# 2. Behavior of Nonstructural Components

Effective seismic risk reduction strategies for nonstructural component damage begins by clearly understanding the scope and nature of nonstructural components in buildings, their behavior in earthquakes, and the consequences of damage. The next section will address the following key questions:

- What are nonstructural components?
- What are the primary causes of damage to nonstructural components during earthquakes?
- What is the significance of nonstructural component damage?
- Which nonstructural components are most vulnerable in an earthquake?
- What are the consequences of damage to nonstructural components?

**A picture is worth a thousand words.**

The Hyogo Earthquake Engineering Research Center in Japan has posted video footage of shake table testing of nonstructural components during a simulated earthquake. Two of these video clips speak volumes about the hazards of nonstructural components during an earthquake. The video clips focus on the behavior of furniture, contents, and some architectural components.

Figure 2-1 Result of shaking table test on room contents (from 01, 2008 test)

Click on the link below and select one of the following video clips:

-Shaking table tests on room safety issue of a high-rise building (01, 2008)

-Shaking table tests on non-structure furniture in a high-rise building (03, 2007)

http://www.bosai.go.jp/hyogo/movie.html – click on English and then click on Movies. Scroll down to Office Space in High Rise Jan 2008 – Click on Video

## 2.1 Definitions

Buildings consist of both "structural" and "nonstructural" components. The distinction between the two types of building components is described below.

### *2.1.1 Structural Components*

The structural components of a building resist gravity, earthquake, wind, and other types of loads and typically include the following elements:

- vertical supports such as columns, posts, pillars, and pilasters
- horizontal supports such as trusses, girders, beams, joists, and purlins
- load-bearing walls that provide vertical support or lateral resistance
- diagonal elements such as braces
- floor and roof slabs, sheathing or decking
- foundation systems such as slabs on grade, mats, spread footings, or piles

The structural system of buildings is typically analyzed and designed by a civil or structural engineer and is presented on construction drawings or plans, except in the case of houses. The structural components of a typical building can be seen on Figure 2.1.2-1 by clicking on the "structural components only" button.

### *2.1.2 Nonstructural Components*

The nonstructural components of a building include all building parts and contents except for those previously described as structural. These components are generally specified by architects, mechanical engineers, electrical engineers, and interior designers. However, they may also be purchased and installed directly by owners or tenants after construction of a building has been completed. In commercial real estate, the architectural and mechanical, electrical, and plumbing systems may be considered a permanent part of the building and belong to the building owner; the furniture, fixtures, equipment and contents, by contrast, typically belong to the building occupants.

In this guide, nonstructural components are divided into three broad categories:

> **Architectural COMPONENTS** such as partitions, ceilings, storefronts, glazing, cladding, veneers, chimney, fences, and architectural ornamentation.

**Mechanical, electrical, AND PLUMBING (MEP) COMPONENTS** such as pumps, chillers, fans, air handling units, motor control centers, distribution panels, transformers, and distribution systems including piping, ductwork and conduit.

**Furniture, Fixtures & Equipment (FF&E), And contents** such as shelving and book cases, industrial storage racks, retail merchandise, books, medical records, computers and desktop equipment, wall and ceiling mounted TVs and monitors, file cabinets, kitchen, machine shop or other specialty equipment, industrial chemicals or hazardous materials, museum artifacts, and collectibles.

The list of nonstructural components is nearly endless and constantly evolving, as new technologies alter our built environment. Figure 2.1.2-1 displays a typical building with nonstructural components discussed in this document, along with typical structural components. Clicking the “structural components only” button strips away the layer of nonstructural components to emphasize the ubiquity of architectural, MEP, and FF&E components in the built environment.

Note that most structural components are typically concealed from view by nonstructural materials, such as architectural finishes. For example, in steel construction, fireproofing is typically applied directly to steel members and then covered with finish materials such as gypsum board. In wood construction, there is usually no way to visually distinguish between a non-load-bearing partition and a structural or shear wall. Steel diagonal braces are often hidden inside walls. Similarly, mechanical, electrical, and plumbing components are also typically concealed by architectural components.

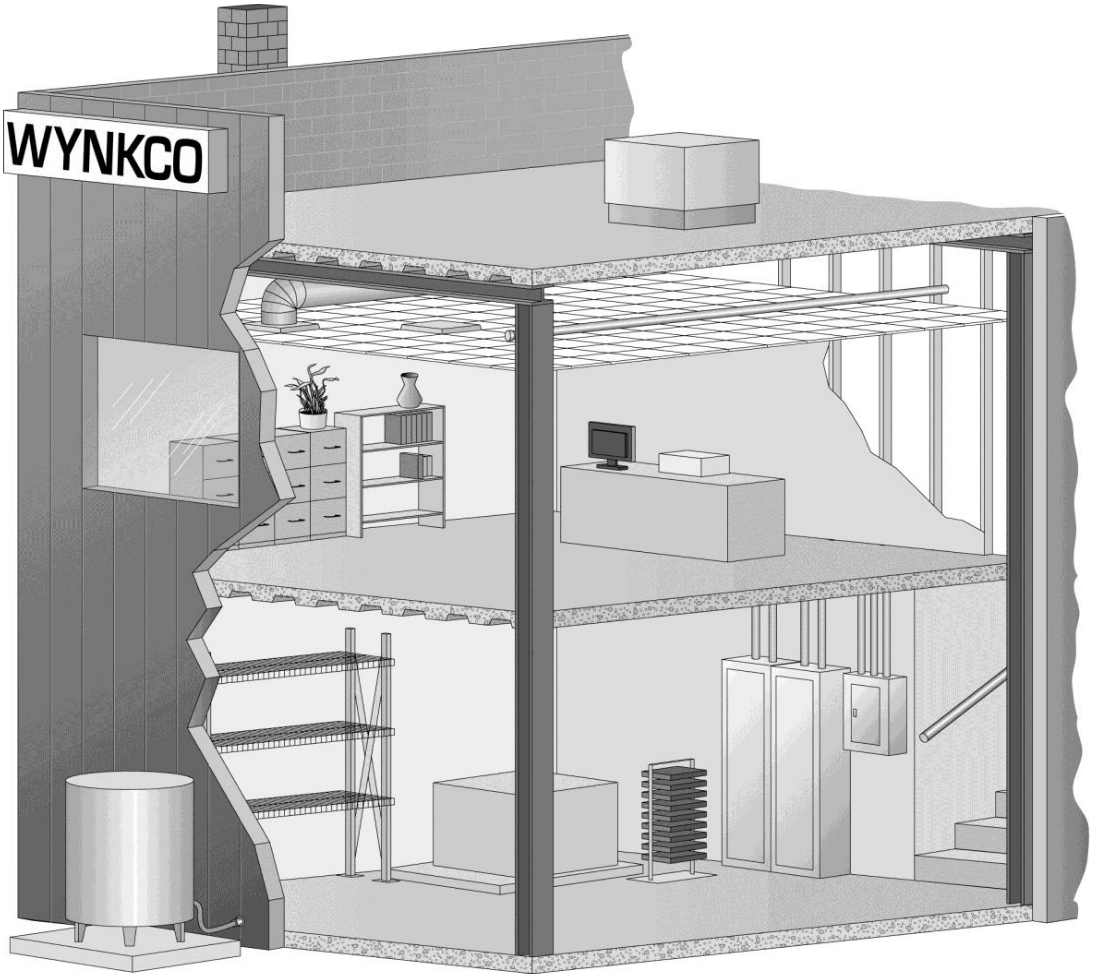

Figure 2.1.2-1 A three-dimensional view of a portion of a building. This figure shows both structural and nonstructural components.

