged due to buckling of the cross braces between the tank legs. [*Electronic Visual 9.27*]

B. In addition to the types of damage listed above, **damage to utilities can trigger secondary damages that affect the community at large. Leaking or broken utilities can cause water damage, fire, or explosion.** Since these systems are interconnected, a loss of one utility system (such as electrical power) often can lead to a loss of other systems.

C. **The Problem:** Vertical tank structures or standpipes may be improperly anchored to their foundation. Tank wall sections may not be adequate to handle ground movements and the dynamic forces generated by water sloshing inside the tank. Horizontal tank structures may not be sufficiently anchored to their foundations to withstand earthquake forces, and elevated tank structures may not be adequately braced against lateral earthquake forces and movements. As a result, tank structures can move, leak, or collapse during an earthquake, destroying the tanks and creating additional hazards. [*Electronic Visual 9.28.*]

Visual 9.27 – Tank damage (buckling at the bottom) following earthquake. Credit: USGS.

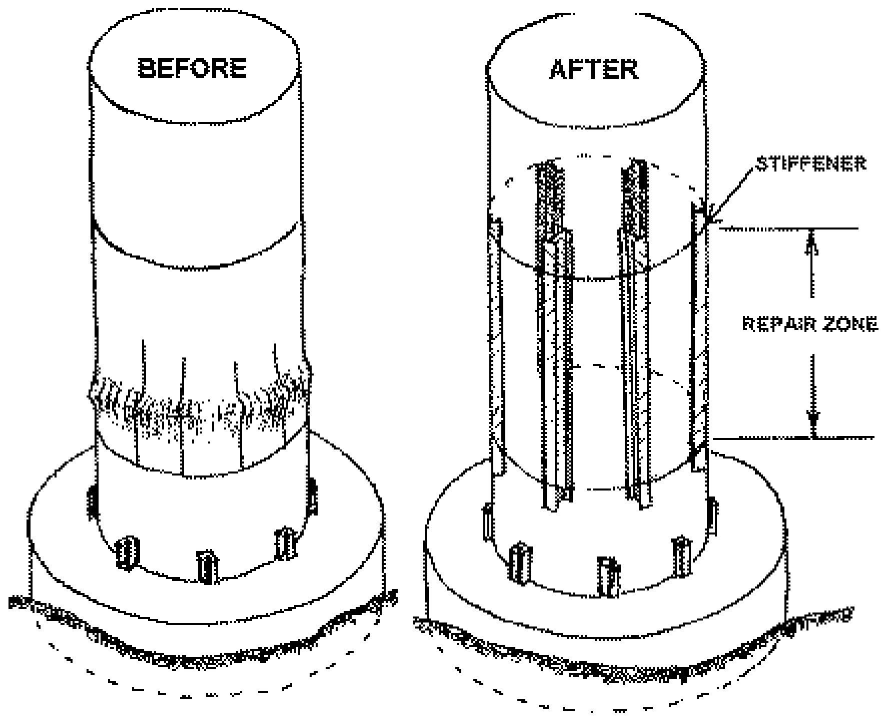
Visual 9.28 – Tank damage (buckling at the bottom) following earthquake. Credit: USGS.

1. **Common mitigation strategy:** Stiffen vertical tank walls

a. Thin tank wall sections can buckle due to seismic forces and the dynamic forces of water sloshing inside the tank. To reduce the risk of future earthquake damage, damaged tank wall sections can be stiffened during repairs with steel beams that are welded to the inside or outside of the tank. [*Electronic Visual 9.29*]

b. Effectiveness: Somewhat effective.

c. Limitations: Repair of tank wall requires emptying, disinfecting, and relining the tank. Can be relatively expensive.



Visual 9.29 – Illustration of damaged tank (left) and stiffening of tank walls (right to mitigate earthquake shaking. Credit: FEMA (2000).

V. Transportation Networks.

A. Earthquakes frequently result in loss of function and significant disruptions of the urban and regional transportation systems. The causes of such disruptions are many: bridge collapse, landslide, impending collapse of an adjacent structure, bursting of a water or natural gas pipe, settlement or compaction, liquefaction, lateral spreading, surface rupture, rock falls, etc.

