

# Chapter 3

## Nonstructural Vulnerability

### Background

A building may remain standing after a disaster, but be incapacitated due to nonstructural damages. Assessment of nonstructural vulnerability seeks to determine the damage that these elements may suffer when affected by moderate earthquakes, which are more frequent during the life of a hospital. Due to the high probability of earthquakes that could affect the nonstructural components, necessary steps must be taken to protect these elements.

The cost of nonstructural elements in most buildings is appreciably higher than that of structural elements. This is particularly true in hospitals, where between 85% and 90% of the facility's value resides in architectural finishes, mechanical and electrical systems and the equipment and supplies contained in the building. A low-magnitude seismic event can affect or destroy vital aspects of a hospital, those directly related to its function, without significantly affecting the structural components. It is easier and less costly to apply damage mitigation measures to nonstructural elements.

It is not enough for a hospital to simply remain standing after an earthquake; it must continue to function. The external appearance of a hospital might be unaffected, but if the internal facilities are damaged, it will not be able to care for its patients. This section focuses on preventing loss of function due to nonstructural failure, which may also affect the integrity of the structure itself.

### Nonstructural elements

The design of any structure subjected to seismic movements should consider that nonstructural elements such as ceilings, panels, partition walls, windows, and doors, as well as equipment, mechanical and sanitation installations, must withstand the movements of the structure. Moreover, it should be noted that the excitation of the nonstructural elements, caused by movements of the structure, is in general greater than the excitation at the foundation of a building, which means, in many cases, that the safety of the nonstructural elements is more compromised than that of the structure itself.

Notwithstanding the above, little attention is generally paid to these elements in the seismic design of structures, to the extent that many design codes do not include standards for nonstructural components. This is evident in the experience of recent earthquakes where structures designed in accordance to modern seismic-resistance criteria performed well, but unfortunately there was a deficient response of the nonstructural elements. If the safety of the occupants of a building, replacement costs, and the losses involved in interrupting the operations of the building itself are taken into account, the importance of seismic design of the nonstructural elements can be understood.

In the case of hospitals, the problem is of major importance for the following reasons:

1. Hospital facilities must remain as intact as possible after an earthquake due to their role in providing routine medical services as well as attending to the possible increase in demand for medical treatment following an earthquake.

2. In contrast to other types of buildings, hospitals accommodate a large number of patients who, due to their disabilities, are unable to evacuate a building in the event of an earthquake.
3. Hospitals have a complex network of electrical, mechanical and sanitary facilities, as well as a significant amount of costly equipment, all of which are essential both for the routine operation of the hospital and for emergency care. Failure of these installations due to a seismic event cannot be tolerated in hospitals, as this could result in the functional collapse of the facility.
4. The ratio of the cost of nonstructural elements to the total cost of the building is much higher in hospitals than in other buildings. In fact, while nonstructural elements represent approximately 60% of value in housing and office buildings, in hospitals these values range between 85% and 90%, mainly due to the cost of medical equipment and specialized facilities.

Experience shows that the secondary effects caused by damage to nonstructural elements can significantly worsen the situation. For example, ceilings and wall finishes can fall into corridors and stairways and block the movement of occupants; fires, explosions and leaks of chemical substances can be life-threatening. The functions of a hospital are dependent on such basic services as water, power and communications. Damage or interruption of these services can render a modern hospital virtually useless.

Nagasawa<sup>1</sup> describes that, as a result of the Kobe, Japan, earthquake in 1995, a significant number of hospitals reported damage due to falling shelves, movement of equipment with wheels without brakes or that were not in use, and falling office, medical and laboratory equipment that was not anchored down. In some cases, even heavy equipment such as magnetic resonance, computerized axial tomography and X-ray equipment moved between 30 cm and 1 m, and equipment hanging from ceilings, such as an angiograph, broke away from its supports and fell, in turn damaging other important equipment.

Nonstructural elements can be classified in the following three categories: architectural elements, equipment and furnishings and basic installations (see table 3.1).

- The architectural elements include components such as non-load-bearing exterior walls, partition walls, inner partition systems, windows, ceilings, and lighting systems.
- The equipment and furnishings include medical and laboratory equipment, mechanical equipment, office furnishings, medicine containers, etc..
- The basic installations include supply systems such as those for power and water, networks for medical gases and vacuum, and internal and external communications systems.

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<sup>1</sup> Nagasawa, Y., Damages caused in hospitals and clinics by the Kobe earthquake, Japan. *Japan Hospital* No. 15.

**Table 3.1.**  
**Nonstructural elements to be considered in the vulnerability assessment**

Architectural	Equipment and furnishings	Basic installations and services
<ul style="list-style-type: none"> <li>• Divisions and partitions</li> <li>• Interiors</li> <li>• Façades</li> <li>• False ceilings</li> <li>• Covering elements</li> <li>• Cornices</li> <li>• Terraces</li> <li>• Chimneys</li> <li>• Surfacing</li> <li>• Glass</li> <li>• Attachments (signs, etc.)</li> <li>• Ceilings</li> <li>• Antennas</li> </ul>	<ul style="list-style-type: none"> <li>• Medical equipment</li> <li>• Industrial equipment</li> <li>• Office equipment</li> <li>• Furnishings</li> <li>• Supplies</li> <li>• Clinical files</li> <li>• Pharmacy shelving</li> </ul>	<ul style="list-style-type: none"> <li>• Medical gases</li> <li>• Industrial fuel</li> <li>• Electricity</li> <li>• Telecommunications</li> <li>• Vacuum network</li> <li>• Drinking water</li> <li>• Industrial water</li> <li>• Air conditioning</li> <li>• Steam</li> <li>• Piping</li> <li>• Waste disposal</li> </ul>

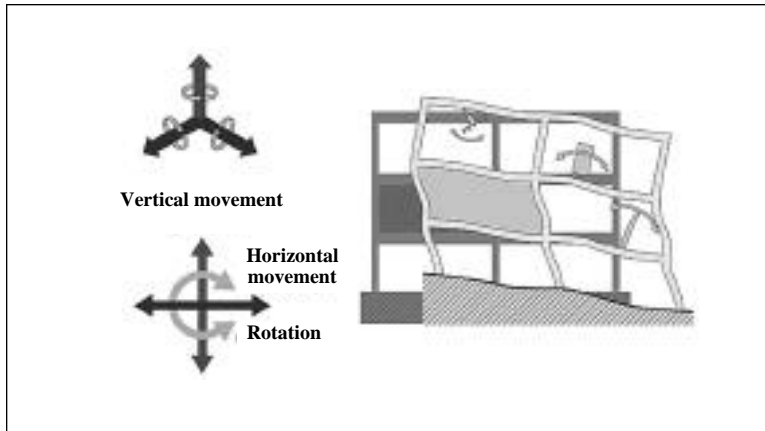
*Source:* Boroschek R., Astroza M., Osorio C., *Capacidad de respuesta de hospitales ante desastres sísmicos: Aspectos no estructurales*. International Conference on Disaster Mitigation in Health Facilities, PAHO, Mexico, 1996.

## Methods of analysis

### Inventory, inspection and assessment

The vulnerability assessment of the nonstructural elements should be carried out after having obtained the results from assessment of structural vulnerability, since the latter is very valuable for judging susceptibility to damage of nonstructural elements. For example, nonstructural elements may be affected by the deformation of the main structure as determined by drift, that is, the relative lateral movement between two stories. Examples in this category would be partitions or other nonstructural elements between floors or placed between structural walls or columns. When there is no direct interaction due to deformation between the nonstructural element and the structural one, the nonstructural element is considered to be sensitive to acceleration. An example would be mechanical equipment located on a certain floor of a building. Equipment placed on higher stories will be subjected to greater forces due to the performance and movement of the structure during seismic vibration. Figure 3.1 illustrates how structures can respond to seismic shaking.