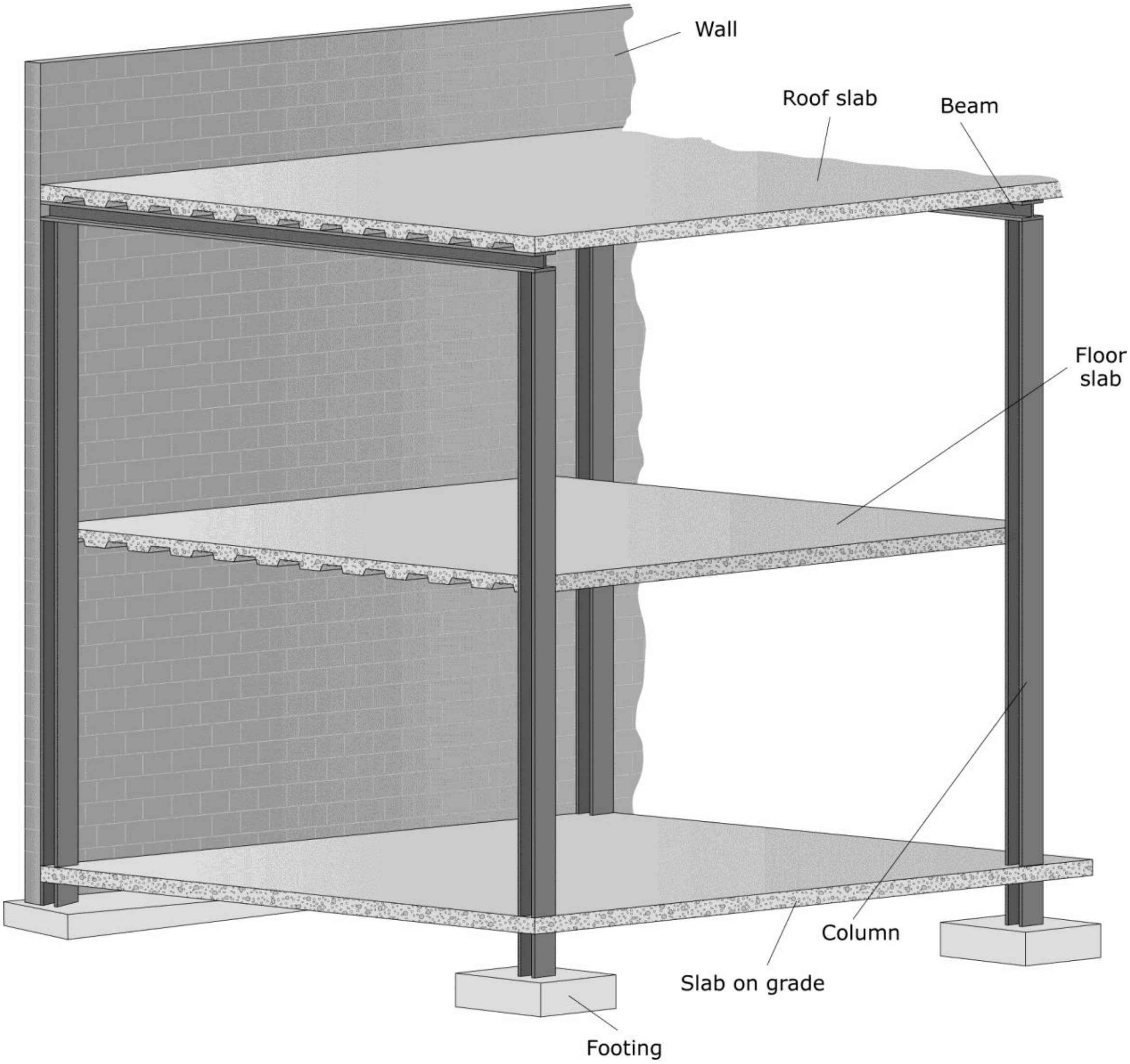

Figure 2.1.2-2 A three-dimensional view of a portion of a building showing structural components only.

### 2.1.3 Relative Costs

In general, the structural components of a commercial building account for approximately 15-25% of the original construction cost, while the nonstructural (mechanical, electrical, plumbing, and architectural) components account for the remaining 75-85% of the cost. Contents belonging to the building occupants, such as movable partitions, furniture, and office or medical equipment, represent a significant additional value at risk. When these costs are compared, it becomes clear that the largest capital investment in most commercial buildings is in the nonstructural systems and contents. This is illustrated in Figure 2.1.3-1 below for three common types of commercial construction (Whittaker and Soong, 2003).

