Cover photo credits (left column): Gary McGavin; Wiss, Janney, Elstner Assoc., FEMA 74; Robert Reitherman; Shojiro Motoyui, Tokyo Institute of Technology (center): Federal Emergency Management Agency, FEMA 74, 3rd edition (right column): Andre Filiatrault; Robert Reitherman; Wiss, Janney, Elstner Assoc., FEMA 74; Wiss, Janney, Elstner Assoc., FEMA 74.
By definition, nonstructural earthquake damage is damage to components that are not structural. For example, a partition, which is non-load-bearing, is nonstructural, while a load-bearing wall is structural. The architectural spandrel material underneath and above windows that fills in between reinforced concrete frame bays is nonstructural while the concrete material is structural.

While this simple definition is generally adequate, some complicating factors come up in the actual case of a real building, a utility installation, or an industrial plant. For example, a partition can play a significant role in providing strength and stiffness on the scale of a small woodframe building. That is a beneficial effect. When the spandrel material used as infill in the concrete frame is masonry, or when a steel or concrete element that is not designed as part of the lateral force-resisting system restrains the deflection of a column by accident, it has the structural effect of shortening the column, in terms of its lateral stiffness. Shear that was assumed to be high near the column-beam joint but low in the mid-height region in fact concentrates where the “nonstructural” element provides the bracing. See Figure 1. That is a negative effect, if the structural designer does not recognize that the required shear reinforcement in the column, in the form of closely spaced ties, needs to be continued up past the nominal ends of the column to the region where it is actually restrained by adjoining material. A number of short column failures have occurred over the years by this accidental effect. There is a saying that “the earthquake doesn’t know how to read,” and whether one calls a component nonstructural or not, the important point is to recognize when it actually has a significant effect on structural behavior.

A further distinction is important in the definition of the term nonstructural. Because architectural and engineering building designers are focused on their own roles and scope, in essence being responsible for what is shown on their construction drawings and in their specifications, they have traditionally left contents out of the definition. The term nonstructural then applies only to the permanent built-in nonstructural parts of a building that are covered by a building code. Contents, however, are what make a house a home, a reinforced concrete or steel frame structure a hospital, or a concrete pad into an electrical substation. In this essay, the term is used to include this important range of components to avoid having to repetitively refer to “nonstructural elements and contents.”

Figure 1. Collapse of a newly constructed four-story building in the October 10, 1980, M 7.7 El Asnam, Algeria Earthquake. The rigid connection of the reinforced concrete stairway to the ground story column unintentionally made the “short column” receive a large mid-height shear force, rather than being able to deflect in flexure throughout its height.

Source: Vitelmo V. Bertero, NISEE-PEER, U.C. Berkeley
The Importance of Nonstructural Components

In the United States, the 1964 Alaska Earthquake marks the first time that a detailed reconnaissance report on nonstructural damage occurred (Ayres et al. 1973). Similar instances of nonstructural damage to heating-ventilating-air conditioning (HVAC) equipment, elevators, partitions, glazing, and other nonstructural components in the 1971 San Fernando Earthquake focused more attention on the subject and was influential in the development of specific building code regulations. This does not mean that there were no earthquake engineers looking at the problem prior to then, but they were in a distinct minority. In Japan, seismic design based on a rigid approach dates back to before the 1920s. Structural engineers such as Riki Sano (1880-1956) and Tachu Naito (1886-1970) were advocates of making the structure very stiff, to reduce upper level amplification, and to prevent distortion of the structure from imposing damaging deformations on the nonstructural components. In California in the 1950s, the state’s office of architecture that governed schools owned by local government school districts and state-run community colleges began some early research and code development on the issue, such as testing how much deflection from one story to the next, i.e., interstory drift, could be tolerated by windows before they shattered (Bouwkamp and Meehan 1960).

There are two basic reasons why nonstructural damage is important. First, most of a building is nonstructural; see Figure 2, which shows that for almost all building occupancies, at least 70% of the original cost is invested in the nonstructure. Since most of a building is nonstructural, most of the value exposed to risk of damage is nonstructural. In other words, when the excavation for the foundation is completed and the concrete foundation elements are installed, and the frame, structural walls, or both are erected along with the floors and roof, only a small part of the building has been built in terms of its total cost, not to mention its actual usefulness.