B. The Loma Prieta, California (October 17, 1989), Northridge, California (January 17, 1994) and Kobe, Japan (January 17, 1995) earthquakes dramatically demonstrated the devastating impact earthquakes can have on highway bridges not adequately protected against seismic forces. So did the bridge collapses observed during the 1999 earthquakes in Kocaeli, Turkey and in Chi-Chi, Taiwan.

C. During the Loma Prieta Earthquake, portions of the Interstate I-880, Cypress Viaduct in Oakland, and one span of the east crossing of the Oakland-San Francisco Bay Bridge collapsed, killing 43 people. The earthquake also caused the collapse of the Struve Slough Bridge near Monterey and damaged 94 other bridges. In addition, the Embarcadero Freeway Viaducts suffered damage so severe they had to be demolished. There were 142 road closures.

D. During the Northridge Earthquake, five bridges collapsed – one on I-5 (Golden State Freeway), one on I-10 (Santa Monica Freeway), two on State Route SR-14 (Antelope Valley Freeway), and one on SR-118 (Simi Valley Freeway). There were 140 road closures. During the Kobe Earthquake, a number of major bridge collapses occurred, including that of the Hanshin expressway.

E. Similarly, during the February 9, 1971 San Fernando (Sylmar) Earthquake, there were two fatalities on the California State Highway System and a number of bridges in the Route 210/Interstate 5 and the Route 14/Interstate 5 interchanges collapsed or had severe damage. The 1964 Anchorage, Alaska Earthquake caused the collapse of nearly all the bridges on a newly completed highway.

F. The principles of structural dynamics, the results of recent researches, and the findings of post-earthquake investigations provide the basis for our current understanding of the seismic response of bridge structures and of their modes of failure. The most frequent causes of failure include:

1. Amplification of the ground motion due to local site conditions.

2. Liquefaction of loose, saturated sands and silts – frequent at bridge sites.

3. Settlement of the abutment fill material and possibly slumping and abutment rotation.

4. Collapse of unrestrained simply supported spans if the seat width cannot accommodate the relative motion of the supports.

5. Unseated girders due to the large relative movements between the girders and the support.

6. Pounding between adjacent spans, at hinges within spans, or between an abutment and an adjacent span.

7. Failure of supporting columns. Single column piers are particularly vulnerable.

8. Failure of their foundations and/or supports and by the lack of integral action between the substructure and the superstructure. Liquefaction of

loose saturated granular foundation soils has been a major source of bridge failure.

G. **The Problem:** The brief summary below shows that the seismic response of bridges is a complex matter and the failure modes are numerous. Therefore, it is not surprising that earthquakes need not be severe to cause serious bridge damage, as evidenced by the collapse of a California freeway bridge (Fields Landing Overhead) during the Trinidad-Offshore Earthquake of November 8, 1980, when the ground acceleration at the bridge site was only 0.10 to and 0.15 g. Clearly, bridges are the most vulnerable component of highway systems, which in most countries are the backbone of the transportation system. [*Electronic Visual 9.30*]

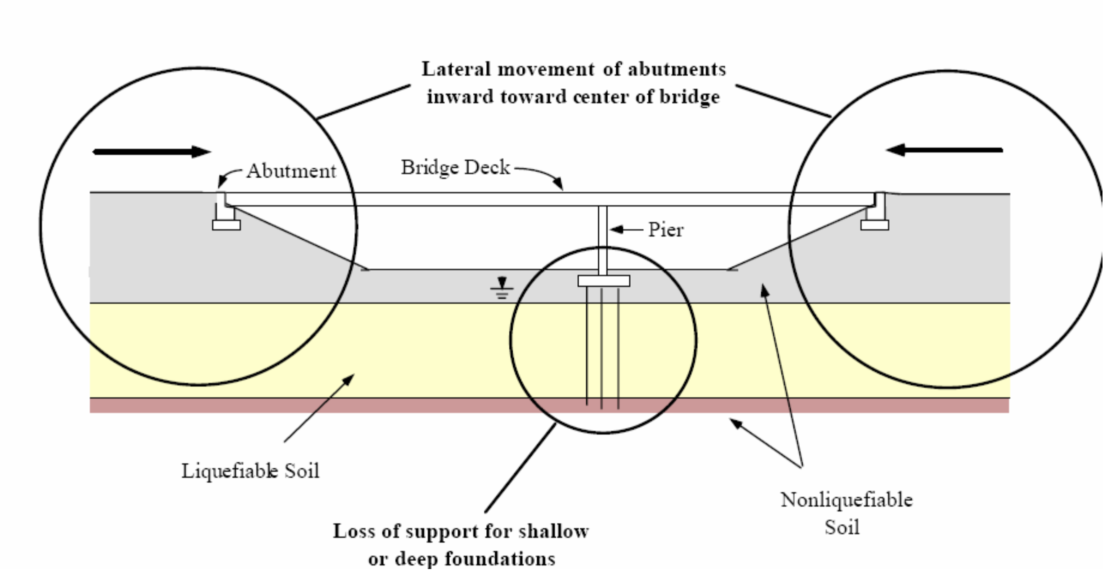
Visual 9.30 - The effects of the 1989 Loma Prieta Earthquake caused collapse of the Cypress Overpass along the Nimitz Freeway. Credt: CalTrans.

