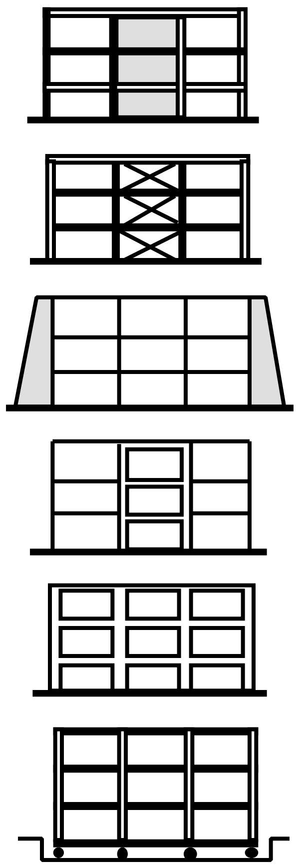
Figure 2.11.
Conceptual solutions for structural reinforcement

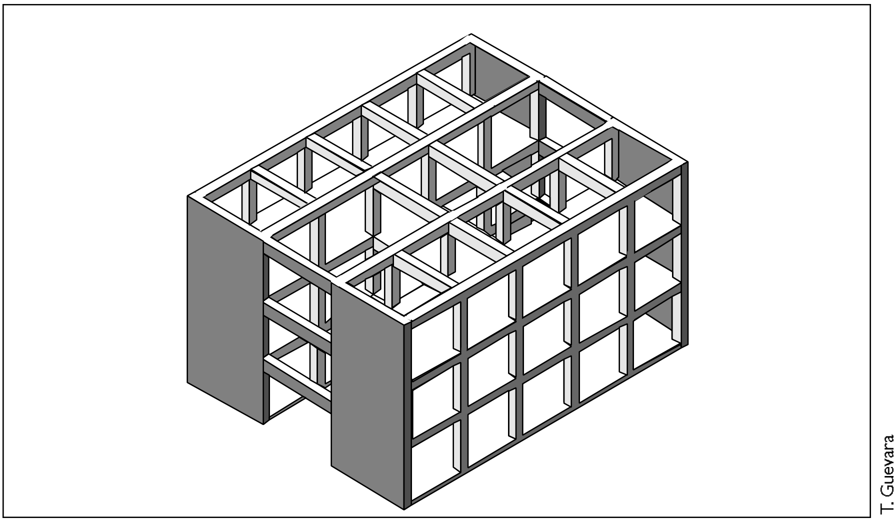
Reinforcement measure	Benefits
Interior walls	Increased resistance and reduced drift
Addition of diagonal bracing	Increased resistance and reduced drift
Addition of buttresses	Confinement and reduced drift
Addition of interior or exterior moment-resisting frame	Confinement and reduced drift
Complete rebuilding	High seismic-resistant capacity and control of typical types of damage
Isolation at the base of the building	Protection of the building through control of shaking



AIA/ACSA

12 Iglesias, J., *Evaluación de la capacidad sísmica de edificios en la Ciudad de Mexico*, Secretaría de Obras, Mexico, 1986.

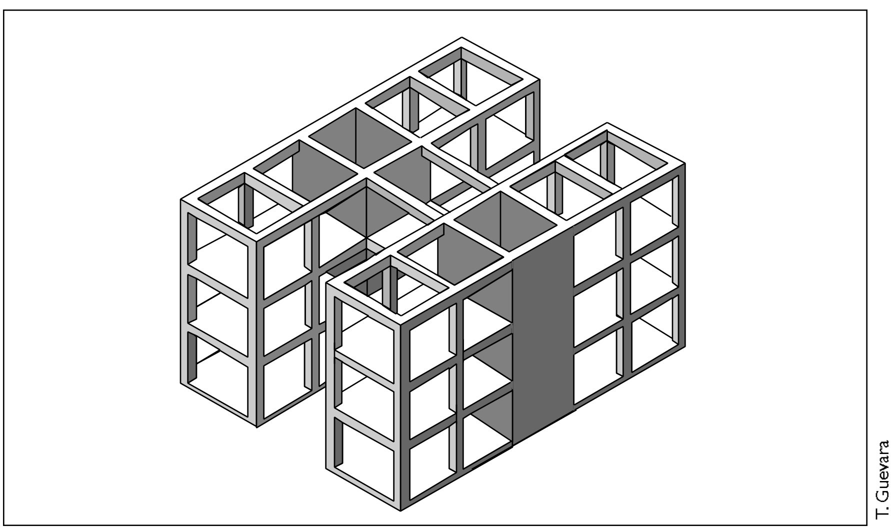
Figure 2.12.
Structural walls in the periphery



Interior structural walls

When it is possible to work inside a building, these walls are an alternative that should be considered, particularly in long buildings where the flexibility of the diaphragm must be reduced (see figure 2.13). They are generally inserted through perforations in the diaphragm, through which the reinforcement bars pass. This method of retrofitting was used in the National Children's Hospital of Costa Rica.

Figure 2.13.
Interior structural walls



Frame walls

Both inside and outside buildings, a practical solution to the problem of stiffness and resistance is to fill frame openings with concrete or reinforced masonry walls. Due to the connection with the column, the stresses on them will change substantially. If the reinforcement of the column is sufficient for the new situation, the connection with the wall can be done solely with soldered bolts. Otherwise, a sheathing of the column, monolithic with the wall, should be constructed.

Buttresses

Unlike exterior building walls, buttresses are placed perpendicular to the face of the building. Aside from providing rigidity, they are useful in preventing tall, narrow buildings from overturning. The Cardiology Hospital of the Mexican Social Security Institute (IMMS) uses this type of reinforcement (see photograph 12). Due to space limitations, however, these are not always feasible.

C. Osorio

Photograph 12.The Cardiology Hospital of the Mexican Social Security Institute was retrofitted using buttresses following the 1985 Mexico City earthquake.

Braced frames

Another frequent solution consists of including several steel frames with diagonals firmly anchored to the diaphragms, as a substitute for stiff walls (see photograph 13).

Sheathing of columns and beams.

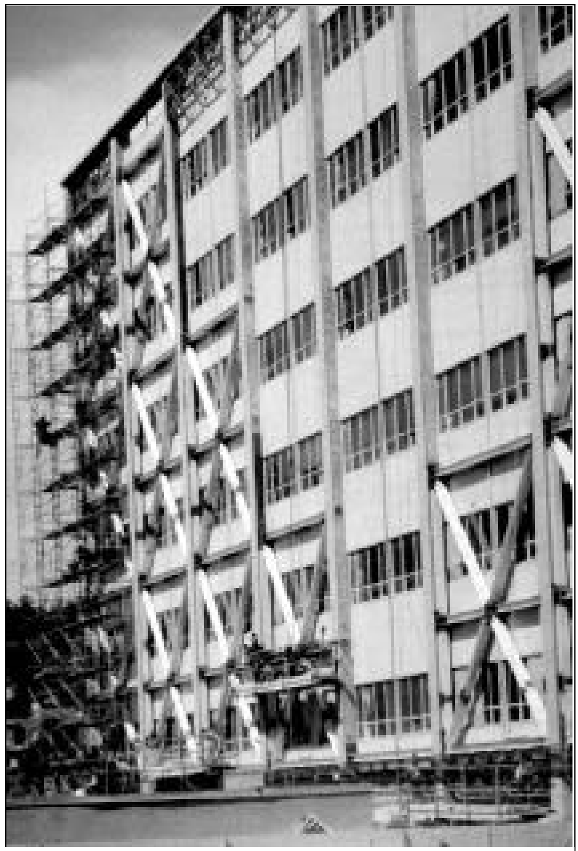
Used for frame systems, this is generally applied on most of the columns and beams in a building in order to increase their stiffness, resistance and ductility alike.

Construction of a new framed system.

On occasion it is possible to carry out a total restructuring by attaching new external perimetric frames to the old structure, like those used in the reinforcement of the Hospital Mexico in San José, Costa Rica (see photograph 14). Usually this is combined with the incorporation of internal structural walls perpendicular to the longitudinal direction of the frames.

Isolation and control of vibrations.

There has been a marked increase in the use of techniques to isolate the foundation and control vibration in structures located in seismic-prone areas. This is an alternative to methods that aim to dissipate energy by tolerance of damage by structural elements entering into the nonlinear range. These systems will undoubtedly be very important in the construction of buildings in general, due to the growing demand for structural and nonstructural safety in the face of strong earthquakes and for comfort amidst environmental vibrations.



Photograph 13. Reinforcement with diagonals.

Photograph 14. Use of external perimetric frames for reinforcement of the Hospital Mexico in a project carried out by the Costa Rican Social Security Fund (CCSS).

Box 2.5. A demonstration of political will in Costa Rica

Vulnerability assessments of the hospitals in Costa Rica were begun in 1984 as part of a research project at the University of Costa Rica and in response to growing public concern about the recurrence of the disaster experienced in 1983 in San Isidro de Pérez Zeledón.The School of Civil Engineering initiated this work thanks to incentives provided by the National Emergency Fund and to the interest shown by officials of the Costa Rican Social Security Fund (CCSS). PAHO/WHO was another driving force of this initiative, since it represented a new field of research in Latin America.

After the study of the Calderón Guardia Hospital in 1984,the University requested financing from the National Council of Scientific and Technical Research (CONICIT) to study the vulnerability of all the hospitals in the country. CONICIT partially approved the financing requested so the University began the project by studying Hospital Mexico in 1986.This funding was attained in part due to the support given the initiative by physicians of the CCSS.The Hospital Mexico study was the first on integral seismic vulnerability in the country, addressing different levels of risk for structural,nonstructural,administrative and functional aspects of the hospital.