The second reason nonstructural seismic design is important is that the nonstructural features of the building are usually more seismically fragile than the structure. The level of motion that only slightly cracks structural walls is usually enough to make non-seismically-designed light fixtures and ceilings collapse or electrical and HVAC equipment slide and overturn. Without strong motion instruments to quantify the shaking, the presence of nonstructural damage in the absence of structural damage is a standard rationale in intensity scales for assigning a relatively low value for the shaking severity.

Is it surprising that nonstructural components typically have a high seismic vulnerability? Not when we realize that the development and invention of most of the nonstructural features that are around us in everyday life occurred in the complete absence of concern about seismic design. Consider the case of the ubiquitous overhead nonstructural “sandwich” composed of the suspended ceiling and fluorescent light fixtures, and above that architectural layer the concealed air handling ductwork and associated equipment such as terminal heating boxes, electrical conduits, the fire sprinkler, and other piping. This nonstructural sandwich is one of the chief sources of overall nonstructural seismic fragility in a modern building.
In the nineteenth and preceding centuries, ceiling materials were applied directly to the floor or roof structure above with candle or later gaslights and then incandescent light bulbs. The 1900s brought the hung ceiling and heavy fluorescent fixtures resting on a pendulous ceiling grid. Rooms were heated with hot water radiators and cooled, if the outside temperature cooperated, by simply opening the windows, then air conditioning became feasible. The breakthrough of Willis Carrier provided cool air and controlled its humidity. Carrier devised equipment that first wrung all the moisture out of the incoming outdoor air by cooling it, then added back to that airstream that was about to be blown by fans throughout the building the precise desired amount of moisture. Ducts then had to extend like arteries (supply air) and veins (return air) throughout the entire building. Banham (1969) chronicles these and other nonstructural building technology developments, marking these milestones:

- 1922, first modern supply-from-above, return-air-under-seats air conditioning system in a theater, Graumann’s Chinese, Los Angeles, California, and 1928, first fully air conditioned office building, Milam Building, San Antonio, Texas
- 1938, Westinghouse and General Electric bring to market practical fluorescent fixtures
- 1950, acoustical (sound-absorbent) ceiling system with integrated fluorescent light fixtures suspended under a concrete-slab-on-metal-deck, with ducts, electrical conduit, and pipes in the above-ceiling “servant-space,” United Nations Headquarters, New York, New York

One milestone that Banham doesn’t include that is related to the above inventions and is also significant, is the invention of the steel stud partition sheathed with gypsum board panels.

In 1916, US Gypsum introduced the product later called Sheetrock. As of the 1940s, gypsum wallboard had not yet become common, as indicated by the fact that gypsum panels are nowhere mentioned in Architectural Graphic Standards (Ramsey and Sleeper 1941) while eight pages are devoted to steel stud and lath-and-plaster partitions. Come the 1981 edition of that architect’s handbook, over 30 of the variations on the theme of steel studs and gypsum wallboard are tabulated in detail in terms of STC (Sound Transmission Class) and fire rating, making that kind of assembly the non-load-bearing wall of choice for architects to put on their drawings and in their specs, and for contractors to install (Packard, ed. 1981). By the mid 1950s, even the single-family home industry had adopted the gypsum board innovation for half its construction, a proportion that continually grew.

Banham notes earlier historical developments than the above milestones, but these points on the timeline are sufficient here as evidence to conclude by the 1950s, the modern nonstructural “sandwich over our heads,” in many if not most, of the non-residential buildings that we enter had become established. Each essential invention came independently, encouraging the others, for non-seismic reasons. The eventual synthesis was achieved by manufacturers and designers adjusting to the needs of each component on an incremental basis. “Synthesis” is probably too strong a word. Putting together these parts into a common kit has been a negotiated compromise as to how to use that three-dimensional space rather than a synthesis of design as to how they respond in earthquakes. It is typically a rather chaotic scene one sees when a tile is popped up to look around in that space above the seeming order of the ceiling tiles. In an earthquake, the components in that sandwich are simultaneously moved, but they are moved to “sing” as a discordant, jostling chorus, each reading from its own score that is unrelated to those of the others. The holy seismic grail remains to get them to all read from the same page. The project led by the University of Nevada at Reno funded by the National Science Foundation is studying that ubiquitous assemblage of components on a system level, rather than as a collection of elements.