1. **Common mitigation strategy:** Use steel or carbon fiber jacket around columns. In some cases it may be necessary to increase the ductility of columns by installing spiral confinement, or to strengthen them using steel jackets, a fiberglass wrap or a composite wrap. Sometimes it is necessary to improve the anchorage of the steel reinforcement in the foundation. [*Electronic Visual 9.31*]

Visual 9.31 – Steel jackets installed on highway columns in Los Angeles, CA as containment for concrete. The jackets prevent the concrete from parting from the steel reinforcing bar, thus keeping the rebar in column and supporintg the column in compression. Credit: CalTrans.

2. **Common mitigation strategy:** Use isolation bearings (see earlier example where this was discussed for buildings). When it is impractical or expensive to upgrade the strength of the bridge superstructure or substructure, it often is possible to use a base isolation system that provides separation of the superstructure from the substructure at the bent cap level. It also can be very economical to use additional passive energy dissipation devices (dampers) to decrease the motion of the superstructure. In these schemes (earthquake protective systems), the dynamic bridge response is modified in such a way that the seismic forces developed in both the substructure and the superstructure are reduced.

3. **Common mitigation strategy:** Use soil improvement in critical zones where liquefiable soils are present. In some instances, strengthening of the foundation is needed to carry the anticipated seismic forces and to prevent liquefaction or slop failures induced by the earthquake. [*Electronic Visual 9.32, 9.33*]



Visual 9.32 – Critical areas where the presence of weak, liquefiable soil is particularly threatening to bridges Credit: Cook (2000).

Visual 9.33 – California site being treated using vibroflot to densify the soils and prevent liquefaction. Credit: J. Mitchell.

VI. Protection and Rehabilitation of Dams.

A. The Problem: Dams located in seismically prone regions are a major source of concern for earthquake as they have very large consequences of failures in terms of potential for loss of life and widespread damage. [*Electronic Visual 9.34*]

Visual 9.34 – Failure of upstream embankment of the Van Norman Dam following the 1971 San Fernando Earthquake. The dam consisted of weak, liquefiable materials. Credit: I. Idriss.

1. **Common mitigation steps:**

   a. Identify condition of dams whose failure could be reasonably expected to endanger human life, the maximum area that could be flooded if the dam failed, and public facilities that would be affected by the flooding.

   b. Ensure that new dams are constructed using methods and procedures that comply with the national dam safety hazard reduction initiative.

   c. Distribute public awareness materials as provided by the state to increase public acceptance and support of dam safety programs.

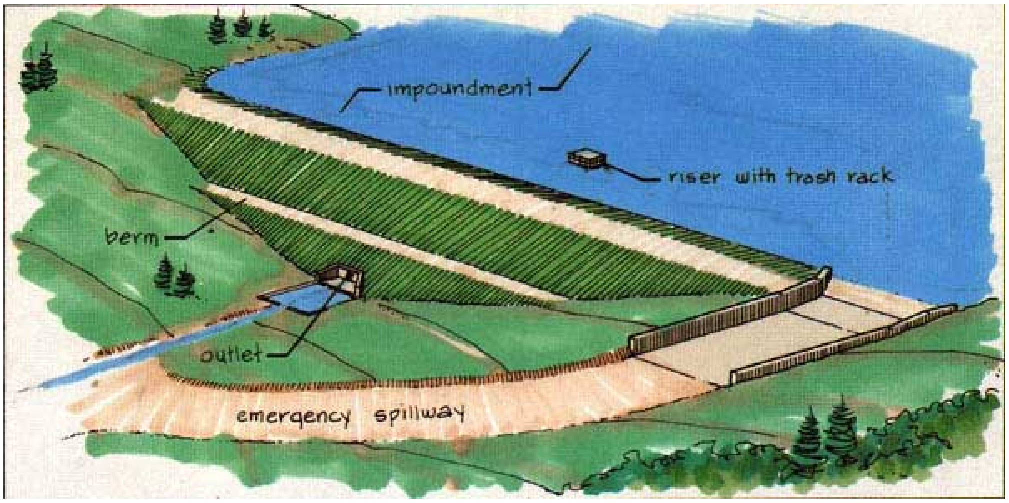
   d. Encourage local representatives or public officials to attend training or workshops regarding hazards associated with dam failure and related matters.