The restructuring of the three buildings that constitute the hospital complex consisted basically of positioning additional columns and beams on the exterior concrete frames and isolating all of the structural walls. In addition, the walls of the emergency stairs were connected to the main structure to decrease the possibility that they would collapse. With this alternative, the stiffness of the buildings was increased which would decrease lateral deformation due to earthquakes; this in turn meant reduced risk of nonstructural and structural damage (see figure 2.14).

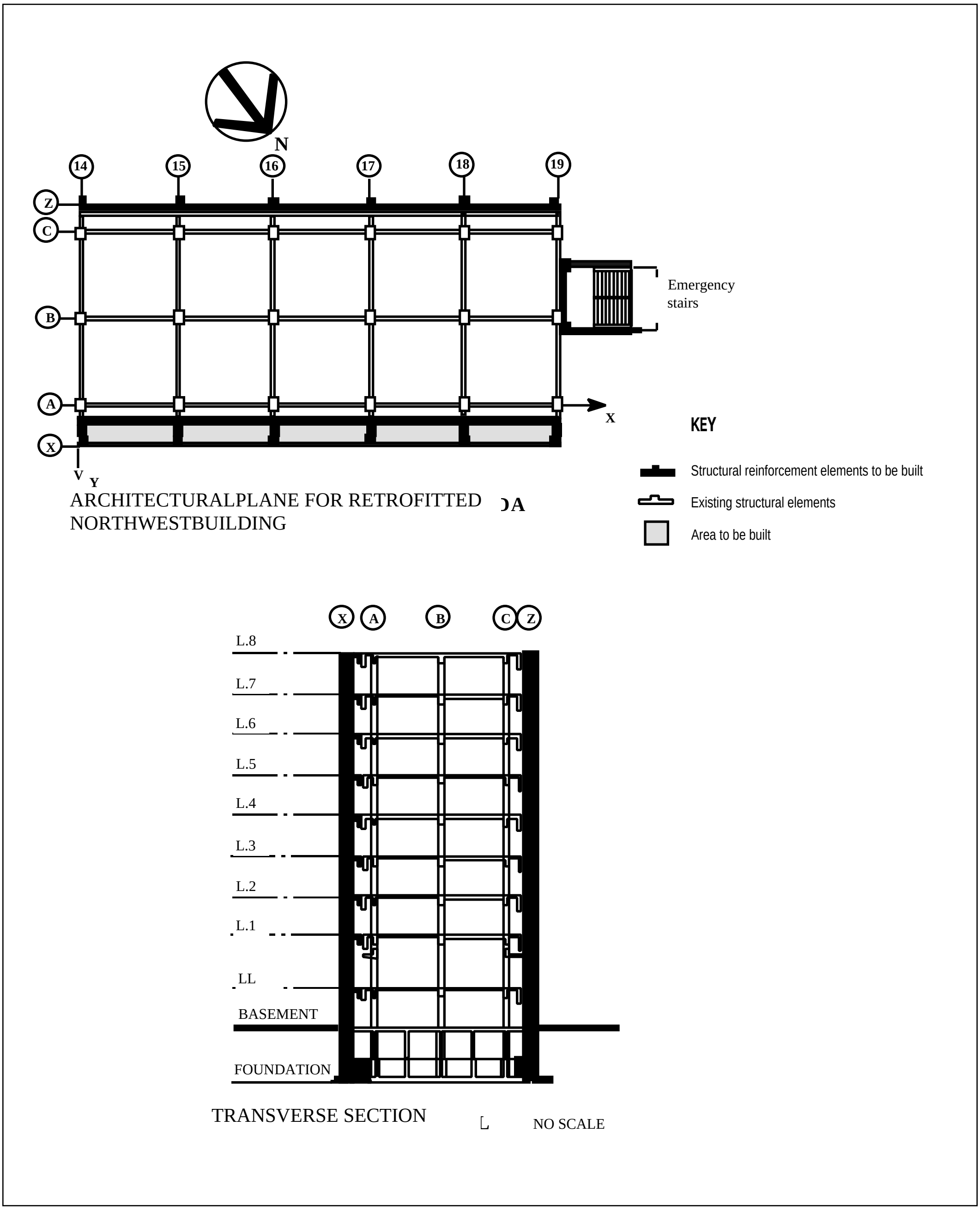
The reinforcement work began in May 1989 and the process required 31 months to complete. The cost of the work was US$ 2,350,000 dollars,which represented 7.8% of the value of the hospital.The hospital had to reduce its number of beds from 600 to 400 during the process, with a consequent increase in the number of patients waiting for medical attention.

Apart from the Hospital Mexico, the CCSS also conducted vulnerability assessments, retrofitting design and rehabilitation of the Hospital de Niños (Children's Hospital) and the Hospital Monseñor Sanabria. Difficulties in the construction process arose in these two cases due to inadequate coordination with hospital administration. However, these experiences permitted the identification of the aspects of coordination and multidisciplinary work that must be taken into account in order to avoid overspending and problems related to the ongoing performance of the facilities.

Several earthquakes have occurred since 1990 that have demonstrated the good fortune of having reinforced these facilities. Particularly, it is believed that the Hospital Monseñor Sanabria would not have survived the earthquake of 25 March 1990.On the other hand,the damages sustained by the Hospital Tony Facio, which had not been reinforced when the earthquake of 22 April 1991 occurred,confirmed the importance of continuing the assessment and retrofitting process. In fact,the CCSS formally incorporated seismic-resistant design and vulnerability assessments into the formulation phase of new projects. In the design of the new Hospital San Rafael de Alajuela, for example, state-of-the-art techniques were used.The design of this hospital is an example of multidisciplinary work in which seismology experts, scientists, engineers, architects, and public health personnel all participated.

Sources: Cruz,M. F.,"Comportamiento de hospitales en Costa Rica durante los sísmos de 1990",Taller Regional de Capacitación para la Administración de Desastres,Bogotá,1991.Cruz,M.F. and R.Acuña, *Diseño sismo-resistente del Hospital de Alajuela: un enfoque integrador*, International Conference on Disaster Mitigation in Health Facilities, Mexico 1996.

Figure 2.14.
Reinforcement of the northwest building of the Hospital Mexico, Costa Rica



Coordinating the retrofitting process

The retrofitting or reinforcing work requires close coordination between hospital personnel and those responsible for design and construction. The director of the hospital, the administrator, those in charge of affected clinical and support services, the chiefs of maintenance and general services, as well as all of the professionals involved in the design and execution of the reinforcement work, must take part in the process. There must be active involvement at all stages of the project, that is during the design, planning and execution of the measures. It should be kept in mind that the same persons may be participating at different times in the coordination efforts.

Lessening the seismic vulnerability of a hospital building is usually more complex than on other types of buildings. Following are some of the aspects that make this type of work different in health installations:

- Normally, the building cannot be vacated in order to carry out the retrofitting;
- The scheduling of the work must take into account the operation of the different health services so as not to cause serious disruptions;
- A wide number of unforeseen tasks can be expected due to the difficulty of precisely identifying details of the construction process before the work begins;
- The effects of structural modifications on nonstructural elements and on architectural finishes should be identified before beginning the process.

In accordance with the above, the development of a retrofitting project should follow a very detailed work plan that addresses the function of the health services at each step of the process. In the same way, the plan should establish proper coordination with administrative personnel, medical services, and hospital maintenance.

Costs of retrofitting

As mentioned earlier, the cost of modifications can only be calculated on the basis of a detailed design of the structural solution and its implications for nonstructural elements. However, it is possible to formulate an advance budget with some degree of precision and that should be adjusted as little as possible during the process.

The additional costs to make a building resistant to hurricanes, earthquakes, or floods can be considered a form of insurance. Studies have shown that the costs of a building designed and built to withstand hazards like earthquakes may increase the total cost of the building by 1% to 4%.

When the costs of preventing damage to specific items is analyzed, the results are dramatic. For example, an electric generator that is severely damaged could result in the loss of power to the hospital and could cost as much as US$50,000 to replace. This situation could be avoided by the installation of seismic isolators and braces to prevent the generator from moving for costs as low as US$250.

In all cases, the high economic and social value of improving the structural performance of vulnerable hospital facilities has been demonstrated. The cost of retrofitting, although it could be considered high in certain instances, will always be insignificant in relation to the provision of health service or in relation to the cost of repair or replacement. One could ask questions such as: The cost of retrofitting would be equivalent to the cost of how many CT scanners? And, how many scanners does the hospital have? The answers could give surprising results, without taking into account the value of all of the other equipment and supplies that are generally in the building, and, of course, the human lives directly or indirectly affected, and the social cost that the loss of health services signifies.

Experience in this area shows that the cost of performing structural seismic vulnerability assessments and designing the required retrofitting may reach between 0.3% and 0.5% of the total value of the hospital. The cost of rehabilitation or retrofitting could range between 4% and 8% of the hospital value (see the example in table 2.2). To illustrate the potential benefit, assume that in a severe earthquake the use of 20% of the existing beds in a hospital would be lost. With an investment in retrofitting of less than 10% of the cost per bed, this loss could be avoided.[13] These figures, while not precise economic assessments, do attest to the cost/benefit ratio achieved when mitigation measures are applied.

Table 2.2.
Cost of retrofitting hospitals in Costa Rica

Hospital	No. of beds	Duration project (months)	Retrofitting cost (US$)	Percentage of of total cost of hospital
Hospital Mexico	600	31	2,350,000	7.8
National Children's Hospital	375	25	1,100,000	4.2
Monseñor Sanabria Hospital	289	34	1,270,000	7.5

13 PAHO, *Lecciones aprendidas en américa latina de mitigación de desastres en instalaciones de salud, aspectos de costo-efectividad*, DHA, IDNDR Secretariat, PAHO, Washington, D.C., 1997.