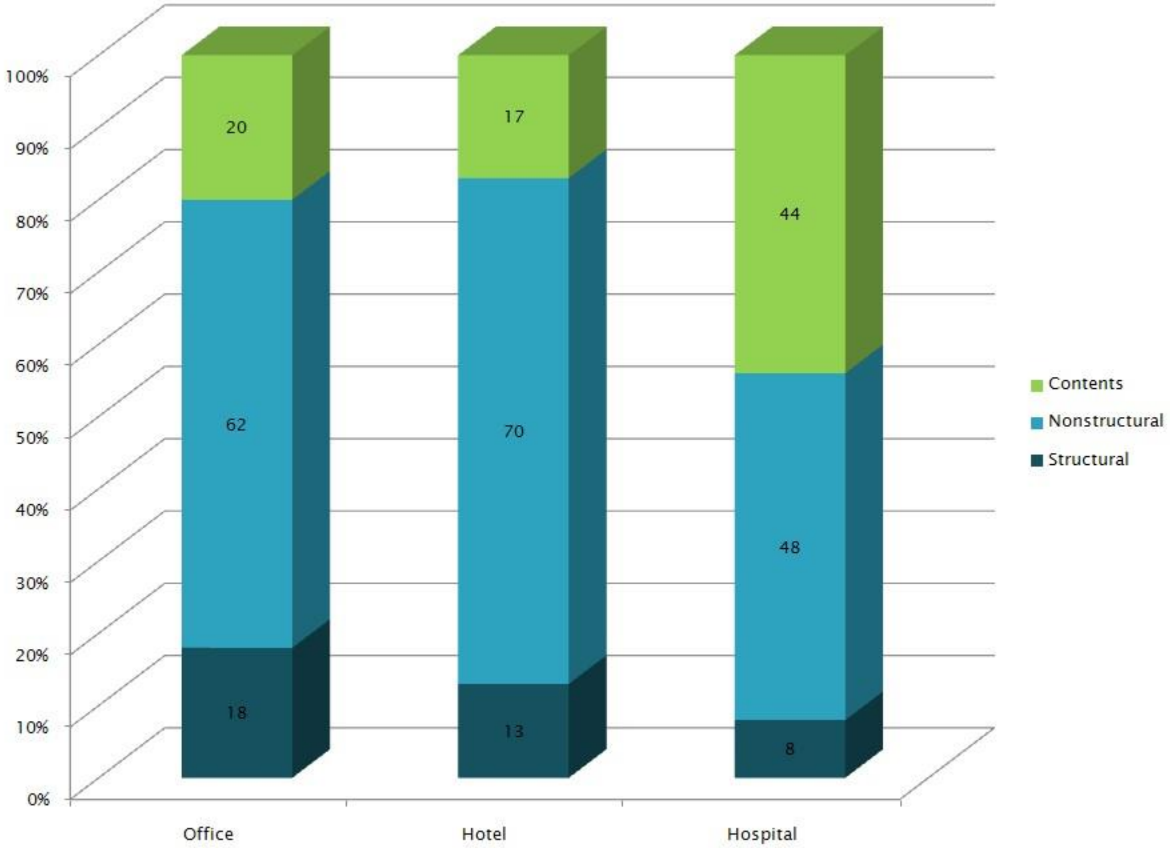

Figure 2.1.3-1 Typical investments in building construction.

## 2.2 Causes of Nonstructural Damage

Earthquake ground shaking causes damage to nonstructural components in four principal ways:

- Inertial or shaking effects cause sliding, rocking or overturning (Section 2.2.1).
- Building deformations damage interconnected nonstructural components (Section 2.2.2).
- Separation or pounding between separate structures damage nonstructural components crossing between them (Section 2.2.3).
- Interaction between adjacent nonstructural components (Section 2.2.4) cause damage.

### *2.2.1 Inertial Forces*

When a building shakes during an earthquake, the base of the building typically moves in unison with the ground. The entire building and its contents above the base experience inertial forces that push them back and forth in a direction opposite to the base excitation. In general, the earthquake inertial forces are greater if the mass of the building is greater, if the acceleration or severity of the shaking is greater, or if the location is higher than the base, where excitations are amplified. Thus, the earthquake forces experienced above the base of a building can be many times larger than those experienced at the base.

When unrestrained or marginally restrained items are shaken during an earthquake, inertial forces may cause them to slide, swing, rock, strike other objects, or overturn (see Figure 2.2.1-1). File cabinets, emergency generators, suspended items, free-standing bookshelves, office equipment, and items stored on shelves or racks can all be damaged as they move and contact other items, fall, overturn or become disconnected from attached components. The shaking can also cause damage to internal components of equipment without any visible damage or movement from its original location.

**Analogy: Passenger in a Moving Vehicle**

As a passenger in a moving vehicle, you experience inertial forces whenever the vehicle is rapidly accelerating or decelerating. If the vehicle is accelerating, you may feel yourself pushed backward against the seat, since the inertial force on your body acts in the direction opposite to that of the acceleration. If the vehicle is decelerating or braking, the inertia forces may cause you to be thrown forward in your seat.

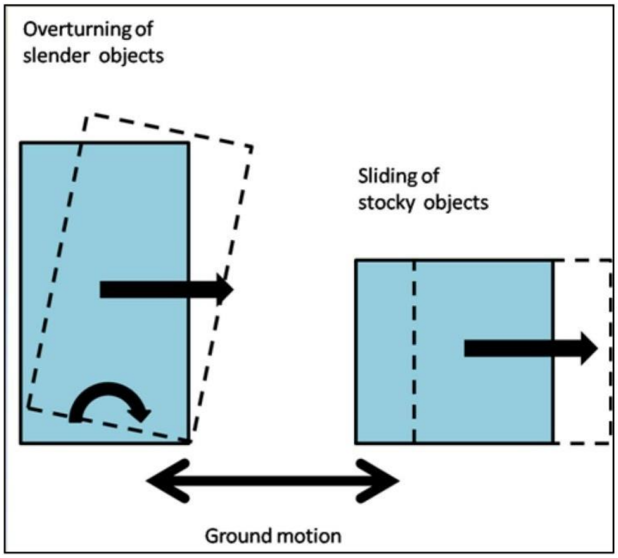

Figure 2.2.1-1 Sliding and overturning due to inertial forces.

### 2.2.2 Building Deformations

During an earthquake, structural members of buildings can deform, bend or stretch and compress in response to earthquake forces. For example, the top of a tall office tower may lean over a few feet in each direction during an earthquake. The horizontal deformation over the height of each story, known as the story drift, might range from a quarter of an inch to several inches between adjacent floors, depending on the size of the earthquake and the characteristics of the particular building structure and type of structural system. The concept of story drift is shown in Figure 2.2.2-1.

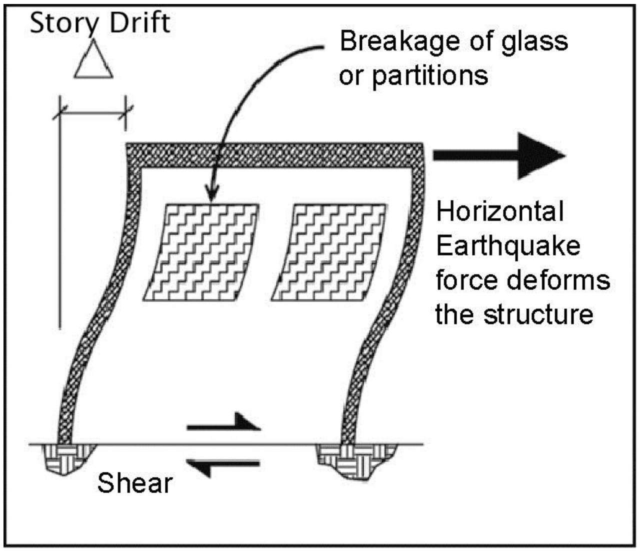

Figure 2.2.2-1 Nonstructural damage due to building deformation.