   e. Create, update, and/or maintain existing emergency procedures to be used if a dam fails or if the failure of a dam is imminent.

   f. Identify, review, and implement mechanisms to foster collaboration among jurisdictions, agencies and special districts.

2. **Common mitigation strategies:**

a. Place berm downstream, densify, or strengthen soils in dam or foundation, drain reservoir, and remove/rebuild structure. [*Electronic Visual 9.35*]



Visual 9.35 – Schematic showing berm placed downstream to increase dam stability. Credit: Wisconsin Department of Natural Resources (2003).

Objective 9.8 Recognize the primary purpose of building codes.

Requirements:

The content should be presented as lecture.

Remarks:

I. The *fundamental concept of a building code is to provide a minimum level of protection to the public who occupy buildings; codes are geared toward life safety, not reducing or preventing damage*. Similar to a recipe, a building code is a set of rules that, when followed, produce a result that we can be reasonably confident meets our goals. In the case of a building code, the goal is to produce safe buildings that afford a minimum level of protection to the occupants by preventing collapse and allowing safe exiting from the building.

A. Facilities constructed under the provisions of a building code require that they be built to resist a specified **minimum** level of force that might be generated by an earthquake.

B. The Kobe and Northridge Earthquakes, hurricanes Andrew and Iniki, and the Oakland Hills Fire provide obvious lessons that building codes are important.

Following the Kobe Earthquake, it was determined that buildings constructed under new standards adopted since 1981 performed well, while older buildings rebuilt hastily after World War II, without proper design, suffered great damage.

C. Buildings built prior to the adoption and **enforcement** of these relatively recent requirements usually do not have the desired earthquake resistance. However, buildings constructed with this minimum level of resistance still could experience considerable structural and non-structural damage. This is especially true considering that ground shaking exceeding the building code anticipated level may occur, resulting in increased damage to all structures.

D. Because current **building codes are aimed to protect life safety and prevent major structural failure and not to limit damage**, owners may not understand that a building that is damaged beyond repair still performed as per the code as long as the building did not collapse and kill any occupants.

E. **Today, however, there is a growing trend toward mitigating economic loss by voluntarily setting higher standards to protect property** and ensure continuance of business operations. The combined economic losses from the Loma Prieta earthquake in 1989 and the Northridge earthquake in 1994 exceed $50 billion. Northridge alone resulted in the largest economic loss caused by a natural disaster in the nation's history. We know mitigation can save lives, but significant increases in economic loss have motivated the movement toward even higher levels of mitigation, or at least more reliable levels **– performance-based design.**

F. **Performance-based design** provides the building owner with the tools to make choices about the expected earthquake performance of the building. One of many surprises to the public following the Loma Prieta and Northridge Earthquakes was that the intent of the Uniform Building Code is to afford occupants of buildings with life safety during a significant earthquake. The intent of the code for most building types is not damage control. Performance-based design steps beyond the code and allows building owners to consider a life-safety, operational, or fully operational earthquake performance level for their building. (Maffei).

II. ***U.S. Building Codes:*** **Building codes in the US are regional as different states and localities adopt different codes. There are three US model codes.**

A. ***International Building Code (IBC2003)****:* As of 2003, most states outside of California and certain agencies of the federal government have adopted the IBC2003 Code. The new IBC2003 is new “consensus code” based on the three model codes used for many years (UBC, SBC, and BOCA). The IBC2003 is published by the International Code Council, a nonprofit organization dedicated to developing a single set of comprehensive and coordinated national codes.