**Acceleration and Drift**

Partitions are lightweight and the inertial loads are low, unless they are heavily loaded with bookshelves hung off of them or anchored to it, may be susceptible to overturning when that mass is accelerated in an earthquake. It is useful in design and code applications to separate the effects of acceleration and of drift on a given nonstructural component. The deflection of one story level vis-à-vis another called drift, is usually the primary cause of partition damage. Details in commercial and institutional buildings often mount the typical steel stud, gypsum wallboard partition
with a sliding detail at the top that can accommodate some degree of drift. Windows are another common drift-sensitive nonstructural component. Figure 3 illustrates damage caused by drift. Equipment and contents are usually damaged by acceleration, rather than drift. Acceleration typically increases up through at least the first few stories of a building. From the point of view of a piece of equipment that is either unanchored or restrained by anchor bolts, the “earthquake” it responds to the motion of its floor, not the ground. See Figure 4 and Figure 5.

Figure 3. Shards of window pane, 1994 Northridge Earthquake.

source: Wiss, Janney, Elstner Associates, FEMA 74

Figure 4. Longitudinal failure of library shelving. The tremendous mass of the books, accelerated along the axis of the shelving, can overwhelm sometimes deficient bracing that is seen only when the books are removed. Bracing rows of shelving transversely, as here with an overhead strut, does not prevent this kind of dangerous damage.

source: NISEE-PEER, U.C. Berkeley

Figure 5. When this shelving in a county assessor’s office was shaken transversely by the October 17, 1989 Loma Prieta Earthquake, the contents spilled to the floor. From the point of the view of the shelving itself, this is beneficial load-shedding, but the contents can be hazardous, cause disruption, and be damaged.

source: Robert Reitherman

Growth in Code Regulations
New Zealand was an early leader in the development of code provisions and innovations in design practice to contend with drift-induced nonstructural damage. Increasing success with controlling structural damage also led the Japanese to focus on nonstructural damage. In many respects, it was only as of the 1980s in the USA that general seismic provisions in the building code (the Uniform Building Code as of then) began to be carried out in detail. The 1971 San Fernando Earthquake was important in bringing to light nonstructural damage. Following that earthquake, nonstructural provisions for hospitals became strictly enforced, but many buildings of ordinary occupancy built after that earthquake had nonstructural features that looked about the same as in buildings built prior to it. The first edition of the SEAOC Blue Book (SEAOC 1959) is a data point in this regard, because the Blue Book over the years was the source for the almost verbatim seismic provisions of the Uniform Building Code. The 1959 Blue Book contained force factors for only a few nonstructural components, such as parapets, exterior appendages, and partitions. By 1978, the Tentative Provisions of Seismic Provisions for Buildings (ATC 3-06) included much more specific nonstructural provisions that slowly made their way into building codes.
Since then, many different kinds of nonstructural components have been tabulated, with associated seismic design requirements. Over the years, the approach of the building code with respect to nonstructural components followed three paths. There were prescriptive requirements for common products that could be lumped together in one generic category, such as suspended ceilings. **Figure 6** illustrates this approach while **Figure 7** illustrates a case where this approach failed to get accomplished. Rather than calculate slightly varying forces for the particular case at hand, an industry-wide standard was developed that architects could routinely include on drawings and contractors apply in the field. Typically, architects provide seismic protection for nonstructural components by including such standard details on their drawings and in their specifications, but when calculations are required, they rely on their consulting structural engineer.

The code imposed increasingly strict drift limits on the structure, both to protect the structure, for example from the P-delta effect, and also to protect drift-sensitive nonstructural components. Even today there are efforts underway to rationalize and improve the way drift is calculated for this purpose. Much seismic design is still conducted on an elastic basis, converting the high seismic forces that are actually anticipated into lower, elastic realm numbers by reduction factors, an approach which has generally proven workable for the structure. However, those same values of forces and deflections do not provide realistic numbers to predict how much drift will actually occur. Thus, calculated deflections that were first lowered by reduction ($R$) factors are then increased by a correction factor ($C_d$).