**Figure 3.1.**  
**Response patterns for different sections of building when subjected to seismic forces**



**Source:** McCue, G., A. Skaff, and J. Boyce, Architectural design of building components for earthquakes. National Science Foundation (RANN), Washington, D.C. MBT Associates, San Francisco, California, 1978.

### Evaluating basic facilities and equipment

Damages sustained in hospitals from past earthquakes illustrate a variety of problems, some of which are described below:

- Power generator tips over causing an interruption in the hospital's power supply and resulting in the failure of life-support systems. This occurs because the anchors to the foundation are corroded and not strong enough to prevent the generator from falling.
- High voltage transformers tilt or tip completely over and oil is spilled. The emergency energy supply is interrupted.
- The telephone switchboard moves, causing a temporary interruption in the hospital's communications.
- Oxygen and flammable gas cylinders tip over, and their contents leak, creating risk of explosion or fire.
- Storage shelving tips over and bottles in the cabinets break. The contents are spilled, representing a loss of necessary medicines and biological samples.
- Laboratory equipment falls over and instrumentation systems break.
- Piping for water, clinical gas and/or steam supply systems break inside the hospital. This generally occurs in areas where these pipes intersect with expansion joints or when they are embedded in partition walls that are damaged by earthquakes.

Among the nonstructural hazards that can affect the life or the health of the occupants of a hospital the following should be mentioned:

- Furniture with sharp edges
- Glass that can fall in transit areas
- Objects that fall from shelves, cabinets and ceilings

- Impact from objects that slide or roll along the floor
- Inhalation of toxic or medical gases
- Contact with corrosive or dangerous liquids
- Steam burns
- Fire
- Disconnection or failure of life-support systems
- Inability to evacuate

To evaluate these elements, a general inventory is made of the equipment considered to be strategic because of certain characteristics (e.g., size, weight, shape), its cost, its importance for essential hospital services, or because of the condition of fasteners.

The first step in the implementation of a nonstructural mitigation program for a hospital is to carry out a systematic, thorough inspection of the facility to evaluate existing hazards. Three risk levels are recommended for classifying the hazard posed by the failure of nonstructural elements:

- Risk of loss of life;
- Risk of loss of equipment and property;
- Risk of functional loss.

Those elements whose failure or malfunctioning due to an earthquake could mean loss of life or injury to the occupants of the hospital will be classified as nonstructural elements that present a risk to life. On the other hand, those elements that represent a risk of loss of goods will be those that, if damaged, would mean a significant loss of assets to the health facility, but would not affect the occupants or the functioning of the building in a significant manner.

A high risk for human life, for example, could be a component mounted on the wall above a patient that could fall, injuring or killing the patient. If equipment is placed on shelves without fastenings, for example, the risk of it being thrown off by an earthquake is high. If it were to be secured with bolts, but not correctly, with a small possibility of falling, it would be classified as a moderate risk; if it were fastened securely, it would be classified as a low risk.<sup>2</sup>

An example of functional loss might be the power generator. If it is not correctly secured and/or enclosed, it could move enough to disengage its electrical connections and stop functioning. In this case, there would be no property loss since the generator may not have been damaged but simply have come loose from its moorings and connections. It would represent a risk to life since almost everything in the hospital depends on electrical power, including the life-support systems for critically ill patients. This demonstrates that, in some cases, two or three types of risk may correspond to a specific component or system: for human lives, for property and/or functional losses<sup>3</sup>.

In order to establish intervention priorities, two parameters are considered:

1. The *vulnerability* of the element or system;
2. The *consequences* of failure or malfunction of the element.

<sup>2</sup> FEMA, *Instructor's guide for nonstructural earthquake mitigation for hospitals and other health care facilities*. [Materials for course given by Emergency Management Institute, Emmitsburg, Maryland, USA. 1988.] See also FEMA, *Seismic considerations: health care facilities (Earthquake hazard reduction series 35; FEMA 150)*. Washington D.C., 1987.

<sup>3</sup> EERI, *Nonstructural issues of seismic design and construction* (Publication No. 84-04). Oakland, California, 1984.

The *vulnerability* of the element or system is the susceptibility to damage, which is measured in terms of:

- Characteristics of ground acceleration;
- Response of the building to acceleration and displacement;
- Size and weight of the element;
- Location of the element in the building;
- Resistance to the building's lateral stresses and relative stiffness of the component with respect to that of the building;
- Characteristics of the connection or joint (or lack of it) between the component and the structure or between the component and another nonstructural support element.

The *vulnerability* of the facilities and equipment can be determined using qualitative and quantitative methodologies<sup>4</sup>, and it is measured in three categories: low, medium and high.

- *Low vulnerability*: the evaluated component is reasonably well anchored and there is a low probability that it would be damaged when faced with the design forces and deformation of the building.
- *Medium vulnerability*: the component is anchored, but there is a moderate probability of this fixture failing when faced with the design forces and the deformations of the building.
- *High vulnerability*: the component lacks fastenings or the fastening is inadequate or incorrect, therefore there is a high probability of damage when faced with the design forces and deformation of the building.

The consequences, or an estimate of the effect of the failure or damage to the component, are seen in terms of:

- Location of the component in the building (according to the service or area);
- Occupation of the building or service and the possible impact on the occupants' lives or on the performance of the building or service in case the element fails.

These consequences may also be measured in three categories:

- *Low consequences*: due to its location in the building or due to its type, the damage to the component represents a low probability of causing injuries to the occupants or of interfering with the performance of the facility.
- *Moderate consequences*: due to its location or due to its type, the component represents a moderate probability of causing injuries to the occupants or of interfering with the performance of the facility.
- *High consequences*: the component represents a high probability of causing injuries (and even deaths) to the occupants, or of seriously compromising the facility's performance.

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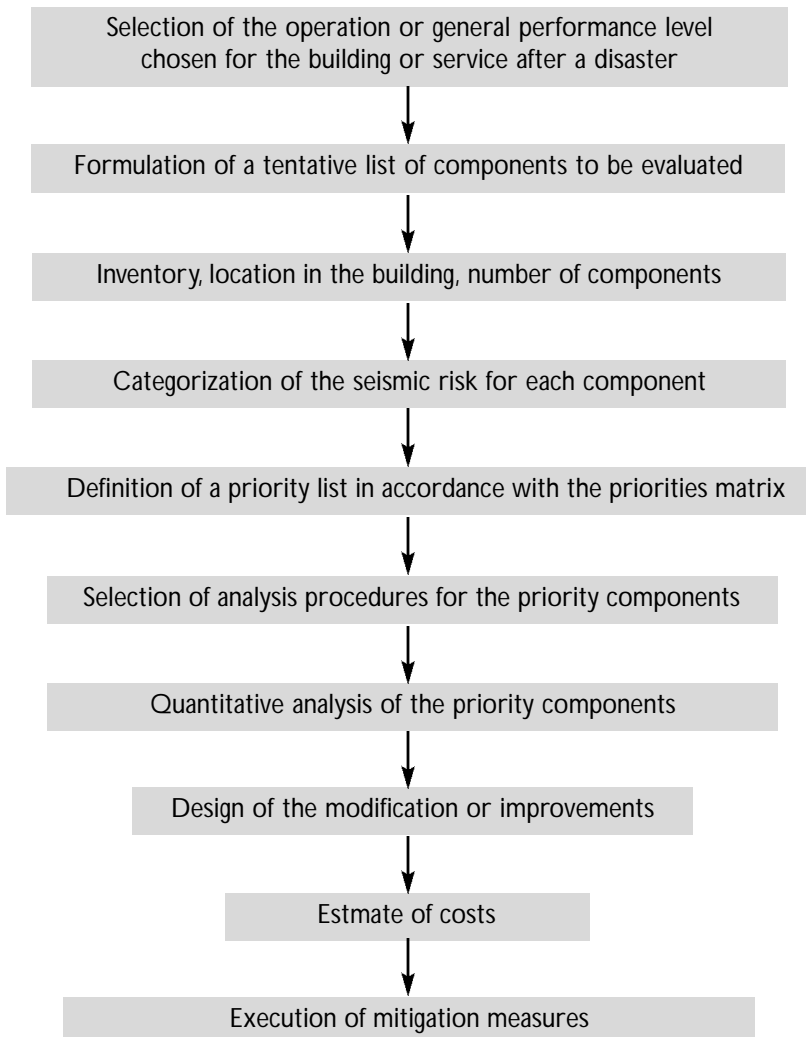
<sup>4</sup> See, for example, McGavin, Gary L. *Earthquake hazard reduction for life support equipment in hospitals*. Ruhnan McGavin Ruhnan Associates, July 1996.