B. ***Uniform Building Code (UBC*) is used** in California and other western states. Developed by the **International Conference of Buildings Officials (ICBO),** the organization consists of representatives from local, regional, and state governments. The group investigates and researches principles underlying safety to life and property in the construction, use, and location of buildings and related structures. It publishes the **Uniform Building Codes**. [*Note that this code soon may be replaced by the IBC2003 as well.*]

C. **National Fire Protection Association (NFPA). NFPA recently published the *NFPA 5000, Building Construction and Safety Code, 2003*.** NFPA 5000 is the only building code accredited by ANSI (American National Standards Institute) that spans new construction, building rehabilitation, and enforcement. NFPA 5000 combines regulations controlling design, construction, quality of materials, use and occupancy, location, and maintenance of buildings and structures, with fire and life safety requirements found in NFPA codes and standards, such as the *NFPA 101 Life Safety Code*.

D. ***Building Officials & Code Administrators National Code (BOCA*) and/or "National Code.**" Historically (until about 2000), this code was used in most midwestern, mid-Atlantic, and northeastern states. **BOCA** was founded in 1915, and is headquartered in Country Club Hills, IL. It is a nonprofit member service organization dedicated to professional code administration and enforcement for the protection of public health, safety, and welfare. The organization publishes the **BOCA National Code**. [*This code is now obsolete, being replaced by IBC2003, but is included here for historical completeness.*]

E. **Southern Building Code Congress International (SBCCI).** Historically (until about 2000), this code was used in most southern states. **SBCCI** is more than fifty years old, and was headquartered in Birmingham, Alabama, with regional offices in Austin, Texas and Orlando, Florida. As a membership organization, **SBCCI** serves more than 6,500 members. Among the services provided by **SBCCI** are code-related training courses; a plans review service; and evaluation of building materials, products, and construction methods for compliance with the standard codes production of instructional video tapes and computer software. SBCCI publishes the **Southern *Building Codes* (SBC)**. [*This code is now obsolete, being replaced by IBC2003, but is included here for historical completeness.*]

III. Reference Standards and Voluntary Guidance and Resource Documents.

A. There are a number of **reference standards** and **guidance documents** available as resource documents for design professionals involved in the practice of seismic engineering.

B. Reference standards have been published by a number of agencies and organizations, with the NEHRP/FEMA documents being the most recognized and widely used.

C. Although these and most other standards are national in scope, **they are not enforceable codes (although they can be adopted by reference in building codes)**; rather, they are designed to improve state-of-practice and assist in code development, and often serve as the basis for provisions that later appear in the model codes.

D. These standards also typically reflect the state-of-the art in seismic design and engineering because they serve as the initial forum through which new findings from research studies are introduced to the engineering community in the form of codified language.

E. After appropriate consideration and debate, these provisions typically are adopted, with modifications, into the model codes. In fact, some reference standards are "consensus documents" that have been voted upon by large organizing bodies, a process that lends more credibility toward usage and presumably streamlines the process of adoption into the model codes. In summary:

1. Reference standards typically reflect the latest state-of-the art provisions for earthquake engineering.

2. Reference standards are not legally enforceable documents, except where adopted by reference in building codes.

3. Provisions in these standards typically are adopted by the three U.S. model codes.

4. **NEHRP/FEMA Reference Standards:**

   a. FEMA publications, but developed by BSSC or ASCE, etc.

   b. New research findings from studies of recent earthquakes are incorporated quickly into these standards.

   c. Building codes typically adopt this material directly or with only minor modifications.

   d. Are not legally enforceable, but can be if governing body so chooses.

   e. One issue with nonenforceability is that none of these documents to date are consensus standards that have been voted on by large governing bodies; however, these documents often serve as the basis for consensus standards, such as ASCE-7 and ASCE-31, which satisfy ANSI requirements.

f. Copies of FEMA documents can be obtained directly from FEMA by calling 1-800-480-2520 or from FEMA's web page: http://www.fema.gov.