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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[1] 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.

[1] 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
• Divisions and partitions • Interiors • Façades • False ceilings • Covering elements • Cornices • Terraces • Chimneys • Surfacing • Glass • Attachments (signs,etc.) • Ceilings • Antennas	• Medical equipment • Industrial equipment • Office equipment • Furnishings • Supplies • Clinical files • Pharmacy shelving	• Medical gases • Industrial fuel • Electricity • Telecommunications • Vacuum network • Drinking water • Industrial water • Air conditioning • Steam • Piping • Waste disposal

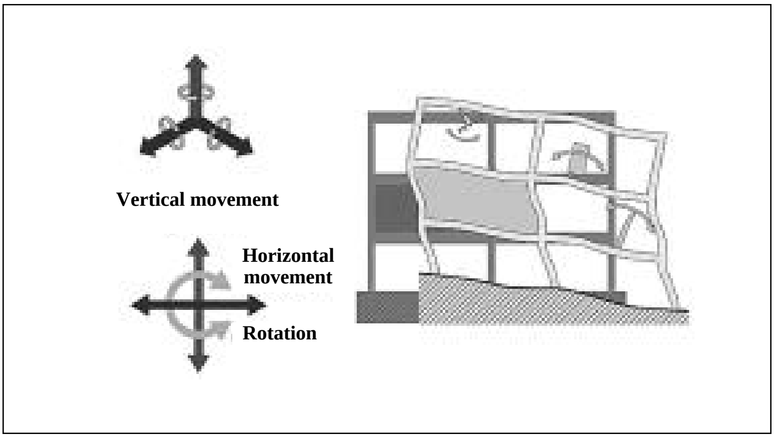
Source: Boroschek R.,Astroza M.,Osorio C., *Capacidad de respuesta de hospitales ante desastres sísmicos: Aspectos no estructurales.* International Conference on Disaster Mitigation in Health Facilities, PAHO, Mexico, 1996.

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.[2]

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[3].

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.

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2 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.

3 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[4], 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.

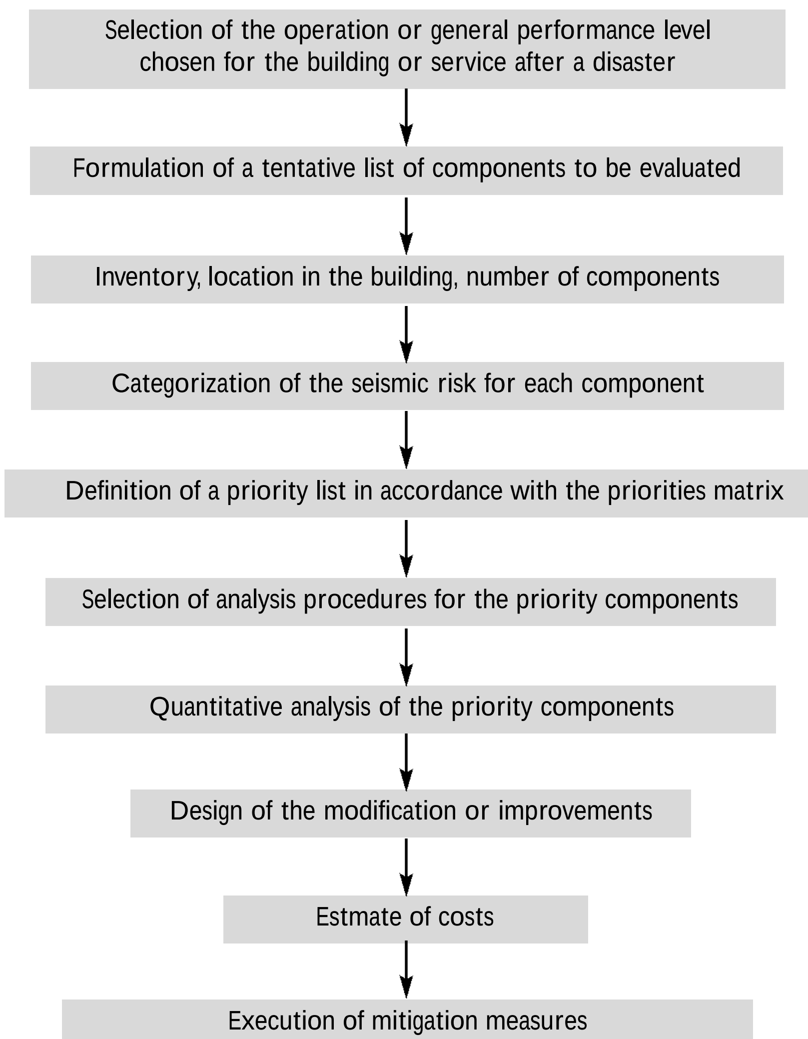
[4] See, for example, McGavin, Gary L. *Earthquake hazard reduction for life support equipment in hospitals.* Ruhnan McGavin Ruhnan Associates, July 1996.

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[5] 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 nonstructural components are shown in tables 3.4 and 3.5.

5 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	
Component	*System or service*	*Characteristics*	*(H,M,L)*	*(H,M,L)*	*f (V, C)*	*Type of support*
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	I	Simple brace
Anesthesia machine with monitor	Operating theaters	1 x 2 x 2.2	H	H	I	
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^2	H	H	H		$20/ m^2	$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
								TOTAL		
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
Lighting system			
INCANDESCENT FIXTURES: Fixed lightning Hanging fixtures Backet type	From slight to total loss	• In the case of fixed bulbs there are generally no damages • The non-supported hanging systems can collide, becoming inoperative • The hanging systems that run on rails might come off their axis • Possibility of inoperative bulbs	■
Emergency lighting	From slight to total loss	• Falling of the equipment due to non-existent or unsuitable fastening • Breakage of equipment should it fall • Power connection may break	֎ ▲ ■
LAMPS: On furniture Free-standing	From slight to total loss	• Overturning and/or falling • Breakage of the equipment	▲ ■
Ornaments and permanent attachments			
Parapets Cornices Projections Balconies Banisters Gratings Posts Pedestals Veneer Signs	From slight to moderate loss	• Shifting • Falling • Overturning • Breakage • Collapse	֎ ▲ ■
Building joints			
Joint cover Condition Open separation Material	From slight to moderate loss	• Damage to tare weight or walls due to filled construction joint (avoid filling the joint space between walls with works material). • Confusion and panic of the users as they wrongly relate the behavior of the construction joint with the physical collapse of the building. • Separation of the joint sheating (metal, wood, aluminum,copper, bronze, etc.)	■
֎ = 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	NOT VISIBLE
BASE:						
Type: metal feet			X			
Isolating material				X		
ANCHOR SYSTEM:						
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	
CONNECTIONS:						X
Flexible joints or flexible tubing				X		
Flexible electrical connection				X		
Flexible connection to ducts						
OTHERS:						
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.

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 then 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.

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

Service status: Deformation level at which damage affects the partition wall.
Last status: 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[6] 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.

[6] Rosenblueth, E. (ed.), *Design of earthquake-resistant structures*. New York, 1981.


O.D.Cardona

Photograph 18. Short-column effect

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

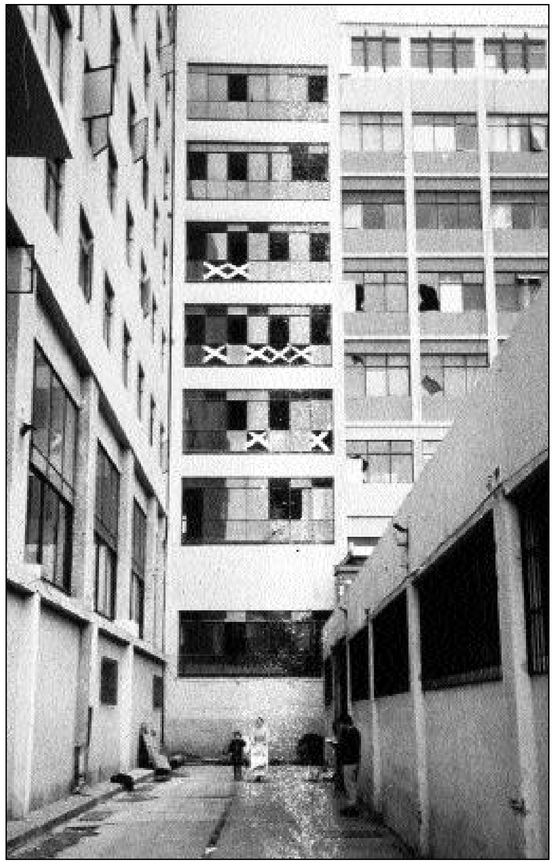
Likewise, care should be taken that the light fixtures, which form part of the ceilings, have an independent support system so that if the ceiling collapses the lighting system can continue functioning.