**Table 3.2.**  
**Priorities matrix**

Vulnerability	Consequences		
	High	Medium	Low
High	1	4	7
Medium	2	5	8
Low	3	6	9

Based on these principles, the assessment procedure is established, which basically follows the steps shown in the flow chart shown in Figure 3.2.

**Figure 3.2.**  
**Steps for conducting vulnerability assessment of nonstructural elements**



Using these two parameters, a priorities matrix<sup>5</sup> may be defined, as shown in table 3.2. The highest priority for retrofitting or repair of an element is assigned priority "1"; components receiving a "2" have the second highest priority for retrofitting, and so on.

In general, the deficiencies found in the fixings or fastenings of non-priority equipment are notoriously bad, but corrective measures are, in general, easy to apply and are inexpensive. Attention to these details, even for low-priority items is important. If they are not corrected they could cause problems in the provision of the service after an earthquake.

In many cases, people without specialized training can carry out a preliminary assessment of the risk level by asking two basic questions for each nonstructural element under consideration:

- Could the element suffer damage in the case of an earthquake?
- If the element did not function properly, would this cause a problem in the hospital?

This will produce a preliminary list of elements for more detailed consideration. In this phase it is better to be conservative and to overestimate vulnerability. After identifying a nonstructural element that could suffer or cause damage, or which has a negative impact in terms of loss of lives, property and/or functionality, suitable measures must be adopted to reduce or eliminate the hazard.

The tabulation of the types and levels of risk for any element in a hospital may be achieved using a format adapted to the needs of the health facility. An example of a list of evaluated equipment appears in table 3.3. In this table the type of equipment, its characteristics or size, its location according to service, its estimated vulnerability level, the consequences of its failure and priority for attention are detailed. The type of support, fixing or fastening of the equipment is also described.

Examples of another approach to using qualitative methods to assign the level of risk posed to non-structural components are shown in tables 3.4 and 3.5.

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<sup>5</sup> ATC (Report ATC 33-03), *Guidelines for seismic rehabilitation of buildings*, 75% Submittal, Third Draft, 3 Volumes, Redwood City, 1995; *NEHRP guidelines for the seismic rehabilitation of buildings*, (FEMA 273).

**Table 3.3.**  
**Example of a list of evaluated equipment**

Type of equipment	Location	Size	Vulnerability (V)	Consequences (C)	Priority	
<i>Component</i>	<i>System or service</i>	<i>Characteristics</i>	<i>(H,M,L)</i>	<i>(H,M,L)</i>	<i>f (V, C)</i>	<i>Type of support</i>
Oxygen tank	Oxygennetwork	5.5 x 2.3	H	H	1	Legs w/ bolts
Transformer	Power network	3 x 2.5 x 2	H	H	1	Bolts
Circuit boards	Power network	6 x 2 x 1	H	H	1	Simple brace
Anesthesia machine with monitor	Operating theaters	1 x 2 x 2.2	H	H	1	
Water tanks	Drinking water supply		M	H	2	
Gas connection	Gas supply		M	H	2	Without anchors
Emergency generator	Power network		M	H	2	Bolts
Miscellaneous equipment	Clinical laboratory	Various	L	H	3	Tabletop equipment
Telephone switchboard	Communications	5 x 1.4	H	M	4	Simple brace
Shelves	Sterilization center	Various	H	M	4	Without anchors
Freezer	Blood bank	2.5 x 2 x 0.5	H	M	4	Simple brace
Oxygen cylinders	Operating theaters	Various	H	M	4	
Elevator engine	Elevators		M	M	5	Bolts
Elevator controls	Elevators	2.5 x 1	M	M	5	Bolts
Elevator pulleys	Elevators		M	M	5	Bolts
Dialysis unit	Hemodialysis	0.8 x 1.2	M	M	5	Simple brace w/ rollers
Lamp	Plastic surgery	Various	M	M	5	Built in
Incubator	Neonatology	Various	M	M	5	Simple brace w/rollers

**Table 3.4**  
**Sample form showing types and levels of risk for nonstructural elements**

Facility: \_\_\_\_\_ Expected intensity of earthquake: \_\_\_\_\_

Priority	Non structural elements	Location	Quantity	Level of risk			Engineer required	Estimated cost of intervention		Observations
				Risk to life	Loss of property	Loss of function		Unit	Subtotal	
2	Air conditioning	Ceiling	1	H	H	M	YES	\$500	\$500	Positioned on a spring system
1	Hanging ceilings	Everywhere	200 m <sup>2</sup>	H	H	H		\$20/ m <sup>2</sup>	\$4000	Lacking diagonal wires
5	Water heater	Service room	1	M	M	M		\$200	\$200	Flammable gases; inflexible piping w/out fastenings
4	Shelving	Storage areas	40 lineal feet	H	M	M		\$80	\$800	Low priority since no essential items are stored;no anchors present; 2.40m high
6	Medium height partitions	Workstations	20 every 2 m	M	M	M		\$602	\$1200	Stable level
3	Hanging fluorescent lights	Offices and lobby	50	H	M	M		\$50	\$2500	Loose connectors from the ceiling
								<b>TOTAL</b>		
L (Low);M (Moderate);H (High)										

**Source:** FEMA, *Reducing the risks of nonstructural damage:a practical guide.* (FEMA 74 supersedes 1985 edition). Washington, D.C. 1994.

**Table 3.5.**  
**Example of assessment of nonstructural components used for the**  
**Hospital Nacional Edgardo Rebagliati Martins of the Peruvian Social Security Institute**

Nonstructural components	Damage level due to unsuitable installation	Consequences and probable damage due to unsuitable protection or installation	Type of risk
<b>Lighting system</b>			
INCANDESCENT FIXTURES: Fixed lightning Hanging fixtures Bucket type	From slight to total loss	<ul style="list-style-type: none"> <li>• In the case of fixed bulbs there are generally no damages</li> <li>• The non-supported hanging systems can collide, becoming inoperative</li> <li>• The hanging systems that run on rails might come off their axis</li> <li>• Possibility of inoperative bulbs</li> </ul>	■
Emergency lighting	From slight to total loss	<ul style="list-style-type: none"> <li>• Falling of the equipment due to non-existent or unsuitable fastening</li> <li>• Breakage of equipment should it fall</li> <li>• Power connection may break</li> </ul>	☄ ▲ ■
LAMPS: On furniture Free-standing	From slight to total loss	<ul style="list-style-type: none"> <li>• Overturning and/or falling</li> <li>• Breakage of the equipment</li> </ul>	▲ ■
<b>Ornaments and permanent attachments</b>			
Parapets Cornices Projections Balconies Banisters Gratings Posts Pedestals Veneer Signs	From slight to moderate loss	<ul style="list-style-type: none"> <li>• Shifting</li> <li>• Falling</li> <li>• Overturning</li> <li>• Breakage</li> <li>• Collapse</li> </ul>	☄ ▲ ■
<b>Building joints</b>			
Joint cover Condition Open separation Material	From slight to moderate loss	<ul style="list-style-type: none"> <li>• Damage to tare weight or walls due to filled construction joint (avoid filling the joint space between walls with works material).</li> <li>• Confusion and panic of the users as they wrongly relate the behavior of the construction joint with the physical collapse of the building.</li> <li>• Separation of the joint sheathing (metal, wood, aluminum, copper, bronze, etc.)</li> </ul>	■
☄ = Risk to life ■ = Risk of functional loss ▲ = Risk of loss of goods			

**Source:** Bellido Retamozo, J.;García, Enrique et al. *Proyecto de diagnóstico de la vulnerabilidad sísmica de hospitales del Perú. Sección III:Componente no estructural.* Report prepared for PAHO/WHO, ECHO. Lima-Peru,1997.