When the building deforms, the columns or walls deform and become slightly out of square and thus, any windows or partitions rigidly attached to the structure must also deform or displace the same amount. Brittle materials like glass, plaster partitions, and masonry infill or veneer cannot tolerate any significant deformation and will crack when the space between stops or molding closes and the building structure pushes directly on the brittle elements. Once cracked, the inertial forces in the out-of-plane direction can cause portions of these architectural components to become dislodged and to fall far from their original location, possibly injuring passers-by underneath them.

**Structural – Nonstructural Interaction: Problem with Short Columns**

There have been many notable examples in past earthquakes where rigid nonstructural components have been the cause of structural damage or collapse. These cases have generally involved rigid, strong architectural components, such as masonry infill or concrete spandrels that inhibit the movement or deformation of the structural framing and cause premature failure of column or beam elements. When a structural column is restrained by nonstructural components, it is often referred to as a "short column" or "captive column." This is a serious concern for the design of structural systems. Designers of nonstructural components must be mindful to isolate their systems from the deformations of the adjacent structural components or to make sure that the structural components have been designed to accommodate the interaction.

## 2.2.3 Building Separations

Another source of nonstructural damage involves pounding or movement across separation or expansion joints between adjacent structures or structurally independent portions of a building.

A seismic joint is the separation or gap between two different building structures, often two wings of the same facility, which allows the structures to move independently of one another as shown in Figure 2.2.3-1.

In order to provide functional continuity between adjacent structures or between structurally independent portions of a building, utilities must often extend across these building joints, and architectural finishes must be detailed to terminate on either side. The separation joint may be only an inch or two wide in older construction or a foot or more in some newer buildings, depending on the expected horizontal movement, or seismic drift between buildings. Flashing, piping, conduit, fire sprinkler lines, heating, ventilation, and air-conditioning (HVAC) ducts, partitions, and flooring all have to be detailed to accommodate the seismic movement expected at these locations when the two structures move closer together or further apart. Damage to items crossing seismic separation or expansion joints is a common type of earthquake damage. If the size of the gap is insufficient, pounding between adjacent structures may result, which can damage structural components but more often causes damage to nonstructural components, such as parapets, veneer, or cornices on the façades of older buildings.

**Base-Isolated Buildings**

A special type of seismic joint occurs at the ground level of base-isolated buildings, which are separated from the ground by seismic shock absorbers or isolators, in order to reduce the transfer of earthquake accelerations to the building. The seismic joint typically occurs between the foundation below the isolator and the building above. These joints may be as much as several feet wide; special detailing is required for all the architectural finishes and

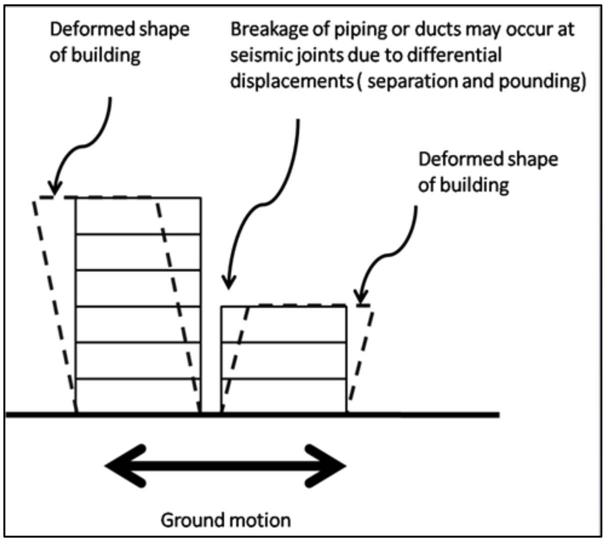

Figure 2.2.3-1 Nonstructural damage due to separation and pounding.

### *2.2.4 Nonstructural Interaction*

An additional source of nonstructural damage is the interaction between adjacent nonstructural systems which move differently from one another. Many nonstructural components may share the same space in a ceiling plenum or pipe chase; these items may have different shapes, sizes, and dynamic characteristics, as well as different bracing requirements.

Some examples of damaging nonstructural interactions include:

- Sprinkler distribution lines interact with the ceiling causing the sprinkler heads to break and leak water into the room below.
- Adjacent pipes of differing shapes or sizes are unbraced and collide with one another or adjacent objects.
- Suspended mechanical equipment swings and impacts a window, louver, or partition.
- Ceiling components or equipment can fall, slide, or overturn blocking emergency exits.

## 2.3 Extent of Nonstructural Damage

There are many factors affecting the performance of nonstructural components during an earthquake and the extent to which they will sustain damage. The degree of damage caused by the four principal effects previously described depends upon considerations such as the components' dynamic characteristics, their location in the building, and their proximity to other structural or nonstructural components. Other factors include the type of ground motion, the structural system of the building, the location and placement of the loads, the type of anchorage or bracing, if any, the strength of the structural supports used for anchorage, potential interaction with other nonstructural components, and the potential for secondary damage.

A survey of 25 damaged commercial buildings following the 1971 San Fernando Earthquake revealed the following breakdown of property losses: structural damage, 3%; electrical and mechanical, 7%; exterior finishes, 34%; and interior finishes, 56%. A similar survey of 50 damaged high-rise buildings, which were far enough away from the earthquake fault rupture to experience only mild shaking, showed that whereas none had major structural damage, 43 of the buildings suffered damage to drywall or plaster partitions, 18 suffered damaged elevators, 15 had broken windows, and 8 incurred damage to their air-conditioning systems (Steinbrugge and Schader, 1973).

ATC-69 *Reducing the Risks of Nonstructural Earthquake Damage, State-of-the-Art and Practice Report* (ATC, 2008) summarizes the current state of knowledge and practice regarding the seismic performance of nonstructural components of buildings. This study confirmed the lack of systematic and comprehensive post-earthquake documentation of nonstructural performance and recommended development of a standardized framework for the collection of future nonstructural earthquake damage data.

**Engineering Considerations: Extent of Damage**

- Unique characteristics of the ground shaking at the site (e.g., high or low frequency motion, proximity to fault)
- Characteristics of the structural system supporting the nonstructural elements (e.g., the structure may be tall and flexible, short and stiff, or short and flexible)
- Location of the nonstructural item within the building (e.g., items may be at the basement, at mid-height or roof level; items may cross seismic joints or may be located in close proximity to deforming structural elements)
- Distribution and placement of loads (e.g., heavy loads situated near the bottom of shelving units and lighter items above, or the reverse; countertop lab equipment close or far from the edges of counters)
- Anchorage or restraint conditions (e.g., items may be unanchored, marginally anchored, or well anchored)
- Condition of structural elements used for anchorage (e.g., location and strength of studs in a wall used to anchor tall cabinets or shelving, location of reinforcing bars in concrete used to anchor heavy items, condition of mortar in old masonry walls)
- Potential interaction with structural elements or other nonstructural elements (e.g., rigid granite veneer covering a flexible steel column or a well-anchored ceiling grid with unbraced sprinkler lines).
- Potential for secondary damage caused by release of fluids, gases, toxins, asbestos, and other hazardous substances (e.g., damage to asbestos insulation requires evacuation, a gas leak results in a fire)

## 2.4 Importance of Nonstructural damage

Historically, earthquake engineers have focused on the performance of structural systems and ways to mitigate structural damage. As the earthquake engineering community moves toward more comprehensive earthquake standards and expectations of improved seismic performance, and as the public demands a higher level of earthquake protection, it is important to understand the significance of nonstructural damage.