A third code focus came in the 1980s and 1990s with refinement of the lateral force design factor used for nonstructural components, depending on their type (e.g., differentiating hazardous or essential ones from ordinary ones) and height in the structure (as related to amplification). The NEHRP Provisions (BSSC 1985, first edition) began on a path toward more detailed categorization of types of components and force factors. An increasing archive of strong motion records obtained from within buildings provided the data to calibrate force levels with height in the structure. Every subsequent edition of that NEHRP proto-code, which now forms the basis, along with ASCE 7 (ASCE 2006), of US seismic code provisions as found in the International Building Code, has revised the sophistication of the way forces on nonstructural components are calculated.

**Figure 6.** Common prescriptive approach to bracing a typical lightweight suspended ceiling, with four-way bracing wires and a vertical compression strut. The detail evolved over the years; for example, the strut was a later addition to the standard developed by CISCA, Ceiling and Interior Systems Construction Association, which was adopted by reference into building codes. In this location, only a conduit is present, but often ducts, pipes, and other plenum-space components complicate the rational layout of bracing patterns.

**Figure 7.** Although this building was constructed in a region where seismic codes required suspended ceiling bracing when it was built, this nonstructural detailing was overlooked. This is not uncommonly found when nonstructural surveys are conducted. The vertical wires shown do not connect to the light fixtures, which should also have their own vertical back-up support wires in the event they dislodge from the ceiling inverted Ts on which they sit.

source: Robert Reitherman
One would be led astray, however, if told that the problem of nonstructural damage has been solved by increasingly sophisticated engineering methods and building code regulations. It is one thing to state what the design loads are on HVAC components, ceilings, and pipes – it is another to get three different professions and allied construction fields to coordinate their design and construction. The mechanical engineer and HVAC subcontractor are responsible for the ducts; the architect and suspended ceiling subcontractor for the ceiling; the fire protection engineer and sprinkler subcontractor for the fire sprinkler piping. The diagonal brace installed for a pipe may prevent the duct from being routed where it needs to be and obtaining its bracing. Vice versa, the duct that is installed before another component may prevent a logical location for that other component’s diagonal brace. Structural engineers seem to be outside the nonstructural fray, but in California where seismic regulations have been most stringently enforced, they tend to be inevitably involved in helping architects and other engineering consultants properly design seismic protection details. Design coordination and field quality control by design professionals and building officials remain imperfectly carried out with respect to nonstructural components.

**The Kinds of Risk Posed by Nonstructural Damage**

A basic reference concerning nonstructural damage, the first edition of which was written by the author in 1983, is *Reducing the Risks of Nonstructural Earthquake Damage: A Practical Guide* (FEMA 2009). In its current form, authored by MaryAnn Phipps, Cynthia Perry, and Eduardo Fierro, it is an extensive text on the subject and the first reference to seek out on this topic. In addition to its own large amount of content, this document provides many references to other works on this topic. The title indicates that the occurrence of the physical damage is not the only consideration: damage causes at least three distinct risks. The physical state that might materialize in an earthquake -- the damage -- may imply different kinds of risk, and this may vary from one type of facility to another.

**Injury.** The risk of injury comes first on the list. An example of a nonstructural component that, if it is damaged, can cause injury is the common ceiling-mounted fluorescent light fixture. The heavier and sharper the object, and the higher it is (the farther it can fall and hit one on the head), the more risk of injury is posed, even if the probability of damage for two components is the same. The same light fixture falling in a storage room where a person is present only a few hours a year, less than 1% of the time, poses less injury risk than one falling in an office occupied 40 hours a week (about 25% of the hours in the year). See Figure 8.

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**Figure 8.** After severe shaking in the January 17, 1994 M 6.7 Northridge Earthquake, light fixtures at Olive View Medical Center were dislodged from their ceiling support, but properly installed back-up safety support wires kept them from falling.

*source: Robert Reitherman*
Property loss. A damaged piece of glassware in one’s kitchen may cost fifteen dollars to replace. A damaged piece of ancient pottery in a museum may be irreplaceable, but for insurance purposes might have a value of several tens of thousands of dollars. See Figure 9.