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.[7]

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

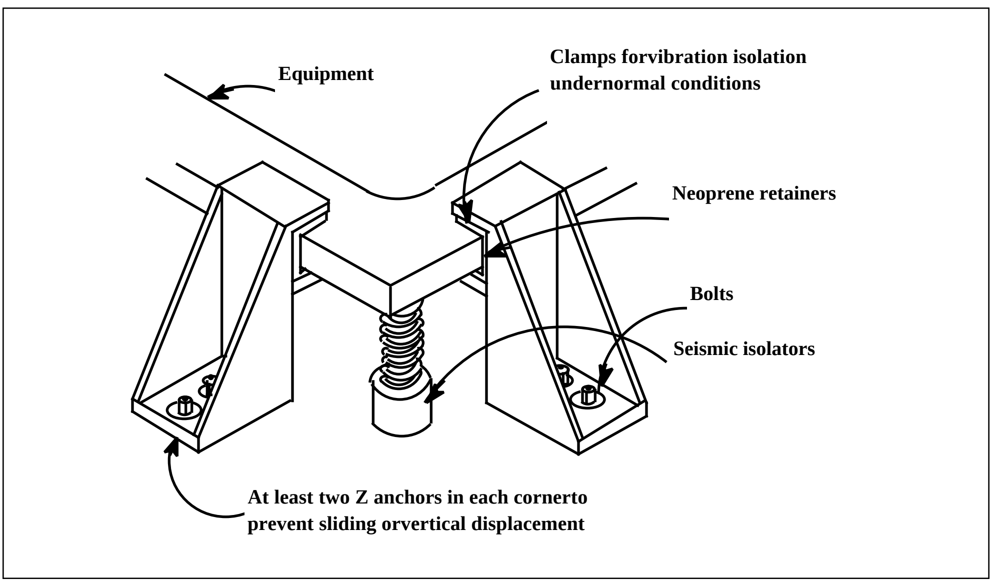
1. Removal
2. Relocation
3. Restricted mobility
4. Anchorage
5. Flexible couplings
6. Supports
7. Substitution
8. Modification
9. Isolation
10. Strengthening
11. Redundancy
12. Rapid response and preparation

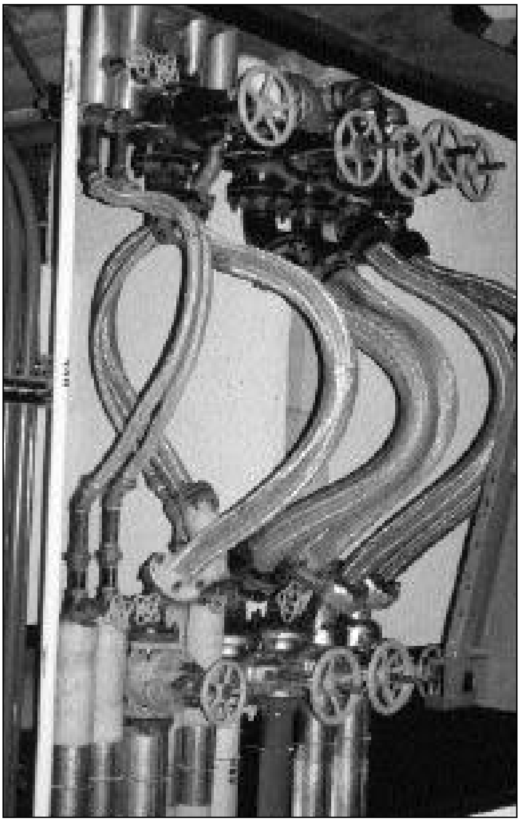
Removal is probably the best mitigation option in many cases. An example is a hazardous material that could be spilled, but it could be stored perfectly well outside the premises. Another example would be the use of a very heavy covering in stone or concrete on the outside of the building, which could 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



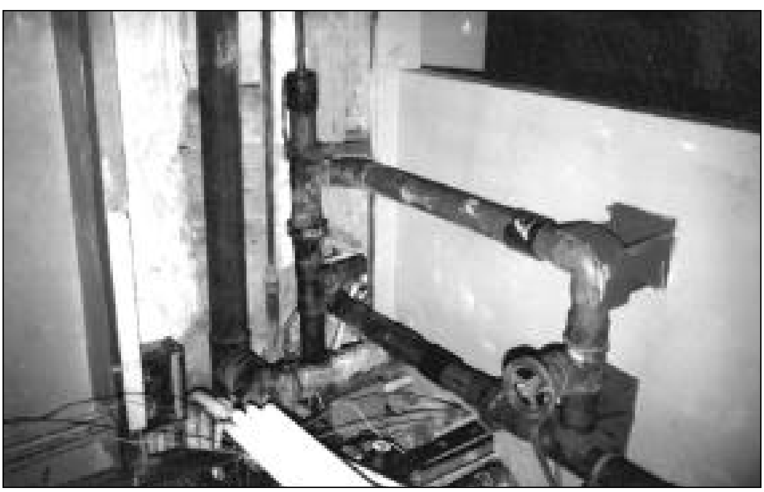


OPS/OMS, C. Osorio

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.

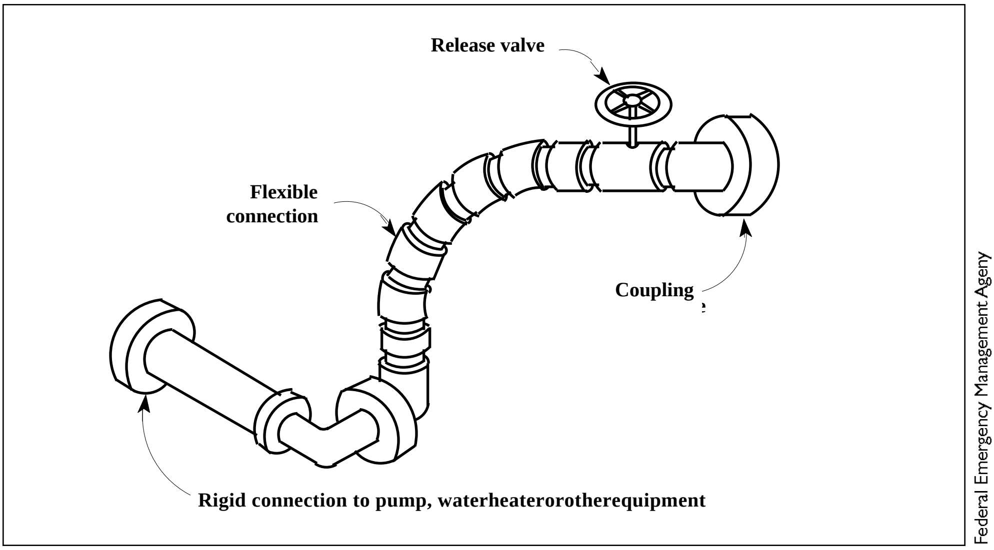
Flexible couplings sometimes are used between buildings and outside tanks, between separate parts of the same building, and between buildings (see photographs 21 and 22). They are used because the separate objects each move independently in response to an earthquake: some move quickly, others slowly. 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

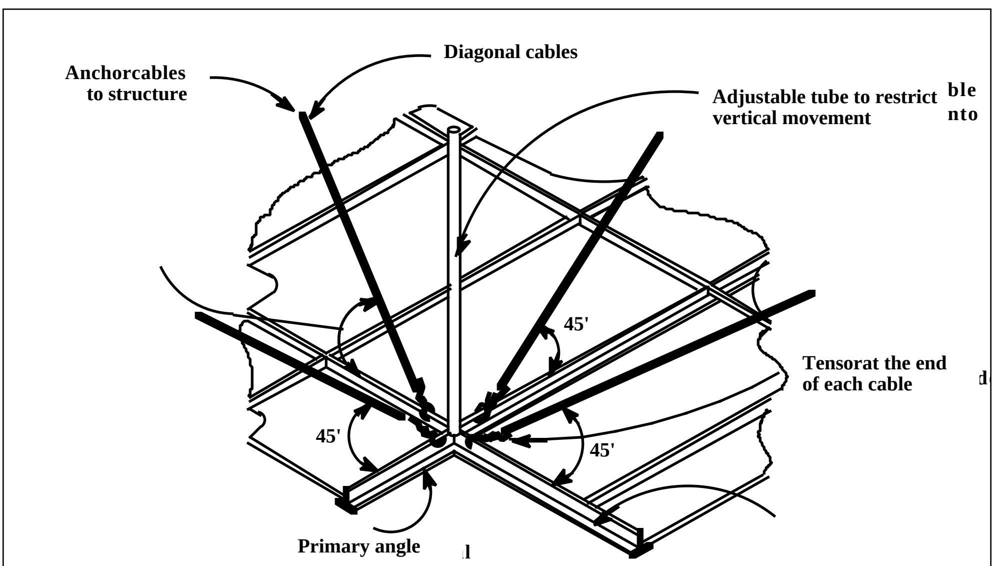
Photograph 22. Rigid piping

Figure 3.4.
Flexible fitting and connection



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.