The failures of nonstructural components during an earthquake may result in injuries or fatalities, cause costly property damage to buildings and their contents; and force the closure of residential, medical and manufacturing facilities, businesses, and government offices until appropriate repairs are completed. As stated previously, the largest investment in most buildings is in the nonstructural components and contents; the failures of these elements may be both dangerous and costly. The potential consequences of earthquake damage to nonstructural components are typically divided into three types of risk:

| | |
|---|---|
| **Life Safety (LS)** | *Could anyone be hurt by this component in an earthquake?* |
| **Property Loss (PL)** | *Could a large property loss result?* |
| **Functional Loss (FL)** | *Could the loss of this component cause an outage or interruption?* |

Damage to a particular nonstructural item may present differing degrees of risk in each of these three categories. In addition, damage to the item may result in direct injury or loss, or the injury or loss may be a secondary effect or a consequence of the failure of the item.

The focus of this guide is on nonstructural hazards; nevertheless, existing structures may also have structural hazards that pose risks to life safety, property, and functionality. While it may make sense to implement simple and inexpensive nonstructural protection measures even in a building with structural hazards, the relative structural and nonstructural risks should be considered, so that limited resources can be used in the most effective manner. It would give little comfort to know that the pipes and ceilings were all well anchored in an unreinforced masonry structure that could collapse during an earthquake.

The three risk categories are also sometimes referred to as:
the **3Ds**: Deaths, Dollars, and Downtime;
the **3Cs**: Casualties, Cost, and Continuity;
or merely Safety, Property, and Function.

### 2.4.1 Life Safety (LS)

The first type of risk is that people could be injured or killed by damaged or falling nonstructural components. Heavy exterior cladding dislodged during earthquakes has killed passersby (Tally, 1988; Adham and Brent, 1985). Even seemingly harmless items can cause death if they fall on a victim. If a 25-pound light fixture not properly fastened to the ceiling breaks loose during an earthquake and falls on someone's head, the potential for injury is great. Life safety can also be compromised if the damaged nonstructural components block safe exits in a building. Damage to life safety systems such as fire protection piping can also pose a safety concern should a fire start following an earthquake. Examples of potentially hazardous nonstructural damage that have occurred during past earthquakes include broken glass, overturned tall, heavy cabinets and shelves, falling ceilings and overhead light fixtures, ruptured gas lines and other piping containing hazardous materials, damaged friable asbestos materials, falling pieces of decorative brickwork and precast concrete panels, dislodged contents stored overhead, and collapsed masonry parapets, infill walls, chimneys, and fences.

The following anecdotes from past earthquakes will help to illustrate the point. Damage photos are shown in Figures 2.4.1-1 thru 2.4.1-5. Additional damage photos are provided in Chapter 6.

- More than 170 campuses in the Los Angeles Unified School District suffered nonstructural damage during the 1994 Northridge, California earthquake. At Reseda High School, the ceiling in a classroom collapsed and covered the desks with debris. The acoustic ceiling panels fell in relatively large pieces, 3 feet or 4 feet square, accompanied by pieces of the metal ceiling runners and full-length sections of fluorescent light fixtures. Because the earthquake occurred during hours when the building was unoccupied, none of the students were injured (Los Angeles Times, 1994).

- A survey of elevator damage following the 1989 Loma Prieta Earthquake revealed 98 instances in which counterweights came out of the guide rails and six instances where the counterweight impacted the elevator cab, including one case in which the counterweight came through the roof of the cab. No injuries were reported (Ding, 1990). An elevator survey following the Northridge Earthquake indicated 688 instances in which counterweights came out of the guide rails, in addition to reports of other types of elevator damage. An occurrence of a counterweight becoming dislodged and impacting the elevator cab was captured on film during the 2010 Chile Earthquake.

- One hospital patient on a life-support system died during the 1994 Northridge Earthquake because of failure of the hospital's electrical supply (Reitherman, 1994).

- During the 1993 Guam Earthquake, the fire-rated nonstructural masonry partitions in the exit corridors of one resort hotel were extensively cracked, causing many of the metal fire doors in the corridors to jam. Hotel guests had to break through the gypsum wallboard partitions between rooms in order to get out of the building, a process that took as long as several hours. It was fortunate that the earthquake did not cause a fire in the building and no serious injuries were reported.
- Damage to industrial storage racks commonly used in "big box" stores has been reported in most recent earthquakes. Damage has ranged from dislodged contents to partial collapse of racking systems. Collapsed racking systems have been documented in both the 1994 Northridge Earthquake and the 2010 Christchurch New Zealand Earthquake. To date, related deaths and casualties have been avoided due to limited occupancy at the time of earthquake shaking.

Figure 2.4.1-1 Failure of office partitions, ceilings, and light fixtures in the 1994 Northridge Earthquake (FEMA 74, 1994).

Figure 2.4.1-2 Shards of broken untempered glass that fell several stories from a multistory building in the 1994 Northridge Earthquake. Failures of this type can be very hazardous, especially if glazing is located above exit ways (FEMA 74, 1994).

Figure 2.4.1-3 Failure of suspended ceilings and light fixtures in a furniture store (FEMA 74, 1994).

Figure 2.4.1-4 Failure of heavy stucco soffit at building entrance in the 1994 Northridge Earthquake (FEMA 74, 1994).

Figure 2.4.1-5 Damage to overloaded racks during the 1994 magnitude-6.7 Northridge Earthquake (FEMA 460, 2005).

### 2.4.2 Property Loss (PL)

As discussed previously, nonstructural components, such as mechanical and electrical equipment and distribution systems and architectural components, account for 75-85% of the original construction costs of a typical commercial building. Contents belonging to the building occupants, such as movable partitions, furniture, and office or medical equipment, represent a significant additional value at risk. For example, a high tech fabricating facility may have contents that are worth many times the value of the building and built-in components of the building. Immediate property losses attributable to contents alone are often estimated to be one third of the total earthquake losses (FEMA, 1981).