Figure 9. Seismic restraint of an object of artistic and historical value with nylon filament (fishing line) in the Tokyo National Museum in Ueno Park.

source: Robert Reitherman

Loss of functionality. If one’s personal computer doesn’t work for a day, it is a major inconvenience, but if a computer essential to 9-1-1 dispatching or air traffic control is out of operation for a day, it causes an emergency situation. See Figure 10.

Figure 10. If only the sign on this large hospital had been damaged in the January 17, 1994 M 6.7 Northridge Earthquake, this essential facility could have continued to function. However, the cosmetic damage is an indicator of the fact that mechanical equipment at the top level lurched loose during the earthquake. Without air conditioning, a modern hospital cannot operate, and this one had to close until repairs were made.

source: Robert Reitherman

Current Research, Changes in Practice, and Industry Innovations

Research has been increasingly focused on the nonstructural earthquake problem. The largest earthquake engineering research program in the USA, the National Science Foundation Network for Earthquake Engineering Simulation, has to date funded three projects in its largest category, called grand challenges. One of those three is on nonstructural systems, headed by Professor Manos Maragakis at the University of Nevada at Reno and involving a large multi-university team in conjunction with practicing engineers and industry experts: University at Buffalo, University of California at San Diego, Cornell University, CUREE, Georgia Institute of Technology, North Carolina A&T, and North Carolina State University. See Figure 11. The focus of this project is on the interacting performance of ceilings, piping, partitions with the structural system from which they are attached or suspended. When these seemingly separate kinds of components move in an earthquake, they contact each other and interact. The ability to predict performance and to design accordingly on the system level of interacting components is a new research area.

Figure 11. Apparatus for full-scale testing of the ceiling-pipe-partition system.

source: Manos Maragakis
In the realm of practice, both design professionals and code officials are becoming more diligent about the "bookkeeping" of seismic design and construction responsibilities for nonstructural components. In the case of St. Louis County, for example, a table listing mechanical and other components that have seismic requirements is included on construction drawings submitted for permits, and the table indicates who is responsible for what.

The construction industry is also at work on developing products that perform better seismically. Increasingly stringent building code requirements, and the increasing geographic span of those requirements beyond the most highly seismic Western US to some less seismic regions of the eastern two-thirds of the country, have begun to provide an incentive for manufacturers to introduce innovative seismic versions of their products.

The following pages illustrate and briefly describe different types of nonstructural components, the same familiar features of buildings and other facilities we see all the time but perhaps seldom consider in the light of how they will perform in earthquakes.

Cited References

American Society of Civil Engineers (2006). *Minimum design loads for buildings and other structures* (ASCE 7-05), Reston, VA.


Latest edition authored by Maryann Phipps, Cynthia Perry, and Eduardo Fierro and available online at: http://www.fema.gov/plan/prevent/earthquake/professionals.shtm


SEAOC (1959). *Recommended lateral force requirements and commentary*, Structural Engineers Association of California, Sacramento, CA. - The first version published in 1959 had no commentary while the 1960 and later editions did and had the title as cited here (with "and Commentary" included).
Complete collapse of a suspended ceiling over a swimming facility.

source: Shojiro Motoyui, Tokyo Institute of Technology

Exposure of complex array of above-ceiling elements, after collapse of the suspended ceiling in the 1994 Northridge Earthquake.

source: Robert Reitherman, NISEE-PEER, U.C. Berkeley

Testing of a suspended ceiling system.

source: University at Buffalo, SUNY

(source) Fallen ceiling and flexible ducts, 1994 Northridge Earthquake.

source: Wiss, Janney, Elstner Associates, FEMA 74

(right) Collapse of heavy plaster ceiling in a theater, 1989 Loma Prieta Earthquake.