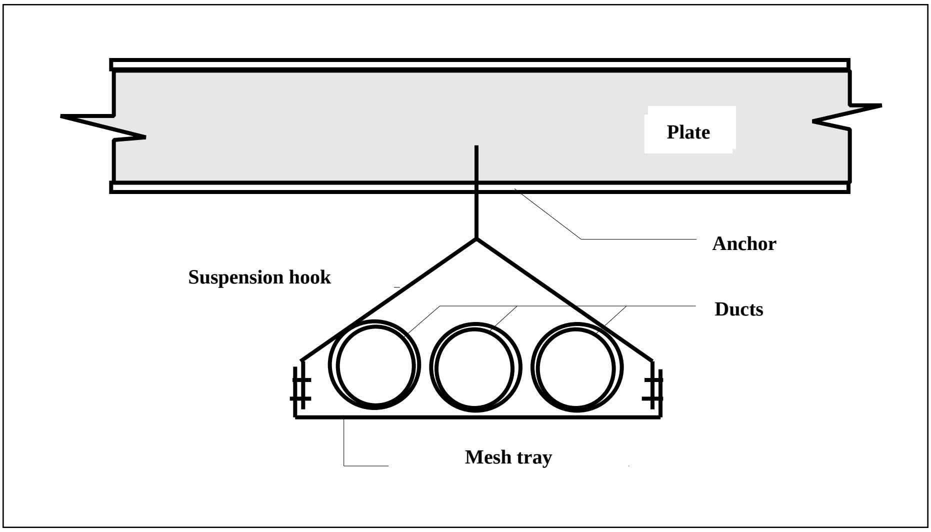
Damage mitigation in basic services

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.[8]

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



Federal Emergency Management Ageny

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:

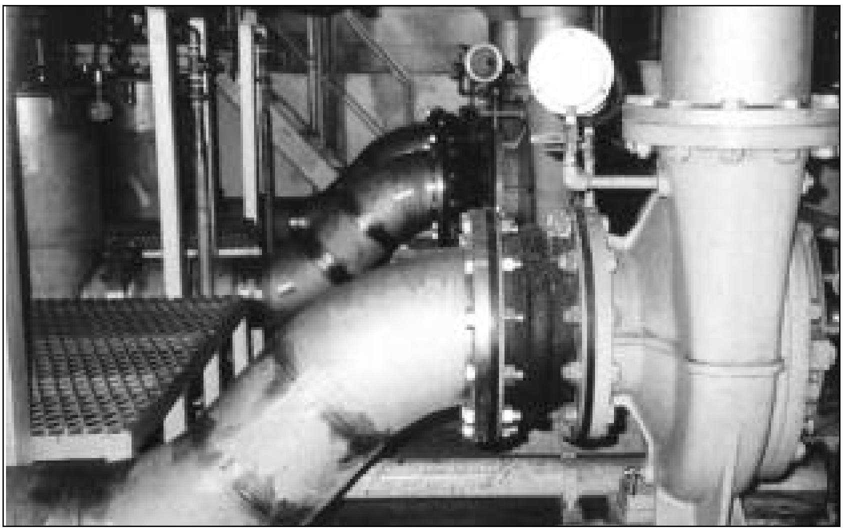
- Flexible hose connections;
- Connections with rotating movement;
- Automatic shut-off valves.

[8] 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/cm2. 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".

J. Grases

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.[9] 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.

9 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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Chapter 4
Administrative and Organizational Vulnerability

Background

Of all the elements that interact in the day-to-day operations of a hospital, the administrative and organizational aspects are among the most important in ensuring that disaster prevention and mitigation measures are adopted before a disaster strikes, so that the hospital can continue to function after an earthquake or other catastrophic event.

Administrative and organizational vulnerability to emergencies and disasters can be analyzed at two different levels. The macro level involves studying the resolution capacity of health facilities, which is based on currently popular concepts of health services modernization and decentralization. This type of analysis is ambitious: its final objective is the implementation of a total quality management policy for health services (see box 4.1). Continually improving the quality of a health facility's services automatically brings about improvements in the structural, nonstructural, and administrative and organizational conditions of day-to-day operations, leading to a hospital that performs more effectively, as a whole, in the event of an emergency or disaster. However, such an analysis lies beyond the scope of this book.

This chapter addresses the micro-level, which normally focuses only on those aspects relevant to a particular health establishment. However, it is possible to draw on the information available from several health facilities, to carry out a micro-level analysis of the administrative and organizational vulnerability of a fairly typical hospital. This includes those operational aspects that might have a negative impact on its ability to provide its services both in normal and in external or internal emergency conditions, as we will see in greater detail below. In order to do this, it is necessary to examine the activities carried out in the different departments of a hospital, their interactions, the availability of basic public services, and the modifications required in the event of an emergency.

Similarly, we will perform a critical review of a typical hospital emergency plan, seen as another administrative and organizational tool, in order to identify its possible weaknesses and underscore the useful components related to guaranteeing the functionality of existing services. It is important to stress that a hospital emergency plan, no matter how well crafted, will be useless if the building suffers serious damage to its physical infrastructure. Accordingly, this analysis is based on the assumption that structural and nonstructural deficiencies have been corrected or, if this has not yet been accomplished, that they have at least been identified and the emergency plan has taken them into account.

Box 4.1. Towards total quality in health care: the continual quality improvement process

The Continual Quality Improvement Process (CQIP) is a new managerial approach that is being introduced in health care programs worldwide.* A CQIP is based on the assumption that many organizational problems result from inadequate systems and processes, rather than individual mistakes. A CQIP encourages the staff at all levels to work as a team, take advantage of collective experience and skills, analyze processes and systems, use available information to identify the nature and magnitude of each problem, and design and execute actions that improve services. Quality is continuously reviewed and incorporated into the working process. Improvements in all functions are carried out gradually and continuously (proactively), and staff members are encouraged to take the initiative, quashing the myth that quality is expensive.

The state of California, in the United States, has very precise terms of reference for contracting preliminary studies and the implementation of CQIP in health services. These include reviewing processes in clinical and non-clinical services, including emergency care, family planning and health education. A CQIP must be steered by a committee that includes the medical director of each health facility, doctors and health personnel, administrators and technicians. CQIP studies must reflect the needs of the population based on age and disease categories.

* Department of Health Services of the State of California. Quality improvement system, 1992.

Note: For a more detailed definition and description of a CQIP program, see *Actualidad gerencial en planificación familiar: estrategias para el mejoramiento de los programas y servicios*, Vol. II, N° 1, 1993.

In the event of a disaster, a hospital must be able to continue caring for its inpatients while treating victims of the event, safeguarding all the while the lives and health of its personnel. For this to happen, the staff must be deployed effectively and know exactly how to respond to such a situation. The building and its equipment, supplies and lifelines must remain operational. Most hospital authorities recognize this fact, which is why they have established formal disaster mitigation plans.

However, most of these plans fail to provide administrative and organizational alternatives in the event of severe damage to the facilities. The issue has received little attention. This is worrisome, particularly in the many locations throughout the Americas where the population only has ready access to one hospital that, if rendered inoperative, could lead to a severe health crisis.

A systematic approach, which takes into account the fluid movement of staff, equipment and supplies in a safe environment during normal operations, is vital if an effective response to disasters is to be in place. This underscores the critical nature and interdependence of the various processes, buildings, and equipment. Deficiencies in any of these areas can plunge a hospital into a crisis.

i) *Processes*: They mostly have to do with the movements of people, equipment and supplies. They also include routine administrative processes such as hiring, acquisitions, human resource management, and the flow of patients through the various clinical and support service areas of the hospital.

ii) *Buildings*: Experience has shown that the design and construction of hospital buildings, as well as their future expansion and remodeling, their everyday operations and maintenance, must be safety-oriented to protect certain critical hospital operations such as emergency care, diagnosis and treatment, surgery, pharmaceutical supplies and food storage, sterilization, patient registration, reservations, or any other areas the institution considers a high priority.

In hospital design, emphasis must be placed on the optimal use of space and the configuration of the services provided, so that the different departments and activities can mesh together with the greatest possible efficiency and the lowest vulnerability. Many facilities have suffered a functional collapse as a result of simple omissions during their design, which could have been easily corrected or addressed at a marginal cost during construction or retrofitting.

iii) *Equipment*: Regular inspections and the proper maintenance can ensure that key and often costly hospital equipment can remain in good working order.

As discussed earlier, it is the duty of the authorities to assess the hospital's vulnerability to natural phenomena and obtain precise estimates of existing risk levels. Once the analysis is complete, the information gathered should be used to determine what level of risk is acceptable. In the case of administrative and organizational vulnerability, the analysis can start with a visual inspection of the facilities and the drafting of a preliminary assessment report identifying key areas that demand attention, alongside a study of administrative procedures, their critical points, and their flexibility in emergency situations.

Administrative aspects

The first aspects that must be evaluated are the administrative procedures related to infrastructure, including the resources that are supplied by public utility networks and on which its function depends, such as communications and information systems, water-supply and sewerage systems, and power supply.

The water-supply system generally includes pumping stations, water treatment plants, and underground mains and other pipes. It may suffer interruptions due to pump failure or, more frequently, pipe ruptures. Hospitals must therefore incorporate water storage tanks into the daily water supply system to ensure that clean water will be available in the event of an emergency.

The power supply system includes generators, high-tension lines, and above-ground substations and equipment. Transformers and porcelain insulators are the weakest points. Health facilities therefore have good reasons to procure emergency generators that can start supplying power at any moment.

During an earthquake, the vulnerability of water, sewerage, gas and fuel pipes depends on their resistance and flexibility. A high degree of flexibility can prevent the rupture of pipes during a moderate earthquake. Differential settlements can be compensated so that ground displacement does not necessarily lead to a rupture. Special attention must be paid to connections entering the building.

For the analysis of administrative procedures, the starting point must be the spatial-administrative relationships within the hospital and with its environment, including special agreements with public utility companies and suppliers in general. The following supplies and lifelines must be taken into account:

- **Water, power and natural gas (if there is a public network)**: Utility company involved; description of the service; location and general state of the main and secondary pipes; normal working conditions; description, general state and location of the main or incoming pipe; and alternative source of supply in the event of the main system failing.

- **Communications**: Service provider; description, general state and location of the link-up; number of lines extensions and expansion capacity; and alternative communications systems through VHF/FM or other frequencies.
- **Roadway system**: Capacity and general state of the main access routes, traffic patterns under normal and critical conditions, and pedestrian routes.

If it is discovered that external public utility networks are intrinsically vulnerable, hospital authorities must demand that utilities assess the vulnerability of external lifelines as part of an integrated local or national vulnerability reduction program. For instance, they must ensure that transformer poles or water mains be reinforced.