Property losses may be the result of direct damage to a nonstructural item or of the consequences produced by its damage. If water pipes or fire sprinkler lines break, then the overall property losses will include the cost to repair the piping (a primary or direct loss), plus the cost to repair water damage to the facility (a secondary or indirect loss). If the gas supply line for a water heater ruptures and causes a fire, then clearly the property loss will be much greater than the cost of a new pipe fitting. Many offices and small businesses suffer losses as a result of nonstructural earthquake damage but may not keep track of these losses unless they have earthquake insurance that will help to cover the cleanup and repair costs.

Figure 2.4.2-1 Complete loss of suspended ceilings and light fixtures in the 1994 Northridge Earthquake (FEMA 74, 1994).

Figure 2.4.2-2 Damage to inventory on industrial storage racks in the 1994 Northridge Earthquake (FEMA 74, 1994).

The nonstructural property losses can be much larger if they occur at library and museum facilities whose function is to store and maintain valuable contents. For example, as a result of the 1989 Loma Prieta Earthquake, two libraries in San Francisco each suffered over a million dollars in damage to building contents; the money was spent primarily on reconstructing the library stacks, rebinding damaged books, and sorting and reshelving books. At one of these facilities, $100,000 was spent rebinding a relatively small number of rare books alone (Wong, 1993; Dobb, 1993).

### *2.4.3 Functional Loss (FL)*

In addition to life safety and property loss considerations, there is the additional possibility that nonstructural damage will make it difficult or impossible to carry out the functions that were normally accomplished in a facility. After life safety threats have been addressed, the potential for postearthquake downtime or reduced productivity is often the most important risk. For example, if a business loses the use of its computers, filing system, or other instruments of service as a result of earthquake damage, then the dollar loss of replacing the damaged items may be relatively small, but the loss in revenue associated with downtime during recovery can be tremendous. In light of the global economy, loss of function can also translate to longer term loss of market share for some businesses as consumers find alternate suppliers for needed goods or services.

Many external factors may affect postearthquake operations, including power and water outages, damage to transportation systems, availability of materials and contractors to repair damage, civil disorder, police lines, and curfews. These effects are generally outside the control of building owners and tenants and beyond the scope of this discussion.

The following are examples of nonstructural damage that resulted in interruptions to postearthquake emergency operations or to businesses:

- During the 1994 Northridge Earthquake, nonstructural damage caused temporary closure, evacuation, or patient transfer at ten essential hospital facilities. These hospitals generally had little or no structural damage but were rendered temporarily inoperable, primarily because of water damage. At the majority of these facilities, water leaks occurred when fire sprinkler, chilled-water, or other pipelines broke. In some cases, personnel were unavailable or unable to shut off the water, and water was flowing for many hours. At one facility, water up to 2 feet deep was reported at some locations in the building as a result of damage to the domestic water supply tank on the roof. At another facility, the emergency generator was disabled when its cooling water line broke where it crossed a separation joint. Other damage at these facilities included broken glass, dangling light fixtures, elevator counterweight damage, and lack of emergency power due to failures in the distribution or control systems. Two of these facilities, shown in the following figures, Los Angeles County Olive View Medical Center and Holy Cross Medical Center, both in Sylmar, California, that had suffered severe structural damage or collapse during the 1971 San Fernando Earthquake had been demolished and entirely rebuilt by the time of the 1994 Northridge Earthquake (Reitherman, 1994).

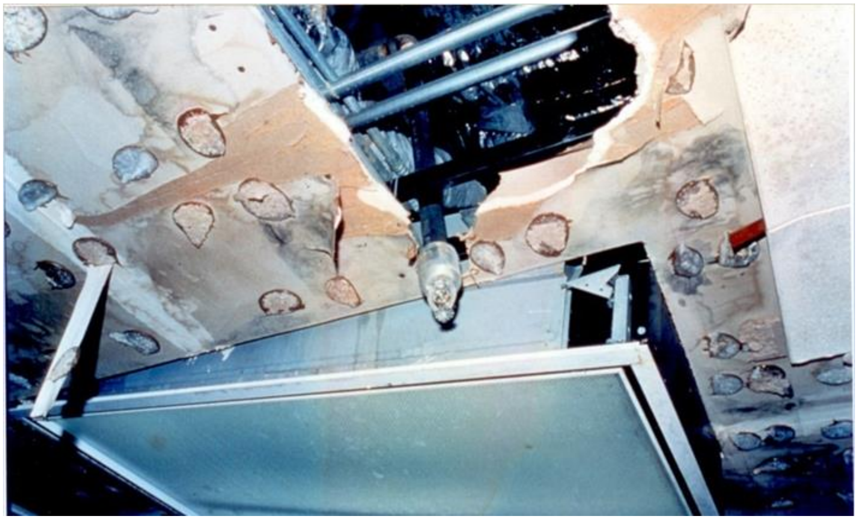

Figure 2.4.3-1 Broken sprinkler pipe at Olive View Hospital in Sylmar, California as a result of the 1994 Northridge, Earthquake. Pipe ruptured at the elbow joint due to differential motion of the pipe and ceiling (FEMA 74, 1994).

Figure 2.4.3-2 HVAC damage at Holy Cross Medical Center in Sylmar in the 1994 Northridge Earthquake. Damage to signage and louvers was caused when suspended fans in the mechanical penthouse swung and impacted the louver panels. HVAC service outage caused the temporary evacuation of patients (FEMA 74, 1994).

- Of 32 commercial data processing facilities surveyed following the 1989 Loma Prieta Earthquake, at least 13 were temporarily out of operation for periods ranging from 4 to 56 hours. The primary cause of outage was loss of outside power. Reported damage included overturning of equipment at two facilities, damage to access floors at four facilities, movement of large pieces of computer equipment over distances ranging from a few inches to 4 feet at 26 facilities, and dislodged ceiling panels at 13 facilities. Twenty of these facilities reported having an earthquake preparedness program in place at the time of the earthquake, three reported having no program, and information was unavailable for nine facilities (Ding, 1990).
- The 1971 San Fernando Earthquake caused extensive damage to elevators in the Los Angeles area, even in some structures where no other damage was reported. An elevator survey indicated 674 instances in which counterweights came out of the guide rails, in addition to reports of other types of elevator damage. These elevators were inoperable until they could be inspected and repaired. Many thousands of businesses were temporarily affected by these elevator outages. The State of California instituted seismic elevator code provisions in 1975 with the intent of allowing for safe elevator shutdown during and after an earthquake (not to make the elevators so earthquake-resistant that they can be relied upon for exiting buildings immediately after an earthquake). While these provisions appear to have helped reduce elevator damage, there were still many instances of counterweight damage in the San Francisco area

> following the 1989 Loma Prieta Earthquake, and 688 cases in the Northridge Earthquake in 1994 (Ding, 1990; Reitherman, 1994). . Since the State of California seismic elevator code provisions have not been adopted nationally, elevator damage – including the potential for life-threatening conditions – remains a concern.