An example is shown below of the qualitative analysis of the liquid oxygen tank in a hospital. It is clear from this analysis that in its design the possibility of a strong seismic movement was not considered (table 3.6). Apart from being a slender tank that might easily overturn because its center of gravity is relatively high, its supports are not adequately anchored to avoid the sliding and tipping caused by lateral inertial force (photographs 15 and 16).

**Table 3.6.**  
**Qualitative analysis of liquid oxygen tank**

**ELEMENT: Oxygen tank**

Description of component	Rating					
	GOOD	AVERAGE	POOR	NOT APPLICABLE	NON-EXISTENT	NOTVISIBLE
<b>BASE:</b>						
Type: metal feet			X			
Isolating material				X		
<b>ANCHOR SYSTEM:</b>						
Surface adequate for placement of anchor			X			
Anchor element firmly attached to pedestal			X			
Size or number of bolts			X			
Vibration isolators					X	
Seismic absorbers					X	
<b>CONNECTIONS:</b>						
Flexible joints or flexible tubing						X
Flexible electrical connection				X		
Flexible connection to ducts				X		
<b>OTHERS:</b>						
Emergency outlet or drain				X		
Protection against corrosion of support elements				X		

**Evaluating architectural elements**

The architectural elements described below have been shown to be the most sensitive to deformation. Therefore, in order to ensure that the facility can meet the safety level of immediate occupation after an earthquake, it is essential to limit the possibility of structural deformations or to take special precautions regarding these elements. To achieve this, seismic rehabilitation of the structure is required or there must be total independence between the architectural elements and the structural components such as walls, beams and columns.

**Nonstructural walls**

Nonstructural walls are those made of masonry or other material and are used to divide spaces. They support their own weight and have a very limited capacity to support lateral stresses or to absorb significant structural deformations.



O.D.Cardona

Photograph 15. Side view of the liquid oxygen tank.

In these walls, failure occurs due to cracking and lateral shifting along the cracks. Small cracks caused by slight movement of the load-bearing structure in general are not critical although they do lead to detachments of the covering (paneling, plaster, tiles), which could interfere with the hospital's performance depending on the size of the pieces that come off. Cracks of more than 0.007 millimeters are a sign of loss of support capacity along the edge and therefore, of serious failure of the wall. In general, to meet a safety level for immediate occupation, it must be determined that these cracks do not compromise the wall's shear-resisting capacity and that there are no deformations outside the plan.



O.D.Cardona

Photograph 16. Detail of support connections for liquid oxygen tank.

Information on the lateral deformation capacity of partition walls used in hospitals is shown in table 3.7.

Although the unreinforced masonry infill, or nonstructural walls in general are not considered to be structural, masonry walls provide stiffness to the building until the moment these walls begin to fail due to the interaction with the flexible structure. If these walls fail irregularly, they can cause serious concentrations of stresses in columns and beams that were not foreseen in the design, a situation that can compromise the structure’s stability.

**Table 3.7.**  
**Lateral deformation capacity (percentage) of partition walls**

Panel type	Service status	Last status	Height x width ratio (cm)
Masonry confined with handmade brick	0.125	0.40	240x240
Masonry confined with machine-made brick	0.25	0.70	240x240
Wood covered with sheets of plasterboard	0.70	1.10	240x240
Wood covered with plasterboard and asbestos-cement	0.65	1.00	240x240
Lightweight concrete	0.20	0.70	240x100
Steel frame covered with asbestos-cement	–	0.55	200x100
Steel frame filled with lightweight concrete panels	0.35	0.95	230x97
Foam polystyrene strengthened with steel mesh and coating	0.35	0.80	240x112
Foam polystyrene core covered with asbestos-cement	0.50	0.75	240x120
<b>Service status:</b> Deformation level at which damage affects the partition wall.			
<b>Last status:</b> When the damage level of the partition wall requires its repair or replacement.			

*Source:* Astroza, M., V. Aguila and C. Willatt. *Capacidad de deformación lateral de tabiques*. Proceedings of the 7th Chilean Meeting on Seismology and Anti-seismic Engineering, Vol.1, La Serena, Chile, November 1997.

***Facings and finishes***

If the heavy covering on the outside of the building partially falls during an earthquake, that is to say, if one side of the building loses a good part of its covering and the other side does not, as well as causing damage to the people or items around the building, an imbalance will occur that will lead to torsion effects to the building (see photograph 17). This torsion may not have been foreseen in the original structural calculations and could result in partial collapse of the building. It is important to emphasize that, after an earthquake, what appears to be significant damage, might only be damage to panelling that does not compromise the hospital’s structural stability. However, such damage could cause difficulties in the function of the hospital due to lack of asepsis or obstructions, etc.



Photograph 17. The addition of aesthetic features on buildings can increase their vulnerability in earthquakes.

Seismic-resistant design codes usually include requirements for limiting drift or deformation between stories with the aim of ensuring the protection of the nonstructural elements affixed to the diaphragm. A limit for hospitals included in the ATC-3 code specifies 0.01 times the free height between floors for the design earthquake. However, if there are any doubts about the proposed limit, it is advisable to isolate these nonstructural elements from structural components.

As regards the masonry walls joined to the structure, the isolation should be in conformity with the overall conception of the structure's design. If the structural design does not include these walls as part of the seismic-resistance system, they can cause problems of torsion due to their asymmetrical position or can create "soft stories" when concentrated on only a few floors. Since these are problems commonly presented by this type of wall, it is advisable to isolate them from the structure. Rosenblueth<sup>6</sup> provides several wall isolation diagrams with respect to the diaphragm and to the portico.

In the case of nonstructural walls that do not present problems because of their position in the plan and elevation, it is advisable to consider them in the analysis as part of the seismic-resistant structure. This is very important since the seismic response of the construction as a whole may be very different from that foreseen by the model if the presence of these walls is ignored. In fact, the variation of stiffness in the model leads to different design stresses, both in moderate and intense earthquakes.

### **Short column**

Another architectural problem that has an impact on the structure is the "short column effect" (see photograph 18). Sometimes, particularly during the remodeling of a building, openings in the structure are closed with masonry infill to a certain level, leaving space for windows in the upper part. This confines the lower part of the columns and essentially shortens their effective length. It is known that such "short columns" fail in the case of earthquakes.

<sup>6</sup> Rosenblueth, E. (ed.), *Design of earthquake-resistant structures*. New York, 1981.



O.D.Cardona

Photograph 18. Short-column effect

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***Ceilings***

Ceilings are nonstructural elements that are sensitive to deformation and acceleration produced by earthquakes. The deformation of the floor slabs can cause horizontal distortion and the deformation of the main structure and the ceiling can lose its support and fall. The seismic behavior of hanging ceilings depends mainly on how the support system responds to seismic movement. The aluminum plate generally performs well when it is correctly attached (suitable wires and supports) and if the adhesive material that joins the plates to the profiles is effective.

Lightweight panels should not be fragile; in other words, they must be able to support deformations without twisting or cracking.

A certain range of deformations in the aluminum plate can cause the massive collapse of ceiling panels (see photograph 19), which poses the threat of possible injuries to the occupants and can cause damage to equipment and block exit routes.