source: NISEE-PEER, U.C. Berkeley

Ceilings

The most common type of ceiling in modern construction is the suspended ceiling, which is a light-gage metal grid hung from the structure above by wires that provide support for acoustic ceiling tiles, along with heavier fluorescent light fixtures and air conditioning diffusers. Separate vertical support wires for those heavier items, along with bracing for the ceiling, are needed to prevent seismic damage. The interaction of ceilings with piping, in particular the sprinkler pipes that serve the sprinkler heads that protrude through the ceiling plane, are being studied in the NEES Nonstructural Project.
Piping comes in various sizes and materials that supply drinking water, drains, water for HVAC equipment such as chillers, medical gases in hospitals and industrial liquids and gases in industry, and fire sprinklers. Fire sprinkler piping, which is regulated by the NFPA 13 standard, typically incorporates bracing in seismic regions, though in earthquakes enough damage to cause expensive leaks and fire protection outages still sometimes occurs. The NEES Nonstructural Project funded by NSF, with experimental work at the University at Buffalo and the University of Nevada at Reno, is currently focusing on fire sprinkler piping.
Partitions

The most common kind of partition in US practice has gypsum board sheathing screwed to wood or metal studs. They are sensitive to in-plane forces causing interstory drift of the structure and, if loaded with attached shelving, to out-of-plane acceleration-induced forces. Some partitions extend only to the height of the suspended ceiling and usually require bracing at their tops; others are full-height up through the suspended ceiling space to the floor or roof above. Interaction of partitions with the ceiling and piping components is being studied in the NEES Nonstructural Project.

(source: Wiss, Janney, Elstner Associates, FEMA 74)

(source: University at Buffalo, SUNY)
Many kinds of contents can slide, overturn, or fall off shelves without great danger, disruption, or dollar loss, but some kinds of contents merit special seismic attention. Museums in seismic regions in recent years have provided unobtrusive restraints for their collections on display or in storage; hospitals have protected their essential medical equipment and supplies; and residents can make sure that heavy or potentially sharp unsecured items are not placed on shelves above head height.

Contents
Today’s buildings often contain a variety of hazardous materials, as indicated by the ubiquitous NFPA 704 hazard-rating diamond placards for flammable, chemically reactive, or toxic substances. Chemistry labs in seismic regions benefit from restraint of chemicals on shelves, plastic shrink-wrap protection of glass bottles needed for some chemicals, and separation of chemicals so that spillage doesn’t lead to hazardous reactions. Slender and heavy compressed gas cylinders require restraint to prevent toppling.

Seismic restraints are only effective when they are used.

(source: William Holmes)

Seismically restrained compressed gas cylinders. Because these cylinders are in use, with attached piping, their restraint must be tight as well as strong.

(source: BFP Engineers)

(left) Overturned medical gas cylinders, 1971 San Fernando Earthquake.

(source: Scientific Service, Inc.)

(above) Seismically restrained hazardous materials, Shizuoka, Japan.

(source: Robert Reitherman)
From a structural standpoint, a window is a hole in a wall, an opening that causes stress concentrations at its corners. All walls deflect when loaded with in-plane forces, tending to take on a parallelogram shape, and the larger the windows, the more they increase structural flexibility and also the more they tend to crack as they try to rotate or distort to match the deformation of the surrounding wall. Storefronts are thus typically the most likely glazing to find broken after an earthquake.

Windows

Shards of window pane, 1994 Northridge Earthquake. Wiss, Janney, Elstner Associates, FEMA 74

(left) Drift-caused damage to windows in the International Building in Mexico City in the M 8.1, September 19, 1985 Mexico Earthquake. source: Karl V. Steinbrugge, NISEE-PEER, U.C. Berkeley

The lower pane has a layer of clear plastic film, the upper does not, but the appearance is the same. Such "security films" are a way to seismically retrofit glazing.

source: Robert Reitherman
Heating-Ventilating-Air Conditioning Systems (HVAC)

Typically the heaviest equipment in a building is its HVAC gear, such as chillers, fans, compressors, furnaces, boilers, and pumps. With high mass comes high inertial forces during an earthquake, a vulnerability compounded by the fact that much HVAC equipment needs to be mounted on springs or other vibration-isolation devices to prevent bothersome noise and vibration during ordinary operation. Either seismic models of these mounts, or add-on restraints (“snubbers”) are needed to keep equipment from lurching during earthquakes.
The ordinary house has few of the nonstructural items other occupancies do that cause seismic risks, but the water heater is one item the house has that requires more than nominal bracing. Weighing approximately 500 pounds, a gas-fired 40-gallon water heater excited by an acceleration of 0.5 g would pull or push on its bracing with a 250-pound force, requiring positive connections and steel hardware for restraint. Stiff as well as strong restraint is needed to prevent rupture of the piping for the natural gas, cold supply water line, and outflow hot water line, as well as the exhaust flue.