In some cases, cleanup costs or the value of lost employee labor are not the key measures of the postearthquake impact of an earthquake. For example, data processing facilities or financial institutions must remain operational on a minute-by-minute basis in order to maintain essential services and to monitor transactions at distant locations. In such cases, spilled files or damage to communications and computer equipment may represent less tangible but more significant outage costs. Hospitals and fire and police stations are facilities with essential functions that must remain operational after an earthquake.

## 2.5 Common Types of Nonstructural Earthquake Damage

Many types of nonstructural components can be damaged in earthquakes, but the items that are most vulnerable and most likely to result in injuries, significant property losses, and interruption will be described here in terms of the risk posed to life safety, property, and functionality.

### *2.5.1 Life Safety*

### Heavy exterior cladding

Cladding is an architectural element used to provide the exterior skin for buildings. Often constructed of heavy precast concrete panels, these panels typically have four support points, two at the top of the panel connecting it to the beam above, and two at its base connected to the level below. Unless specifically designed to accommodate the anticipated inter-story drift and out-of-plane seismic forces, these supports can fail. A female student was killed in the 1987 Whittier Narrows

**Threshold for Damage to Unreinforced Masonry:**

Masonry damage has long been used to estimate earthquake ground motion intensity in the absence of instrumental recordings. The Modified Mercalli Intensity (MMI) scale identifies levels I to XII to characterize the seismic intensity. MMI Intensity VI and VII both include descriptions of cracked masonry that can be used to estimate the level of ground shaking (Richter, 1957).

Recent efforts to correlate the MMI scale with recorded peak ground accelerations (PGAs) suggest that the threshold for masonry damage, MMI Intensity VI, is associated with low levels of seismic excitation with PGAs in the range 0.10g to 0.15g (CISN, 2009).

Earthquake when a 5,000-pound precast panel fell 25 feet off of the exterior of a parking garage at California State University, Los Angeles. The student was attempting to exit from the ground floor parking level when she was struck by the falling panel (Taly, 1988).

### Heavy interior walls

Nonstructural walls in older buildings are often built of heavy, unreinforced masonry materials such as brick, concrete block, or hollow clay tile. These materials are advantageous for fire and sound proofing and thermal insulation, but are brittle since they do not have a grid of horizontal and vertical steel reinforcing bars embedded in them. Falling masonry in hallways and stairwells is a particular hazard for occupants attempting to exit buildings during an earthquake.

### Unbraced masonry parapets or other heavy building appendages

Unreinforced masonry parapets are a common feature of vintage commercial construction in many parts of the country. Parapets are the short walls around the perimeter of a roof, constructed to help prevent fire from jumping from one roof to the next, to provide guardrail protection for people on the roof, to hide roof-mounted equipment, or to provide an architectural effect of greater height. While some communities have enforced ordinances that require unreinforced masonry parapets to be braced or anchored, many jurisdictions have no such mandatory provisions. As these parapets often fail at the roofline and fall outwards onto the sidewalk, they represent a particular hazard for pedestrians and occupants attempting to exit damaged buildings. Two children were killed on their way to school due to falling unreinforced stone masonry in Challis, Idaho during the 1983 Borah Peak, Idaho earthquake (Adham and Brent, 1985). Unreinforced masonry parapets have also fallen inward and penetrated through the roof of buildings.

### Unreinforced masonry chimneys

Residential chimneys are typically built of brittle unreinforced brick masonry that may be damaged even in relatively small earthquakes. This is also true of many commercial chimneys. Broken chimneys can fall through the roof and pose a safety risk to building occupants. The 1992 Landers Earthquake caused one related fatality where a child was sleeping next to a fireplace. A similar fatality occurred in the 2000 Napa earthquake where a child sleeping next to a fireplace was killed during a slumber party. Chimneys can also fall against the side of the building, onto an adjacent building or onto a public sidewalk, posing a hazard to neighbors or passersby. Use of a cracked flue chimney can cause an indirect hazard when carbon monoxide enters a home or leads to ignition of a fire.

### Suspended lighting

Suspended overhead lighting is prone to damage in earthquakes, especially if the lights are supported solely by unbraced suspended ceilings, or if they interact with unbraced piping or other suspended components. There were several instances where suspended lighting fixtures in Los Angeles school district classrooms fell during the 1994 Northridge Earthquake.  No casualties occurred since school was not in session at the time of the earthquake.

### Large, heavy ceilings

Heavy suspended ceilings and soffits can be damaged during earthquakes, sometimes causing heavy and dangerous material to fall and injure people below.  Figure 2.4.1-2 shows a failed stucco soffit above a building entrance damaged in the 1994 Northridge Earthquake.  During the 1989 Loma Prieta Earthquake, the proscenium arch ceiling at the Geary Theatre in San Francisco fell and covered the first six rows of seats in the auditorium; the theater was not in use at the time and no one was injured (Ding, 1990).

### Tall, slender, and heavy furniture such as bookcases and file cabinets

Tall slender shelving, bookcases, or file cabinets frequently overturn during earthquakes if they are unanchored or poorly anchored.  These items are particularly hazardous if they are located adjacent to a desk or bed or located where they can jam doors or block corridors and exits.  Recent shaking table tests conducted in Japan predict injuries to occupants represented by mannequins crushed by tall unanchored pieces of furniture.

### Heavy unanchored or poorly anchored contents, such as televisions, computer monitors, countertop laboratory equipment, and microwaves

Heavy contents situated above the floor level include a wide range of items that could become falling hazards in an earthquake.  Many rooms have overhead wall- or ceiling-mounted televisions and monitors, offices have desktop computer monitors, or microwaves may be perched high on counters or shelves.  Any of these items could cause injury if they fell and hit someone; damage to fallen items can add to property loss and downtime.  During the 1989 Loma Prieta Earthquake, an overhead monitor fell at the San Francisco International Airport, hitting a passenger on the shoulder.

## Glazing

Damage to storefront windows in older commercial buildings is common during earthquakes, often causing hazardous conditions on sidewalks in commercial areas. Glazing failures were relatively common in high-rise buildings in Mexico City in the 1985 Earthquake. U.S. earthquakes have not yet caused numerous high-rise glazing failures, though it remains a possibility.

## Fire protection piping

Damage to suspended fire protection piping and other system components can render the system inoperable following an earthquake. The resultant loss of fire life safety protection can pose a serious risk to the life safety of building occupants.

## Hazardous materials release

There have been a number of examples of hazardous materials release resulting from earthquake damage to piping, stored chemicals, commercial, medical, or educational laboratory facilities. Breakage of containers of chemicals can cause them to mix and lead to hazardous reactions. Exposure of asbestos materials due to earthquake activity has also resulted in the postearthquake evacuation of facilities that otherwise had little structural damage.

## Gas water heaters

Residential and small commercial water heaters have ignited fires following earthquakes, in instances where the gas supply line was damaged. As water heaters are typically tall and slender, the gas supply line can break if the water heater tips over.