5. In addition to **NEHRP/FEMA,** the following organizations are involved with the development and publication of reference standards for seismic engineering practice [*Note that only a partial list is provided*]:

a. **American Society of Civil Engineering (ASCE).** ASCE standards are published at both the national and state level. ASCE also develops standards for FEMA. Contact: 1801 Alexander Bell Drive, Reston, VA, 20191; 1-800-548-2723.

b. **American Institute of Steel Construction (AISC.** AISC is a nonprofit trade association and technical institute established in 1921 to serve the structural steel industry in the U.S. Its purpose is to promote the use of structural steel through research activities, market development, education, codes and specifications, technical assistance, and quality certification and standardization. Contact: http://www.aisc.org

c. **American Iron and Steel Institute (AISI).** AISI's overall mission is to provide high-quality, value-added products to a wide array of customers, lead the world in innovation and technology in the production of steel, produce steel in a safe and environmentally friendly manner, and increase the market for North American steel in both traditional and innovative applications

d. **American Forest and Paper Association (AFPA).** AFPA works to provide a unified forum for industry segments to come together to share information and ideas, support important policy initiatives, promote products, and to work on programs beneficial to the industry. AFPA works with organizations such as the American Hardwood Export Council (AHEC), the Softwood Export Council (SEC), APA – the Engineered Wood Association, and the Southern Forest Products Association (SFPA).

e. **Applied Technology Council (ATC).** ATC develops consensus opinions on structural engineering issues, conducts seminars for structural engineers and other professionals, and sponsors projects and workshops to compile resource documents needed for development of guidelines, codes, standards, etc. Contact: 201 Redwood Shores Parkway, Suite 240, Redwood City, CA 94065 Telephone: (415) 595-1542; Fax: (415) 593-2320.

f. **Structural Engineers Association of California (SEAOC).** SEAOC works for the development of improved design and construction provisions for buildings and other structures, especially with respect to earthquake resistance. It encourages general betterment of professional standards. Also, it produces "Blue Book" ("Recommended Lateral Force Requirements and Commentary"), which was the basis for seismic code provisions of the former **Uniform Building Code (UBC)**. Contact: P.O. Box 19440, Sacramento, CA 95819; Telephone: 916-427-3647

g. **American Concrete Institute (ACI).** ACI is a technical society of engineers, architects, contractors, educators, and others interested in improving techniques of design construction and maintenance of concrete products and structures. It operates a 2000-volume library, a speakers bureau, and offers specialized seminars. Contact: P.O. Box 19150, Detroit, MI 48219-0150; Telephone: 313-532-2600; Fax: 313-538-0655.

h. **National Council of Structural Engineers (NCSEA).** NCSEA is a national society of engineers concerned with improving personal safety and economic security through enhanced performance of buildings and structures. These enhancements are achieved through continuing education, including collaboration and cooperation with homeowners, contractors, builders, developers, and government. Contact: http://www.ncsea.com.

i. **National Institute of Building Sciences (NIBS).** The NIBS is a nongovernmental, nonprofit organization established by Congress in 1974 to serve the public interest by promoting a more rational regulatory environment for the building community by facilitating the introduction of new, innovative technology, and disseminating nationally recognized technical information. The NIBS has several councils and standing committees, including the Building Seismic Safety Council (**BSSC**) and the Multihazard Mitigation Council (**MMC**). Contact: 1090 Vermont Avenue, Suite 700, Washington, DC 20005-4905. Web: http://www.nibs.org/nibshome.htm.

6. **Some other organizations that are involved with the development and publishing of standards include** [*Note that only a partial list is provided***]:**

a. **American National Standards Institute** (**ANSI**). ANSI is a private, not-for-profit organization that serves as a clearinghouse for nationally coordinated voluntary standards. It gives status as "American National Standards" to standards developed by agreement from all groups concerned. Contact: 1819 L Street NW, Suite 600, Washington, DC 20036; 212-642-4900.

b. **National Conference of States on Building Codes and Standards (NCSBCS)** was founded in 1967 by the nation's governors to help states improve their building code and public safety programs. It promotes the development of an efficient, cooperative system of building regulation in order to ensure the public's safety in all residential and commercial buildings. Contact: 505 Huntmar Park Dr., Suite 210; Herndon, VA 22070; Telephone: 703-437-0100; Fax: 703-481-3596.

c. **Portland Cement Association (PCA)** consists of manufacturers and marketers of portland cement in the United States and Canada. PCA seeks to improve and extend the uses of portland cement and concrete through market promotion, research and development, educational programs, and representation with governmental entities. Contact: 5420 Old Orchard Rd., Skokie, IL 60077-4321, Tel: 708-966-6200; Fax: 708-966-9781.

d. **Precast/Prestressed Concrete Institute (PCI).** PCI consists of manufacturers, suppliers, educators, engineers, technicians and others interested in the design and construction of prestressed concrete. Compiles statistics, presents annual awards, sponsors continuing fellowships. Contact: 175 W. Jackson Blvd., Chicago, IL 60604, Telephone: (312) 786-0300; Fax: (312) 786-0353.