O.D.Cardona

Photograph 19. Damage to ceilings

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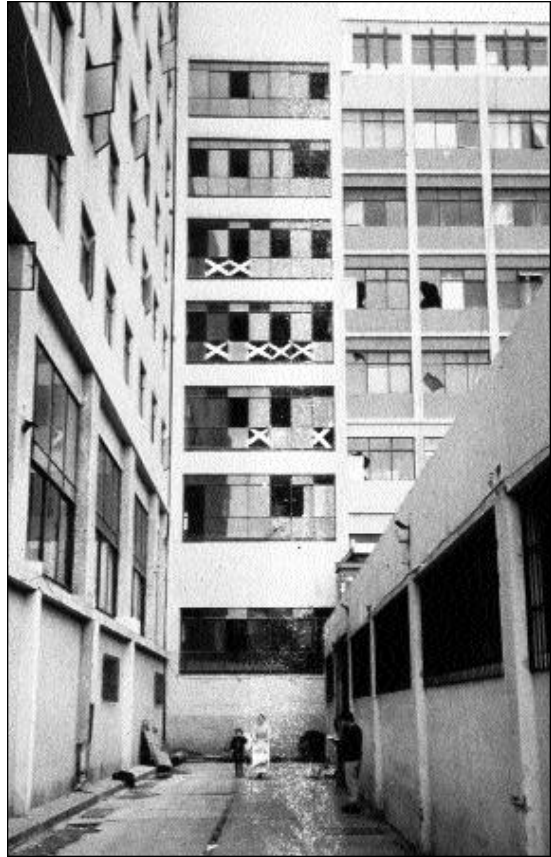
Likewise, care should be taken that the light fixtures, which form part of the ceilings, have an independent support system so that if the ceiling collapses the lighting system can continue functioning.

### **Windows**

The metal window frames attached to the structure or to the nonstructural walls twist and buckle when they are subjected to large deformations, causing the glass to come out of the frame or to break (see photograph 20). This problem is due to several causes:

- The glass has been cut too small for the opening;
- The glass has been cut too large for the opening, leaving little or no margin for it to adjust to deformations in the frame;
- The glass does not fit well in the frame, so that it moves independently of the frame and can break or fall out.

Due to the above, and to the fact that the structure does not have adequate stiffness to restrict lateral deformations and angular distortion of the window openings, it can be expected that in the case of a moderate or intense earthquake a significant number of windowpanes will break.



R. Boroschek

Photograph 20. Broken windows can injure building occupants and obstruct circulation and evacuation routes.

## **Reducing nonstructural vulnerability**

To carry out measures to reduce nonstructural vulnerability, a disaster mitigation plan for the facility must be developed with the involvement of the following professionals: hospital director, chief administrator, head of maintenance, head of clinical and support services and professionals who are experts in applying mitigation measures. It may be appropriate to include other professionals on the team, depending on the type of project being undertaken.

Once a nonstructural element has been identified as a potential threat and its priority established in terms of loss of lives, of property and/or function, the appropriate measures must be adopted to reduce or eliminate the hazard. Twelve applicable mitigation measures, which have been effective in many cases, are listed below.<sup>7</sup>

<sup>7</sup> FEMA, *Non-structural earthquake hazard mitigation for hospitals and other care facilities* (FEMA IG 370). Washington, D.C., 1989.

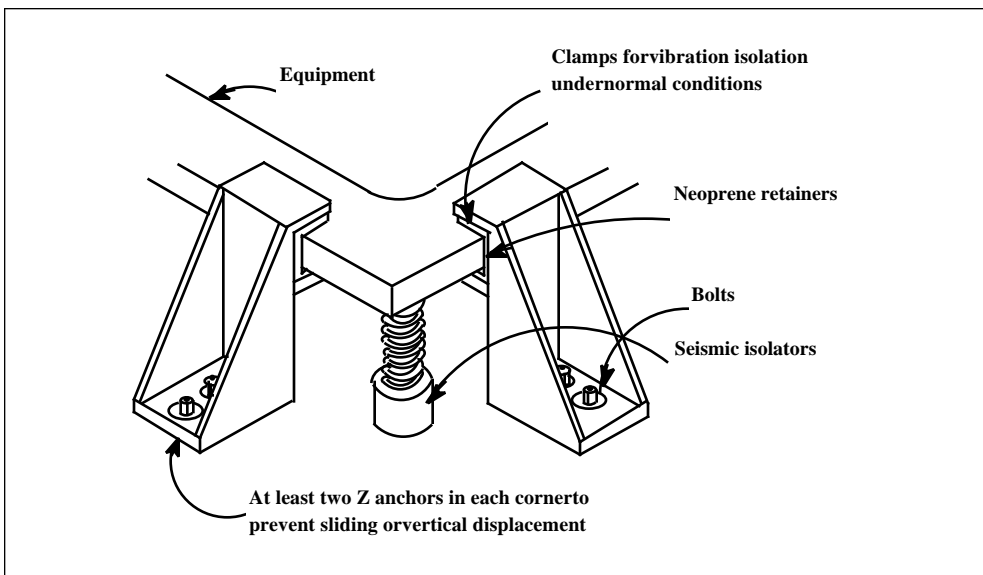
1. Removal
2. Relocation
3. Restricted mobility
4. Anchorage
5. Flexible couplings
6. Supports
7. Substitution
8. Modification
9. Isolation
10. Strengthening
11. Redundancy
12. Rapid response and preparation

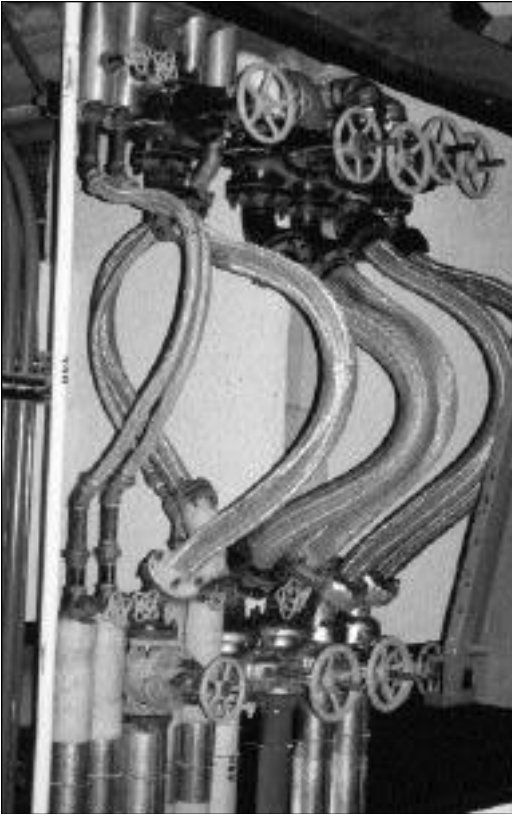
**Removal** is probably the best mitigation option in many cases. An example is a hazardous material that could be spilled, but it could be stored perfectly well outside the premises. Another example would be the use of a very heavy covering in stone or concrete on the outside of the building, which could easily come loose during an earthquake. One solution would be better fastenings or the use of stronger supports, but the most effective solution would be removal and replacement.

**Relocation** would reduce danger in many cases. For example, a very heavy object on top of a shelf could fall and seriously injure someone, as well as breaking and causing economic losses. If it is relocated to a floor-level shelf it would not represent any danger to human lives or to property.

**Restricted mobility for certain objects** such as gas cylinders and power generators is a good measure. It does not matter if the cylinders shift as long as they do not fall and break their valves. Sometimes back-up power generators are mounted on springs to reduce the noise and vibrations when they are working, but these springs would amplify ground motion. Therefore, restraining supports or chains should be placed around the springs to keep the generator from shifting or being knocked off its stand (see figure 3.3).

**Figure 3.3.**  
**Vibration isolation clamps**





OPIS/OMS, C. Osorio

Photograph 21. The use of flexible piping in critical areas such as between buildings and equipment helps to prevent breakage

**Anchorage** is the most widely used precaution. It is a good idea to use bolts, cables or other materials to prevent valuable or large components from falling or sliding. The heavier the object, the more likely it is that it will move due to the forces produced by an earthquake. A good example is a water heater, of which there will probably be several in a hospital. They are heavy and can easily fall and break a water main. The simple solution is to use metal straps to fasten the lower and upper parts of the heater against a firm wall or another support.