Water Heaters

(source: Robert Reitherman)

(source: Wiss, Janney, Elstner Associates, FEMA 74)
Shelving and Cabinets

Schools, offices, homes, factories, stores, maintenance yards, warehouses, libraries—it’s hard to think of an occupancy that doesn’t have shelving. Tall shelving is intrinsically more likely to overturn, and more hazardous when it does, than shorter shelving. Anchorage of the bases of tall and heavy shelving is needed, but in addition the shelving needs to be structurally designed as if they were small buildings in their own right to perform well longitudinally (often using diagonal bracing) and transversely (often small moment-frames) in an earthquake.
Electrical service outages are common after earthquakes, though in regions where the utility has taken construction and emergency response measures in advance, service can be quickly restored. In the 1994 Northridge Earthquake, the power outage in Los Angeles essentially lasted only one day. For critical purposes, such as powering emergency communications systems, hospitals, and elevators, back-up power generators need to operate reliably after an earthquake. The heavy motor-generator set (mounted oftentimes on vulnerable vibration-isolation springs), batteries, fuel tank, electric control panel, and exhaust ductwork are all vulnerable unless braced.

Generators
Light Fixtures

Light fixtures that sit on suspended ceiling grids need their own independent support wires to keep them from falling if the ceiling distorts—one wire each at two diagonally opposite corners. Pendant fixtures, such as the common long rows of fluorescent fixtures hanging from stems a few feet long in classrooms, can swing excessively and break off if not designed specifically to resist earthquakes. The most common nonstructural hazard over one's head is the light fixture.
Veneer and Chimneys

Veneer is made of heavy and hard materials such as brick and stone—exactly the sorts of materials you would not want to fall from above onto your head. Veneer has historically been so damage-prone in earthquakes that earthquake insurance typically excluded it from coverage. Modern seismic code provisions limit the thickness or weight of the veneer and govern how it is attached to the supporting wall behind, and how it is reinforced with small-diameter reinforcing rods or straps. Unreinforced masonry chimneys are typically a very vulnerable construction feature, fracturing and falling at low ground motion levels.
Simulation of the Seismic Performance of Nonstructural Systems
A NEES Grand Challenge Research Project

The largest National Science Foundation-funded earthquake engineering project aimed at reducing nonstructural earthquake damage, “Simulation of the Seismic Performance of Nonstructural Systems,” a NEES (Network for Earthquake Engineering Simulation) Grand Challenge project, is currently underway. The Principal Investigator, Professor Emmanuel (Manos) Maragakis of the University of Nevada at Reno is also that university’s dean of the college of engineering. The timespan of the project is five years, and it is approximately half completed.

The system-level analysis and experimentation in the project is devoted to the ceiling-piping-partition system, a set of disparate nonstructural components designed and installed separately that nonetheless interact in earthquakes as a physical system. Research on the component level, beginning with partitions in 2008-2009 and piping 2009-2010, with ceiling studies to follow, is integrated into system level modeling and physical experimentation. To date, most of the testing has been done at the University at Buffalo under the direction of Professor André Filiatrault, and a complete installation of suspended ceilings, sprinkler piping, and partitions will be tested at the University of Nevada at Reno in a two-story test set-up that extends across multiple shake tables. Professor Tara Hutchinson of the University of California at San Diego heads up the simulation effort, using test data to calibrate fragility relations. Professor Steven French of the Georgia Institute of Technology is conducting planning studies to estimate the reduction in earthquake losses in three metropolitan areas over future timespans, and Bob Reitherman of the Consortium of Universities for Research in Earthquake Engineering leads the education and outreach effort. Bill Holmes, structural engineer with Rutherford & Chekene, directs the practice committee and provides real-world input to the research effort, for example prioritizing the kinds of components to be tested and how the results can be applied to codes, standards, and industry practice.