Objective 9.9 Discuss non-structural mitigation measures (building contents)

Requirements:

The content should be presented as lecture. The lecture will be enhanced if the instructor presents electronic slides or overheads of the figures below. The instructor is cued as to when accompanying electronic visual files should be presented. The homework should be distributed at the end of this objective.

*[Instructor note: It is very important to re-emphasize that building **contents and/or their mechanical systems or loss of operation also represent a significant threat to life safety and financial losses** and often are much more significant sources of losses than the structural losses. Given the importance of this issue, for brevity purposes, this section presents only a very abbreviated coverage of the basic concepts.]*

Electronic Visuals Included:

Electronic Visual 9.36 Special gas valve designed to automatically shutoff
Electronic Visual 9.37 Computers strapped down to table to prevent overturning
Electronic Visual 9.38 Bookcases strapped to wall to prevent overturning

Handouts Included:

Handout 9.1: Homework Assignment 9.1

Remarks:

I. The Problem: Many injuries in earthquakes are caused by nonstructural hazards, such as attachments to all types of buildings. These include lighting fixtures, windows (glass), pictures, tall bookcases, computers, ornamental decorations on the outside of the buildings (like parapets), gas lines, etc.

A. Common mitigation strategies include:

1. **Anchoring tall bookcases and file cabinets, installing latches on drawers and cabinet doors, restraining desktop computers and appliances, using flexible connections on gas and water lines, mounting framed pictures and mirrors securely, and anchoring and bracing propane tanks, water heaters and gas cylinders**. [*Electronic Visuals 9.36, 9.37, and 9.38*]

Visual 9.36 – Special gas valve designed to automatically shut off if ground shaking and/or movement exceeds a preset threshold. Photo credit: J. Shea, FEMA news photo

Visual 9.37 – Computers strapped down to table to prevent overturning during an earthquake. Photo credit: WMD (2003); © Copyright 2003, The State of Washington, Washington Military Department, Emergency Management Division. All rights reserved (photos are subject to copyright but can be used for this document; see http://emd.wa.gov/site-general/terms-conditions.htm).

Visual 9.38 – Bookcases strapped to wall to prevent overturning during an earthquake. Photo credit: WMD (2003); © Copyright 2003, The State of Washington, Washington Military Department, Emergency Management Division. All rights reserved (photos are subject to copyright but can be used for this document; see http://emd.wa.gov/site-general/terms-conditions.htm).

2. **Secure suspended ceilings and overhead lighting.** Suspended ceilings and overhead lighting fixtures typically fail where anchorage is poor, or

the runners that support the panels and lights are too weak to withstand lateral earthquake forces. Unbraced suspended ceilings can swing independently of the supporting floor and be damaged or fall. Installing "four-way" diagonal wire bracing and compression struts between the ceiling grid and the supporting floor will significantly improve the ceiling's seismic performance. In addition to the struts, the connections between the main runners and cross runners should be capable of transferring tension loads

3. **Bracing large windows.** Glass windows typically crack or shatter when the frames are distorted or damaged. The principle causes of glass breakage are window frame distortion and inadequate edge clearance around the glass. Stiffening bracing or redesigning of the window frame can reduce future damage. Bracing usually consists of steel tie rods anchored to the corners of the window frame and connected by a turnbuckle. Another method is to use specially designed windows that use wider frames and include a compressible material between the frame and the window glass to avoid direct contact between the window and the frame

4. **Bracing interior partitions.** Interior partitions of all types and ages of buildings often are made of materials that fail when not secured to the floor or roof system. Partitions in older buildings may be constructed of heavy, brittle materials and can topple unless they are braced against the floor or roof of the building.

   Interior partitions can fail during an earthquake. Retrofitting can be done with connections that restrict the partitions from sideways movement while allowing vertical movement. Interior partitions generally need lateral support from ceilings or from the floor or roof framing. Unreinforced masonry partitions also can be replaced with drywall partitions.

   Unbraced partitions that do not extend to the floor or roof framing should be braced to the framing. Steel channels sometimes are provided at the top of the partition to provide lateral support, and allow some floor or ceiling movement without imposing any loads on the partition.

[*Distribute Handout 9.1: Homework Assignment 9.1*]

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