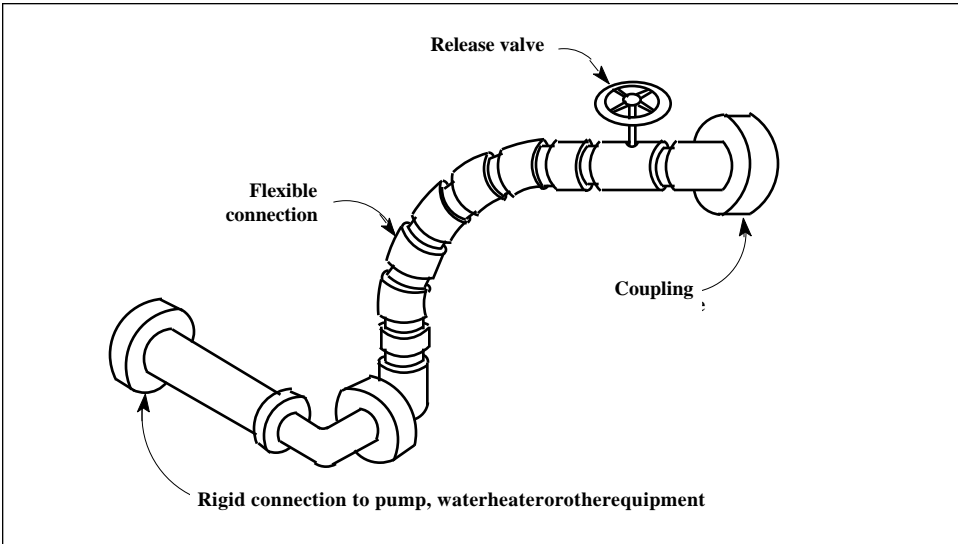
**Flexible couplings** sometimes are used between buildings and outside tanks, between separate parts of the same building, and between buildings (see photographs 21 and 22). They are used because the separate objects each move independently in response to an earthquake: some move quickly, others slowly. If there is a tank outside the building with a rigid connection pipe that joins them together, the tank will vibrate at frequencies, directions and amplitudes that are different to those of the building, causing the pipe to break. A flexible pipe between the two would prevent ruptures of this kind (see figure 3.4) .



O.D.Cardona

Photograph 22. Rigid piping

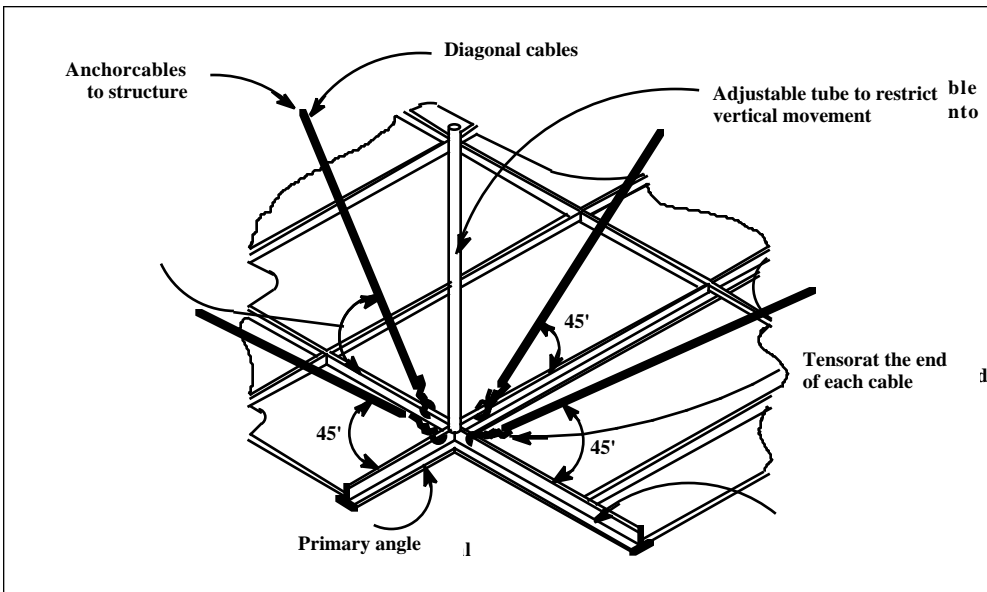
**Figure 3.4.**  
**Flexible fitting and connection**



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**Supports** are suitable in many cases. For example, ceilings are usually hung from cables that only withstand the force of gravity. When subjecting them to the horizontal stresses and torsion of an earthquake, they easily fall (figure 3.5). They can cause serious injury to the people who are underneath them and obstruct evacuation routes.

**Figure 3.5.**  
**Supports for ceiling**



**Substitution** by something that does not represent a seismic hazard is appropriate in some situations. For example, a heavy tiled roof does not only make the roof of a building heavy, it is also more susceptible to the movement of an earthquake. The individual tiles tend to come off, creating a hazard for people and for objects. One solution would be to change it for a lighter, safer roofing material.

**Modification** is a possible solution for an object that represents a seismic hazard. For example, earth movements twist and distort a building, possibly causing the rigid glass in the windows to shatter and launch sharp glass splinters onto the occupants and the passers-by around the hospital. Rolls of transparent adhesive plastic may be used to cover the inside surfaces and prevent them from shattering and threatening those inside. The plastic is invisible and reduces the likelihood of a glass window causing injuries.

**Isolation** is useful for small, loose objects. For example, if side panels are placed on open shelves or doors with latches on the cabinets, their contents will be isolated and probably will not be thrown around if an earthquake were to occur.

**Reinforcement** is feasible in many cases. For example, an unreinforced infill wall or a chimney may be strengthened, without great expense, by covering the surface with wire mesh and cementing it.

**Redundancy** or duplication of items is advisable. Emergency response plans that call for additional supplies are a good idea. It is possible to store extra amounts of certain products, providing a certain level of independence from external supply which could be interrupted in the case of earthquakes.

**Rapid response and repair** is a mitigation measure used on large oil pipelines. Sometimes it is not possible to do something to prevent the rupture of a pipeline in a given place, therefore spare parts are stored nearby and arrangements are made to enter the area quickly in case a pipe breaks during an earthquake. A hospital should have spare plumbing, power and other components on hand, together with the suitable tools, so that if something is damaged repairs can be easily made. For example, during an earthquake the water pipes may break; it may be impossible to take prior measures to totally eliminate this risk, but it should be possible to ensure that everything necessary for quick repair is at hand. With prior earthquake planning it is possible to save the enormous costs of water damage with a minimum investment in a few articles.

These general measures are applicable to almost all situations. However, in many cases, it is enough to be creative and to devise one's own way of mitigating the effects of disasters.

### **Damage mitigation in basic services**

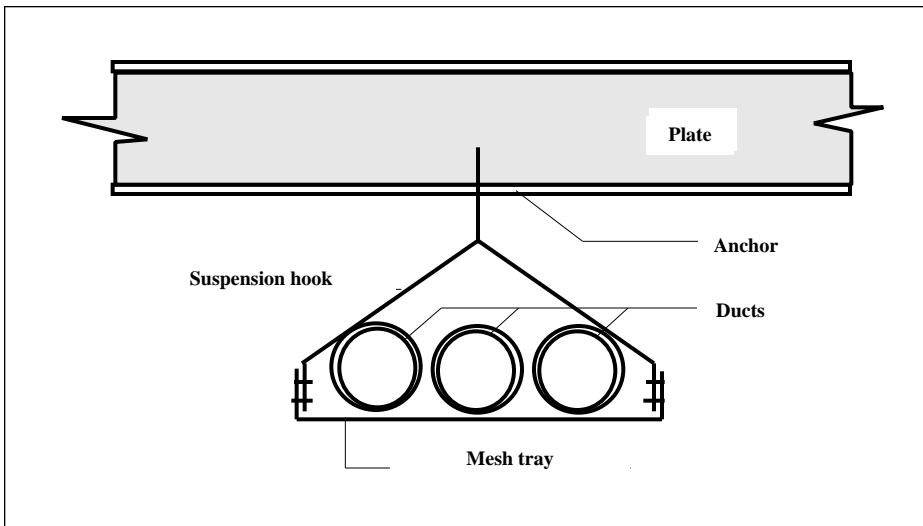
The objective of applying mitigation measures in basic services is to ensure that the hospital has a guaranteed, continuous supply of key utilities such as water and power. This would include having, for example, adequately sized reservoirs to maintain water supply and a power plant so that it is not dependent on municipal or other networks.