## Other components

The following components pose a high risk of direct injury requiring hospitalization, or possibly causing death, if installed without seismic bracing, seismic anchorage, seismic restraint or allowance for differential movement in zones of high seismicity. Other components posing indirect risks to life safety are also identified.

- Exterior walls (including veneer, prefabricated panels, glazing, glass block, curtain wall and storefront window systems)
- Partitions (hollow clay tile, unreinforced masonry or similar)
- Ceilings (plaster or other heavy material, particularly if suspended)
- Parapets and appendages (unreinforced masonry)
- Canopies, marquees and signs

- Chimneys and stacks (unreinforced masonry)
- Stairways
- Suspended equipment weighing over 20 pounds
- Fuel tanks
- Fuel or hazardous material piping
- Suspended light fixtures (recessed, surface-mounted or pendant) weighing over 20 pounds
- Elevators
- Tall and slender shelves, bookcases, file cabinets, vending machines, lockers or similar
- Industrial storage racks and contents

The following components pose life safety concern when located in path of egress:

- Glazed partitions
- Demountable partitions
- Metal stud partitions with heavy veneer such as tile or stone
- Suspended acoustic tile ceiling including light or other components supported by the ceiling grid only and weighing 20 pounds or more
- Clay or concrete roof tiles

The following components pose indirect life safety risk:

- Emergency generation system (in hospitals, emergency communication centers or similar)
- Fire protection systems

For a more detailed list of components and risk ratings, refer to Appendix E.

### *2.5.2 Property Loss*

#### Suspended piping for water or waste

Failures of suspended piping have led to costly property loss in past earthquakes. While such failures are not often associated with life threatening injuries, they often result in costly property loss: both the cost to replace the damaged system and the cost to repair damage caused by the release of both clean and contaminated or hazardous fluids. Secondary damage due to fluid release is often a large component of nonstructural property losses.

## Suspended fire protection piping

Failures of suspended fire protection piping have resulted in both direct and indirect property loss following earthquakes. Some of these systems have failed or fallen and had to be replaced. More costly are the failures of sprinkler piping, connections, or sprinkler heads. These have resulted in the release of great volumes of water in plenum or occupied spaces. Flooded plenums have resulted in collapsed ceilings which cause the consequent loss of property and disruption of operations. In extreme cases, entire floors or buildings were abandoned as a result of the water damage. Flooding in occupied spaces has resulted in water damage to furniture, files, computer equipment, and interior finishes. As fire sprinkler lines are widespread in occupied spaces, this type of failure has been one of the most costly types of nonstructural damage.

## Unanchored and poorly anchored equipment, particularly roof-mounted equipment and unrestrained vibration-isolated equipment

Roof-mounted HVAC equipment is often vulnerable to earthquake damage, in part because the seismic accelerations are typically larger at the roof level than they are at the lower levels of the building. Such equipment is often mounted on vibration-isolation springs to prevent the transmission of the equipment vibrations to the building and building occupants. While these springs allow the equipment to move vertically a small amount in order to isolate its rapid vibratory motion from the building, this equipment is especially vulnerable to the much larger motions caused by an earthquake, unless it is also designed with seismic restraints. Damage to roof-mounted equipment, as well as other suspended or floor-mounted equipment, can disable the infrastructure of a building.

## Partitions

Non-load-bearing gypsum board partitions can be detailed to reduce the impact of seismic distortions of structural systems, with a connection detail at the top of the partition that allows the interface with the floor or roof above to accommodate sliding. However, this often is not detailed properly, resulting in extensive cracking and tearing at joints and points of attachment. Heavy partitions constructed of concrete masonry units, brick, or hollow clay tile are also often damaged in earthquakes and are costly to repair. Even when partition damage is minor to moderate, it may still necessitate complete interior patching and painting and may cause business interruptions in the affected interior spaces. Pacific Gas & Electric Company, which operates throughout much of Northern California, reported close to $50 million in area-wide property damage following the 1989 Loma Prieta Earthquake, much of which was from damage to gypsum board partitions, glazing, and air conditioning units. While this nonstructural damage represented relatively minor losses for each building, it added up to large aggregate losses for the firm (Ding, 1990).

### Ceilings

Suspended ceiling systems have failed in many earthquakes resulting in major repair or replacement costs for the ceilings and interconnected lighting or fire sprinkler lines as well as interruption in the use of the occupied spaces.

### Hazardous Materials Release

Release of some hazardous materials can create a point of ignition for a fire. An entire three story university chemistry building burned down to the steel frame as a result of a hazardous materials release in the 2010 Chile Earthquake (see Section 6.5.4.1).

## *2.5.3 Functional Loss*

### Emergency generators for critical facilities and related components such as day tanks, batteries, and mufflers

Continued operations of critical facilities following an earthquake depend on the integrity not only of the emergency generator itself but also of many related subcomponents such as batteries, battery racks, day tanks, exhaust and sometimes water-cooling connections, electrical connections to control panels, and mufflers. All of these items must be adequately restrained or anchored in order for the emergency systems to remain operational.

### Suspended piping for water or waste

As noted above, damage to these systems results not only in primary damage to the piping and connected systems but also can result in costly outages resulting from the release of fluids into occupied spaces. Also, many facilities cannot operate without water and sanitary sewage service. As an additional concern, process piping may require extensive inspection prior to equipment restart, whether it appears damaged or not, resulting in additional time for functional loss.

### Suspended fire protection piping

Failures of suspended fire protection piping have resulted in costly business interruption as well as disabling hospitals in past earthquakes. The small bore lines and sprinkler heads often are built in a grid with ceiling and lighting systems; incompatible motions of these systems have sometimes resulted in damage to the sprinkler heads and subsequent overhead water release.

### Hazardous materials release

Breakage of containers of chemicals can cause them to mix and lead to hazardous reactions. Also, due to disruption of building materials, asbestos release has occurred during earthquakes. Any of these types of releases can cause building closures, evacuation, and costly delays until specially trained HAZMAT crews can be brought in to identify and clean the spills.

### Failure of equipment needed for functionality, such as computer data centers, controls, servers, hubs, routers, switches, and communication systems

Computer networks form the backbone of many operations. Earthquake damage can result in extended downtime.

### Equipment needed for functionality, including HVAC systems

Many facilities cannot maintain operations without HVAC equipment because temperature control and air filtration systems are required in many hospitals, laboratories, and high tech manufacturing facilities.

### Equipment needed for functionality, such as elevators and conveyors

Many facilities cannot resume normal operations without the use of passenger and freight elevators or material conveyors. Hospitals need elevators to move gurneys and portable equipment from floor to floor. Occupants of multistory buildings depend upon the use of elevators to move work materials, supplies, and equipment.