The community's Local Emergency Committee must also make sure that the various actors play the role expected of them in the emergency plan in order to guarantee the supply of basic public services to the hospital. This would include cordoning off nearby roads to ease the access of emergency vehicles and establishing security procedures to control access to the facilities. One of the functions of a Local Emergency Committee must be to ensure that lifelines remain operational or are quickly up and running again if disrupted. The institutional members of the Operational Committee must collaborate in key activities such as the provision of first aid, the prompt transport of the injured by ambulances and other vehicles, and public order in general.

Spatial distribution

To carry out an analysis of the internal and external spatial distribution of a hospital vis-à-vis its operation, both in normal and emergency situations, the following steps must be taken:

1. Develop an assessment model, based on current guidelines and existing models, and on desirable performance patterns. Assign priorities to the spaces that need to be assessed on the basis of the clinical or support services considered indispensable for emergency response.
2. Have the medical staff and participating architects and engineers review the building plans, the building inspection process, and the location of each relevant area, and establish the functional relations between them that must be reflected in the spatial arrangements of the various medical and support areas.
3. Analyze and evaluate the internal and external spatial organization of the hospital and compare with current standards and best practices.
4. Make recommendations on how to improve the functionality of deficient aspects.

Spatial distribution must be assessed on the basis of normal operations and their ability to respond to the massive need for emergency services, as well as the ability of other spaces to be adapted quickly to support the above services. An example of the physical and operational interdependency between services is included in figure 4.1.[1]

To reduce administrative and organizational vulnerability, recommendations must be made concerning efficient spatial distribution and interaction, once again both in normal conditions and when the number of victims exceeds the everyday capacity of the hospital. These recommendations must include solutions to help improve the internal and external functionality of the services provided by the hospital and their interactions in the event of an emergency.

[1] A similar chart may be found in Isaza, Pablo and Carlos Santana, *Guías de diseño hospitalario para América Latina*. PAHO Health Services Development Program, Series N° 61, 1991.

The issues to be considered include the following:

- *Access to the hospital complex*: Vehicle and pedestrian access; access by the staff and the public; auxiliary pedestrian access (exclusively for hospital and services staff); and air access, if available, in the form of a heliport or nearby runway.
- *Internal spatial relations (general hospital ground plan)*: Division between critical and complementary functional areas; internal and external spatial organization; spatial capacity to provide emergency response services without ignoring regular functions.

Figure 4.1.
Hospital services interrelationship matrix

	Administration	Training	Outpatient Care	Radiology	Clinical Laboratory	Pathological Anatomy	Physiotherapy	Emergency Care	Surgery	Obstetrics	Sterilization	Intensive Care	Hospital Admissions	Staff Dressing Rooms	Kitchen	Maintenance	Machine Room	Laundry Room
Training	●																	
Outpatient Care	●	●																
Radiology	●	●	■															
Clinical Laboratory	●	●	■	▲														
Pathological Anatomy	●	●	▲	✚	●													
Physiotherapy	●	●	●	■	✚	✚												
Emergency Services	●	●	●	■	■	■	✚											
Surgery	●	●	●	■	■	■	✚	■										
Obstetrics	●	●	●	■	■	■	✚	■	■									
Sterilization	●	●	●	▲	▲	▲	✚	■	■	■								
Intensive Care	●	●	●	■	■	■	✚	■	■	■	●							
Admissions	●	●	✚	●	●	■	●	■	■	■	■	■						
Staff Dressing Rooms	●	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲					
Kitchen	▲	✚	✚	▲	▲	▲	▲	▲	▲	▲	▲	▲	■	●				
Maintenance	▲	✚	✚	▲	▲	▲	▲	▲	▲	▲	●	▲	▲	●	●			
Machine Room	▲	✚	✚	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	●	■	■		
Laundry Rooms	▲	✚	✚	▲	▲	▲	▲	▲	▲	▲	●	▲	■	●	■	■	■	
General Storage	▲	✚	●	▲	●	▲	▲	▲	▲	▲	▲	▲	●	■	▲	●	●	■

■ Key relationship
● Direct relationship
▲ Indirect relationship
✚ No relationship

The hospital's functionality, depending on the kinds of parameters used to measure it, can be rated as follows:

Good: The parameter under review satisfactorily meets current local standards in disaster reduction; there is no need to modify it.

Average: The parameter under review satisfies local standards only moderately; a minor modification could improve performance significantly.

Poor: The parameter under review does not meet local standards; it must be modified substantially to resolve this deficiency.

An example of functional-spatial assessment: the Ramón González Valencia Hospital in Bucaramanga, Colombia		
Relationship between the hospital and its environment	Good	The hospital is surrounded by a major roadway, Quebrada Seca Ave.; a main road, Carrera 33; and two secondary roads (Carrera 32 and Calle 32) that are wide and permit easy access both for pedestrians and drivers from the neighborhoods served by this hospital. It is close to a military camp (the Caldas Batallion), with a heliport that can be used during a major emergency.
	Access	
Vehicle access 1 (V-1) to the main parking lot of the hospital complex, from Carrera 33, for employees only	Good	Cars can come in and out at the same time without hindrance, due to the width of V-1. V-1 can also be used to deliver patients or emergency supplies to the main building entrance without having to go through the parking lot. It is a controlled access, since only employee vehicles are allowed in.
Vehicle access 2 (V-2), from Carrera 32, to provide maintenance to power plant and storage tanks	Good	Fluid access by maintenance vehicles. Only maintenance vehicles allowed.
Vehicle access 3 (V-3), from Carrera 32, to the Emergency Care Unit, the Health Faculty and the Morgue	Average	While it provides access to the Emergency Care Unit, the Morgue and the Triage Area (formerly the Emergency Unit parking area), vehicle movements are obstructed when ambulances and private cars are delivering patients to the Emergency Unit. Moreover, it is not easy to turn around and get out.

Access		
Pedestrian access 1 (P-1) to the Main Hall	Good	Provides access to the public, ambulatory patients, visitors and staff from the square in front of the Main Hall.The Main Hall provides access to the Administration Dept., internal access to other hospital areas, and vertical access to the upper floors of the building.
Pedestrian Access 2 (P-2) to Outpatient Services	Good	It is an independent,direct access from the public square to the main lobby or entrance hall of the hospital.Due to its location,it facilitates the arrival of ambulatory patients,visitors and the general public.
Pedestrian Access 3 (P-3) to the Blood Bank, ground floor	Good	It is an independent,direct access from the public square to the main lobby. People who use this service are not necessarily hospital patients, so having an entrance that is completely independent from the other hospital areas is convenient.
Adjacent Structures		
Adjacent Buildings (1)	Good	The main building is made up of volumes of different heights and geometric configurations. However, no structurally independent modules were identified that might act as adjacent structures and produce a knock-on effect.
Adjacent Buildings (2)	Average	In the case of the other buildings in the hospital complex,no adjacencies were identified. However, due to the proximity of the Health Faculty building to the Emergency Care Area and the Morgue, any falling debris due to structural or nonstructural damage might block access to these units.
Source:Cardona, O.D.,et al. *Informe final del proyecto vuln erabilidad funcional y no-estructural del Hospital Ramón González Valencia,* Colombia,1997.		

Organizational aspects

Among organizational aspects, many of the problems faced by a hospital in its day-to-day operations are caused by deficiencies in its preventive maintenance programs, or even by the lack of such programs. Ordinarily, this is not due to a lack of administrative will to implement maintenance standards, but to a lack of human and financial resources to carry out this task. In addition, lack of planning when expanding or modifying the physical facilities can lead to disorganized growth, which in turn can affect operations negatively, interrupting or slowing down some services and causing frustration among users.

It is important to stress that the disaster response elements outlined in this chapter must be seen as part of a broader, systematic disaster mitigation and prevention plan for the hospital.

A hospital can face two kinds of emergencies: external or internal.

- An external emergency, for our purposes, can be the result of a natural disaster that has struck the community, requiring the hospital to remain minimally operational (i.e., with little or easily manageable structural or nonstructural damage), or it can be related to an enormous increase in the demand of some service, frequently emergency care, due to a specific external factor such as an epidemic or a massive traffic accident in the vicinity.
- An internal emergency takes place when a given set of circumstances leads to the functional collapse of one or more of the services provided by the hospital. These circumstances can include a fire (an operational failure) or the sudden unavailability of lifelines or indispensable equipment due to, for instance, an explosion, or even something as simple as lack of preventive maintenance.

In some cases, both types of emergency may coincide.

Regardless of the type of emergency, the institution must be capable of resolving the technical deficiencies that may arise, in the shortest possible time, and reorienting the necessary human and logistical resources towards the services that most urgently require them. It is also necessary to plan in advance, with the support of public service providers such as firefighters, paramedics, civil defense officials, and transit authorities, in order to establish cooperation and coordination agreements. This might require setting up a formal emergency response network at the local level, including a system of referral facilities that can accommodate an overflow of emergency patients or that might transfer patients presenting injuries of a certain level of complexity.

All these inter-institutional mechanisms must be taken into account in the hospital's disaster mitigation and prevention plan, on the basis of the vulnerability of the structure, its equipment, and its administration and organization. A clear distinction must be made of the kinds of activities appropriate for each type of emergency. The plan must be a flexible tool, but must cover all functional relationships identified, so that services can continue to operate.

Internally, each of the services provided by the hospital will be of greater or lesser importance in the management of an emergency. Indispensable services, by definition, require immediate logistical support, both in terms of human resources and in basic supplies (water, power, food, pharmaceuticals). Non-critical services should be prepared to cede part or all of their personnel and even their facilities, so that they can be temporarily converted into additional emergency treatment areas in disaster situations. Table 4.1 lists typical hospital activities and their relative importance in the event of an emergency.