Installations for the supply of water, clinical gases, steam and power are vulnerable and in most cases they are located above the false ceilings. If special care is taken during construction to install these networks by suspending them, for example, from mesh plates and anchoring special supports to the

plates, they can be prevented from falling or being disconnected in the case of an earthquake. Another advantage provided by mesh support is to extend the rigid network, combined with stretches of flexible networks every certain number of meters, thereby avoiding breakage of the network.<sup>8</sup>

The same solution should be applied to vertical ducts, which, if properly located with sufficient space, can absorb seismic movements. It is also important to provide for doors in these ducts to allow access for inspections and maintenance to the system (see figure 3.6).

**Figure 3.6.**  
Detail of the hanging duct



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A solution that has been used recently is to leave all mechanical installations on the façades in full view. This facilitates not only normal inspection of the installations but also easy access for repair in case of damage. It would also be advisable in individual rooms or other areas to plan the placement of installations in a way that would allow the number of beds to be increased if the situation demanded it. This would increase the response capacity in emergency situations.

Hot water and steam in kitchen areas are potential hazards and must be subjected to ongoing inspection by maintenance personnel to verify, among other things, that conduits are securely anchored and that there are no possibilities of leakage.

A large part of the equipment in a hospital requires connections to electrical or mechanical systems. In the event of an earthquake it is necessary to carry out an immediate inspection. Although the equipment may be appropriately installed, there might have been enough movement to alter the rigid connections. This alteration can endanger lives of the patients if essential equipment connected to the water, steam or gas networks malfunctions. The following may be noted as possible solutions to this situation:

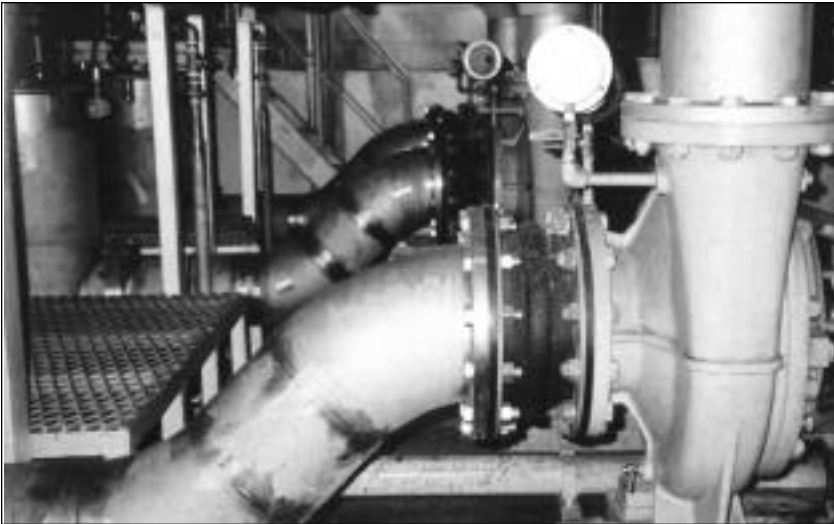
- Flexible hose connections;
- Connections with rotating movement;
- Automatic shut-off valves.

<sup>8</sup> FEMA, *Reducing the risks of nonstructural earthquake damage: a practical guide*. (FEMA 74 Supersedes 1985 Edition) Washington 1994.

Emergency power plants are heavy objects; the heavier they are, the greater the possibility that they will move. Mounting this type of equipment on springs amplifies the movement in an earthquake, which must be taken into account when designing constraining measures. The movement of a generator can block entrances, shift structural components or sever the power and fuel supply lines. Therefore, the connections and installation must have special treatment. Flexible connections are recommended.

Among the recommendations for protecting the emergency power plant, the following are worth mentioning:

- The plant should be anchored or restrained in such a way that it can not move or slide;
- The fuel source must be available during and after the earthquake;
- The start-up batteries or automatic start-up system must be in perfect working order.



O.D.Cardona

Photograph 23. Piping with flexible connections

Fuel to operate the emergency plant must be continuously available, regardless of the damage that is produced by any movement or accident. It is also necessary to make sure that the spare batteries are stored on properly braced shelves so that they will not fall.

Communications, both internal and external, must continue to function at all times. In emergency situations portable radio systems, loudspeakers, etc. must be on hand to organize both the personnel and the users of the building. Communications are also essential to maintain contact with the outside world, with referral hospitals or with the patients' families.

Some equipment necessary in hospitals is hung from the ceilings or the floor slabs, as in the case of overhead lamps in operating theaters and obstetrics, x-ray units that need a certain amperage, some equipment in exercise therapy rooms, and exhaust hoods in kitchens and some laboratories. Recommendations and specifications for securing these items supplied by the manufacturers generally specify beams and special bolts for hanging the equipment.

It is also recommended that furniture containing medicines, bottles and containers of different types have a railing in front of each shelf to prevent the stored items from falling or spilling, causing danger or obstacles for the users.

### Box 3.1 Assessing nonstructural vulnerability in Colombia

Bucaramanga is a city located in northeastern Colombia, in an area of high seismic risk. Its main health facility, the Hospital Ramón González Valencia, is a massive, twelve-story building designed and built at the beginning of the 1950s on a frame structure with isolated footings at a depth of two meters, due to the fact that the soil has a capacity that exceeds 4 kg/cm<sup>2</sup>. Due to its age and its structural configuration, it may be concluded that this type of building is significantly vulnerable to earthquakes. This is not the result of lack of care in its design and construction, but rather because in 1950 knowledge was lacking about seismic hazards in the area and structural behavior of this type of building when faced with earthquakes.

For several years, the authorities of the hospital and of the region tried to identify local, regional and national resources to carry out a seismic structural vulnerability assessment, without positive results. In 1996, the Ministry of Health finally managed to obtain some financing for nonstructural and functional vulnerability studies. These were the first formal nonstructural vulnerability assessments carried out in the country and paved the way for carrying out other studies in hospitals in Bogotá and Manizales.

One of the most important results of the nonstructural study was the confirmation of the need to assess the structural response of the building in strong earthquakes. Due to the flexibility of the structure and its potentially poor performance in the case of strong seismic events, it was concluded, using simplified, qualitative methods, that the deformations that the structure could undergo would cause serious damage to nonstructural elements, be they equipment, installations or architectural components. The study indicated that while addressing nonstructural and functional vulnerability would be highly beneficial, structural damage would compromise the operation of the hospital. In 1997, after overcoming several bureaucratic obstacles, resources for the structural seismic vulnerability assessment and the retrofitting design were finally achieved.

*Source:* Cardona, O.D., Análisis de vulnerabilidad no estructural y funcional del Hospital Ramón González Valencia de Bucaramanga, Consultant contract 972-96, Ministry of Health, Bogotá, 1997.

## Damage mitigation in architectural elements

The selection of the covering materials and finishes in a hospital is important not only for reasons of aesthetics and durability, but also for considerations about disaster mitigation. It is not enough for the hospital not to fail structurally. Its finishes, walls, doors, windows, ceilings, and so on must remain in place, so that they do not become a threat to human life or hinder the movements of the patients, medical and paramedical personnel and others who are inside or who visit the building at the moment of a disaster.

Ceilings are usually hung from the structure or floor slab, and in hospitals, they become an almost unavoidable system since the space between the floor slab and ceiling houses the supply networks for water, light, clinical gases, communications, etc. The specifications for the ceilings must meet aseptic standards and be built with non-flammable, lightweight materials that are capable of resisting movement.