Table 4.1.
Typical hospital activities and relative importance in an emergency

Clinical and support services	Importance in the event of an emergency
Trauma and Orthopedics	5
Intensive Care Unit / Intensive Treatment Unit	5
Urology	5
Emergency Care	5
Sterilization	5
Diagnostic Imaging	5
Pharmacy	5
Nutrition	5
Transport	5
Recovery	5
Blood Bank	5
Outpatient Consultation/Admissions	4
Pediatric Surgery	4
Pediatrics	4
Laboratory	4
Laundry Services	4
Hemodialysis	4
Internal Medicine	3
Gynecology and Obstetrics	3
Administration	3
Neonatology	3
Respiratory Medicine	2
Neurology	2
Ophthalmology	2
Filing and Case Management	2
Dermatology	1
Psychiatry	1
Oncology	1
Otorhinolaryngology	1
Dental Services	1
Therapy and Rehabilitation	1

Scale of importance:
5:Indispensable 4:Very necessary 3:Necessary 2:Preferable 1:Dispensable

Source: This is a modification of a table prepared by R.Boroschek,et al.in *Capacidad de respuesta de hospitales ante desastres sísmicos:aspectos no estructurales*. International Conference on Disaster Mitigation in Health Facilities,Mexico City, 1996.

External emergencies

As mentioned earlier, a hospital should be able to face a significant natural disaster in its vicinity in such a way that, regardless of the structural and nonstructural damage suffered, its vital operations can continue to function without interruption or with the briefest possible disruption.

The U.S. Veterans' Administration[2] requires that the essential activities of health facilities be able to continue unimpeded for at least three days after a disaster takes place, in order to deal with existing inpatients and handle the injured as a result of the event. In defining essential activities, it is assumed that the hospital structure remains nearly intact and most electrical and mechanical systems still function, albeit with some limitations. Energy, communications and water supply must be guaranteed.

The emergency plan must also contemplate the fact that a natural disaster, particularly a seismic event, is likely to produce certain kinds of injuries, such as fractures, cuts, traumas, lacerations and burns, as well as others related to extreme anxiety such as insulin comas and heart attacks.

Some sources[3] estimate that in the event of a quake roughly 50% of inpatients will have to be transferred to less complex hospital facilities or even back to their own homes. Estimates also suggest that in severely critical situations the hospital might be called upon to expand its care capacity as much as tenfold, depending on the reliability of lifelines such as the water supply system or the medical supplies already stored in the hospital.

The emergency plan must contemplate the conversion of existing facilities for massive emergency care. This of course depends on the physical distribution of the various departments, the availability of equipment and personnel, and the severity of the quake, including the number of victims.

Essential activities in the event of an external emergency

The following is a list of the areas considered essential for caring for the victims of an earthquake (table 4.2). Emergency care, of course, plays the leading role, which may require physical expansion by converting Outpatient Consultation and other nearby areas. The table shows the activities that are directly related to victim management (patient care), support services, and institutional support.

Table 4.2.
Essential activities in the event of an external emergency

Patient care	Medical support	Institutional support
Emergency care	Pharmacy	Command post
Classification of patients	Clinical lab	Maintenance dept.
Immediate ambulatory care	Imaging (X-rays,etc.)	Information services
Non-urgent care / Admittance	Morgue	Nutrition
Surgery	Sterilization	Supplies
Recovery		Storerooms
Intensive care		Communications

2 Veterans Administration. *Study of establishing seismic protection provisions for furniture, equipment and supplies for VA Hospitals*. Office of Construction, Washington D.C., 1980.

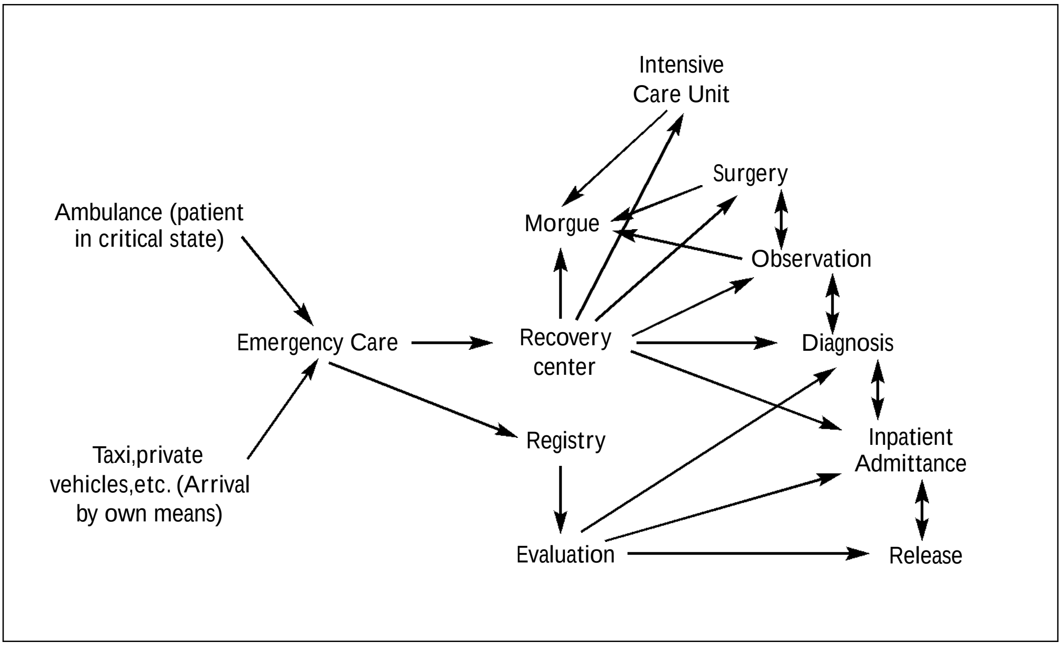
3 Ibid.

The following section provides a description of how one of these services will function both in its day-to-day operations and in the event of an emergency.[4]

Emergency care

Statistics must be analyzed—or gathered, if currently unavailable—concerning the average number of patients handled by the Emergency Care Unit, including overflow provisions and the availability of a surgical unit exclusively for emergencies, with personnel availability around the clock. Figure 4.2 illustrates the normal flow of patients.

Figure 4.2.
Patient flow in an emergency



The key difference in the event of a disaster is that triage is performed prior to the arrival of patients to Emergency Care, and the successive inflow of patients is determined by their classification. No treatment of any kind is carried out in the triage area. Patients classified as "green" are sent to Outpatient Consultation (expansion area), while "yellow" and "red" patients remain under observation or are sent to Recovery, the Intensive Care Unit, surgery or any other urgent service required.

In the course of the emergency, it is essential for the following services and supplies to be available: lighting and power, water, medicinal gas and the vacuum network (if possible, although individual suction can be used). The communications system is especially important.

4 See Cardona, O.D., et. al: *Informe final del proyecto vulnerabilidad funcional y no estructural del Hospital Ramón González Valencia*, Colombia, 1997.

Assessment of essential activities

An example of an assessment of the institutional and logistical support for essential activities required in the event of a massive earthquake can be found in table 4.3. The ratings system work as follows:

- **Optimal**: Efficient allocation of resources or personnel
- **Adequate:** Acceptable allocation of resources or personnel; operations can proceed normally
- **Minimal:** Barely acceptable allocation of resources or personnel; operations can proceed with certain restrictions
- **Inadequate:** Unacceptable assignation of resources or personnel; severe limits on the activity in question, or impossibility of carrying out the activity in question

Table 4.3.
Example of an assessment of institutional/logistical support for key activities

Activity	Support of vital services	Assigned personnel
Emergency Care	Adequate	Optimal
Patient Classification	Adequate	Adequate
Immediate Ambulatory Care	Adequate	Adequate
Non-urgent care	Minimal	Minimal
Surgery Units	Minimal	Adequate
Recovery	Minimal	Minimal
Intensive Care	Minimal	Adequate
Respiratory Therapy	Adequate	Minimal
Pharmacy	Minimal	Adequate
Lab	Minimal	Adequate
Diagnostic Imaging	Minimal	Adequate
Morgue	Minimal	Adequate
Command Post	Minimal	Optimal
Maintenance	Minimal	Adequate
Information Center	Inadequate	Adequate
Nutrition	Inadequate	Minimal
Supplies	Minimal	Adequate
Storeroom/Warehouse	Inadequate	Adequate

Internal emergencies

Internal emergencies can have a variety of causes, such as a minor natural disaster or one caused by human activity that only affects the hospital. Some operational aspects may lead to the functional collapse of the hospital. Consequently, the hospital's organization must have the necessary mechanisms in place to restore normal functioning within a reasonable time.

One tool that must be available in the event of total functional collapse must be an evacuation plan, whether total or partial. Evacuation routes must be properly identified throughout the facilities.

Evacuation is a combination of activities and procedures aimed at preserving the life and well-being of people by means of their orderly flow to lower-risk areas. The decision to evacuate partially or totally must be taken by the hospital director, the head of medical care, the administrator, the head of nursing or the physician in charge. It may also be taken by external personnel, such as firefighters, whose prior knowledge of the hospital's emergency plan, including the key facilities, enables them to play a leadership role when required.

A description of an internal emergency plan and all of its procedures (including warning, execution of plan, care of evacuees, safety and administration) can be found in the specialized literature.[5]

5 See for instance: PAHO, *Organización de los servicios de salud para situaciones de desastre* (Publicación Científica No. 443), Washington DC, 1983; PAHO/WHO, *Establecimiento de un sistema de atención de víctimas en masa*, Washington DC, 1996; PAHO/WHO, *Simulacros hospitalarios de emergencia*, Washington DC, 1995.