Sometimes aesthetic aspects must be sacrificed to satisfy mitigation needs, as happens with roofs, particularly in hospital buildings with horizontal design. A tiled roof is very heavy, a situation that makes it more vulnerable to earthquakes. The tiles can also fall and injure people nearby.

The use of covering materials on the façade is very common; these can come off in the case of earthquakes. To mitigate this aspect it is advisable to use structural materials on the façade, such as open-faced brick or other materials that have not presented problems in past earthquakes.

Very large surface areas of glass constitute a danger in the case of earthquakes. Designers can specify safety glass or reduce the size of panes.

There is a tendency to use prefabricated elements for railings on balconies. In most cases, sufficient fastenings are not specified for them to form an integral part of the building, increasing the likelihood of their becoming detached. The same occurs when designing banisters, handrails, etc.; these elements must be firmly anchored to the structure so that there is no risk of their coming off.

Some designers choose to place flower boxes on the façades thereby increasing loads. This type of element should not be used in hospitals.

Large canopies often are used in solarium areas, which in many cases are finished with glass and can be extremely dangerous. Although acrylic or plexiglass panels are not foolproof, they may be used with a greater level of confidence to prevent the risk of accidents when tremors occur and elements used in the canopy come off.

To the extent possible, furniture should be placed along walls, and anchored, if possible, on both the sides and back.

The decision to isolate masonry elements must be done with care. They must be suitably anchored to compensate for their independence and to prevent collapse (see photograph 24). In general, the structure's masonry should be isolated in the following cases:

- When its position in the plan tends to cause strong eccentricities in stiffness and, due to this, significant torsion;
- When it tends to produce excessive stiffness on one or several stories in relation to the others, converting them into "soft stories".



Photograph 24. Walls destroyed due to flexibility of the structure

## Mitigating damage to equipment and furnishings

Most hospital equipment and supplies are essential for the functioning of the facility and for protecting the lives of its occupants, and yet they can represent a danger in case of an earthquake.<sup>9</sup> Some of the equipment and furnishings that should be included in vulnerability assessments are presented in table 3.8. The selection has been made considering their importance both for life support of patients and for providing emergency care after an earthquake. Another factor is their cost.

**Table 3.8.**  
**Equipment to be assessed for vulnerability**

Anesthesia machine with ventilator	Industrial freezer
Autoclave	Infusion pump
Automatic cell counter	Kitchen equipment
Bilirubin meter	Laparoscopy equipment
Biochemical analyzer	Lontofor equipment
Blood bank freezer	Microcentrifuge
Boilers	Microscopes
CT scanner	Operating table
Centrifuges	Osmometers
Kitchen equipment	Oxygen concentrator
Culture incubator	Oxygen cryogenic tank
Ovens	Oxygen cylinder
Dryers	Pavilion lamp
Electric photometer	Plate developers
Electrocardiogram defibrillator monitor	Plate processing equipment
Electrodiathermy	Power generator
Electrostimulator	Pulmonary function analyzer
Elevator and/or freight elevator	Pulse oxymeter
ELISA analyzer	Respirators
Ethylene oxide sterilizer	Sterile and non-sterile material stores
Flame photometer	Suction machine or pump
Freezer	Telephone switchboard
Gamma chambers	Ultrasound
Gas analyzer	Urine analyzer
Gas cookers	Vital signs monitors
Geiger counter	Washing machines
Hemodialysis machines	Water pump system
Image intensifier	X-ray equipment
Incubator	

*Source:* Boroschek R.,Astroza M.,Osorio C.,Kausel E. "Análisis de vulnerabilidad y preparativos para enfrentar desastres naturales en hospitales en Chile". Universidad de Chile, Study conducted for PAHO/WHO – ECHO, Santiago, Chile, 1996.

<sup>9</sup> FEMA, Seismic protection provisions for furniture, equipment, and supplies for Veterans Administration hospitals, Washington, D.C., 1987.

Below are some special considerations for these equipment and installations, as well as for other elements:

***Essential diagnostic equipment:***

Phonendoscopes, tensiometers, thermometers, otoscopes, ophthalmoscopes, reflex hammers and flashlights should always be available for physicians, paramedics, and administrative staff.

***Mobile carts:***

Carts used to move special equipment for crisis intervention are particularly important for saving lives and storing supplies. They are found in all patient care areas. Objects must be secured to the trolley. When not in use the trolleys must have their brakes on and be parked against dividing walls.

***Respirators and suction equipment:***

This equipment should be secured in such a way that they do not become disconnected from the patients.

***Hazardous substances:***

Many of the products used in a hospital are classified as hazardous. Storage shelves containing medicines or chemicals, if overturned, can constitute a hazard by virtue of their toxicity, both in liquid and in gas form. On many occasions fires start by chemical action, overturned gas cylinders or ruptures in gas supply lines.

***Heavy articles:***

Heavy articles such as televisions on high shelves near the beds, in waiting rooms or meeting spaces can pose a threat if they fall. Some specialized pieces such as X-ray equipment, ceiling lamps, sub-stations, etc. could be damaged if not firmly fastened.

***Filing cabinets:***

In most cases they store clinical notes and a large amount of information necessary for patient treatment. They must be secured to the floors and walls to prevent them from tipping over.

***Computers:***

Much of a hospital's general information is contained on computers; they must be well secured to desks to prevent them from falling and losing their function. Computer services must take the recommendations made for networks into account, and computers should be backed up by the emergency power plant.

***Refrigerators:***

It is particularly important for the blood bank refrigerator to maintain continuous cooling, and it should be connected to the emergency power supply. If this is not the case the blood reserve can be lost along with medicines, food and other supplies that require refrigeration and that are necessary in emergency situations.

***Nuclear medicine:***

This sector presents particularly hazardous situations, given the type of equipment and materials used.

***Kitchen area:***

During emergencies, food service must be guaranteed; therefore all its equipment such as cooking pots, ovens, stoves, exhaust hoods, grinders, industrial blenders, thermal trolley, etc., must be sufficiently anchored to tables, walls or ceilings to ensure that they continue to function and do not fall and cause injuries.

***Gas plant:***

It has been observed that inappropriate location of this service may constitute a major hazard in the case of an earthquake and proper safety standards must be applied in this regard. The plant must be sufficiently ventilated and preferably located outside the building block. The plant should face areas that are unoccupied by people in the event of an explosion.

Gas cylinders are also used by some hospitals and are found throughout the building, mainly in support areas. Some contain toxic gases and others flammable gases. They must be isolated to avoid injury to the personnel, to the patients or damage to the cylinders themselves.

***Maintenance workshops:***

They are very important both in normal situations and in emergencies, since they are used for the repair of a large number of electrical, health and plumbing installations, etc., that are necessary in the event that the building is damaged.

It would be practically impossible to make a complete list of all the elements involved in the performance of a hospital. Therefore, in applying disaster mitigation measures common sense must be used at each step, such as for example, avoiding placing equipment and other items above patients, staff and transit areas in order to prevent them causing serious damage if they shift or fall.

The preparation of a complete assessment for mitigating seismic risk or another type of disaster is a complex task. Consequently, it is more a matter of raising issues that can be dealt with more thoroughly over time. Each person or organization can add its own procedures, adding new solutions to those already implemented, so long as priorities are established, since it is almost impossible to do everything that needs doing. Any advance represents an important step toward decreasing risk factors and the possibility of losing hospital functions when they are most needed.

In general, it is possible to divide mitigation recommendations into two categories:

- Those that are easy to implement and should be carried out by the hospital's maintenance staff or by contractors.
- Those that require consultation with specialists and capital, such as costly modifications or new constructions to be implemented in the medium or the long term.

In many cases, the implementation of mitigation measures is the responsibility of the maintenance staff, which can be an advantage given their knowledge of the facility and the possibility of carrying out periodic inspections of the mitigation measures adopted. In fact, the improvement of existing buildings and structures can be carried out during routine repairs and maintenance.

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