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Annex*
Methods for the Analysis of Structural Vulnerability

Qualitative and quantitative methods of analysis of varying degrees of complexity exist to determine structural vulnerability, depending on the objective.

Qualitative methods use general characteristics to describe the structure. They are generally associated with universal indices that have been calibrated from damage experienced in existing structures, allowing the identification of risk in general terms and, in some cases, the level of damage. Among these methods, those proposed by Hirosawa[1], Gallegos and Rivers[2], Meli[3], Astroza *et al*.[4] and Shiga[5] merit special mention.

The quantitative methods are based on analyses that are not necessarily more precise. Typically they are extensions of the analysis process and current seismic-resistant design recommendations.

As an example of a preliminary assessment, this Annex gives a brief description of a variation of the Hirosawa method that has been used in countries like Chile, Peru, Mexico and Ecuador. The changes introduced make this methodology valid for the construction styles and materials typically used in Latin American countries.

According to this method, structural vulnerability is determined by comparing:

(a) The strength, configuration of buildings, maintenance and previous damages in the building;
(b) The level of seismic demands on performance of structure, representing the seismic hazard and the local conditions of the site where the building is located.

In the case of the Hirosawa method, the comparison is done by calculating two indices and establishing that the building is seismically safe when the index corresponding to the resistance provided for the building (I_S) is greater than the resistance demanded (I_{SO}).

Hirosawa method

The method proposed by Hirosawa is used in Japan by the Ministry of Construction in the assessment of the seismic safety of buildings made of reinforced concrete. The method recommends three lev-

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* The technical content of the following annex has been taken from the document *"Análisis de vulnerabilidad y preparativos para enfrentar desastres naturales en hospitales en Chile"*, Universidad de Chile. Study made by PAHO/WHO – ECHO, Santiago, Chile, 1996.

1 Hirosawa, M., *Retrofitting and restoration of buildings in Japan*, IISEE Lecture Note, Seminar Course, Tsukuba, Japan, 1992.

2 Gallegos, H. and R. Ríos, *Índice de calidad estructural sismorresistente*. 4as Jornadas Chilenas de Sismología e Ingeniería Antisísmica, Volume 2, Viña del Mar, Chile, 1986.

3 Meli, R., *Diseño sísmico de muros de mampostería, la práctica actual y el comportamiento observado*, Simposio Internacional de Seguridad Sísmica en Vivienda Económica, CENAPRED, Mexico City, Mexico, 1991.

4 Astroza, M., M.O Moroni and M. Kupfer, *Calificación sísmica de edificios de albañilería de ladrillos confinada con elementos de hormigón armado*. Memorias de las XXVI Jornadas Sudamericanas de Ingeniería Estructural, Vol. 1, Montevideo, Uruguay, 1993.

5 Shiga, T., Earthquake damage and the amount of walls in reinforced concrete buildings. *Proceedings 6th World Conference of Earthquake Engineering*, New Delhi, India, 1977.

els of assessment that go from the simplest to the most detailed. It is based on the analysis of the seismic behavior of each floor of the building in the main directions of the floor plan.

The method was originally proposed for use in existing or damaged buildings made of reinforced concrete and possessing six to eight floors built with walls or porticos. In more recent studies the method has been applied to buildings made of mixed reinforced concrete and masonry.[6]

Structural vulnerability is established according to the following considerations:

(a) If $I_S \geq I_{SO}$ the building will demonstrate seismically safe behavior in case of a seismic event;

(b) If $I_S < I_{SO}$ the building will demonstrate unstable behavior in case of a seismic event and is, therefore, considered unsafe.

Calculation of the I_S index

This index is calculated using the following equation:

$$I_S = E_O * S_D * T$$

where:

E_O: is the basic seismic index of structural behavior,

S_D: is the index of structural configuration, and

T: is the index of deterioration of the building.

Calculation of E_O

When applying the first level of assessment, the Eo index is determined by the simple calculation of the absolute shearing strength of each floor. This resistance is calculated for each direction of the floor plan by the sum of the product of the area of the cross-section of a wall or column and its shearing strength. This product is then reduced by a factor (α_i) that represents the presence of elements that reach their resistance to a level of deformation that is less than that of the rest of the seismic-resistant elements (e.g., short columns or masonry walls, either reinforced or not, when compared with reinforced concrete walls or columns).

The E_O index is proportional to the product of the resistance coefficient (C) and ductility coefficient (F).

$$E_O \propto C * F$$

For the calculation of E_O, all elements or vertical substructures that form part of the seismic-resistant building must be classified under one of the following categories:

i. Short reinforced concrete columns. These are all the columns in which the h_O/D ratio—between the vertical clearance (h_O) and the width of the cross-section (D)—is equal or less than 2. The seismic behavior of these columns is controlled by shearing failure characterized by the low level of resistance to deformation and by the low capacity of inelastic deformation. In order to establish the vertical clearance, due account was given to the presence of architectural elements that reduce the height of the column (i.e., elements that are not isolated from the column).

6 Iglesias, J., The Mexico Earthquake of September 19, 1985 – Seminar zoning of Mexico City after the 1985 earthquake, *Earthquake Spectra*, Vol. 5, No1, 1989.

ii. Reinforced concrete columns. These are all the columns in which the h_o/D ratio is greater than 2.
iii. Reinforced concrete walls. These are the reinforced concrete elements with a cross-section in which the relation between the larger side and the smaller side of the cross-section is greater than 3.
iv. Infilled brick walls. These are brick walls, normally with little or no reinforcement, located in openings of the resistant substructure (porticos) without being isolated from them.
v. Reinforced brick walls or brick walls confined with thin elements of reinforced concrete, pillars and framing.

The above-mentioned walls correspond to those that have been designed and constructed in order to transmit horizontal and vertical loads from one level to a lower level and to the foundation. Walls that merely resist loads ensuing from their own weight are not considered, including infilled parapets and partitions or dividing walls that are isolated from the seismic-resistant structure.

This classification must be made to determine resistance and to address the smaller capacity for inelastic deformation and capacity for energy dissipation that some elements display (for example, the short columns and unreinforced, infilled brick walls when they control performance).

The E_o index is calculated by means of the following equation:

$$E_p = \frac{(n_p + 1)}{(n_p + i)} * \{ \alpha_1 * (C_{mar} + C_{sc} + C_a + C_{ma}) + \alpha_2 * C_w + \alpha_3 * C_c\} * F$$

where:

α_1: reduction factor of the resistant capacity in accordance with the deformation level at which the elements that control seismic behavior resist.[7] The values of these factors are given in table A1 when the seismic capacity is controlled by the weakest elements (Type A), less weak elements (Type B) and ductile elements (Type C), respectively

N_p: number of floors in the building

i: the level under assessment

C_{mar}: the resistance index exhibited by the infilled brick walls

C_{sc}: the resistance index exhibited by the short reinforced concrete columns

C_a: the resistance index exhibited by the unreinforced or partially confined brick walls

C_{ma}: the resistance index exhibited by the confined brick walls

C_w: the resistance index exhibited by the reinforced concrete walls

C_c: the resistance index exhibited by the reinforced concrete columns that are not short

F: the ductility index associated with the vertical elements

F = 1.0 if C_{mar}, C_a and C_{sc} are equal to zero

F = 0.8 if C_{mar}, C_a and C_{sc} are not equal to zero

In case the confined brick walls control the resistant capacity, the value of F is equal to 1.0 considering the capacity for inelastic deformation that is obtained with the confining elements.

7 Murakami, M., K. Hara, H. Yamaguchi, S. Shimazu, Seismic capacity of reinforced concrete buildings which suffered the 1987 Chibaken-toho-oki earthquake, *Proceedings 10th World Conference of Earthquake Engineering*, Madrid, Spain, 1992.

Seismic capacity must be calculated first by considering the failure of the weakest elements. Nevertheless, if the failure of this group does not produce instability in the system, seismic capacity must be calculated by considering the next group and rejecting the resistance of the elements that have failed.

Table A1.
Values of the coefficients α_i

Type	α_1	α_2	α_3	Failure
A	1.0	0.7	0.5	Infilled brick walls or short columns or non-reinforced and partially confined brick walls or confined brick walls control failure.
B	0.0	1.0	0.7	Reinforced concrete walls control failure.
C	0.0	0.0	1.0	Reinforced concrete columns control failure.

The term (n + 1)/(n +i) refers to the relation between the coefficient of basal shearing and the coefficient of shearing of floor i, when these shearing forces are established as a function of the weight of the building divided by the level being considered.

The resistance indices (C_i) were determined based on the strengthening characteristics of the reinforced concrete walls constructed in Chile (quantity and means of reinforcement), which incorporates changes in the figures proposed by Hirosawa and Iglesias. For the brick walls, the resistance proposed by Iglesias for infilled walls (diaphragm-type walls) and the resistance of diagonal cracking recommended by Raymondi[8] for confined brick walls were utilized.

The equations used were:

$$C_{mar} = \frac{0.6 * 0.85 * \tau_o * \sum A_{mar}}{\sum_{j=i}^{n_p} W_j}$$

$$C_{sc} = \frac{f_c}{200} * \frac{15 * \sum A_{sc}}{\sum_{j=i}^{n_p} W_j}$$

$$C_{mar} = \frac{0.6 * (0.45 * \tau_o + 0.25 * \sigma_o) * \sum A_{ma}}{\sum_{j=i}^{n_p} W_j}$$

8 Raymondi, V. , *Anteproyecto de norma de diseño y cálculo de albañilería reforzada con pilares y cadenas*, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Santiago, Chile, 1990.

$$C_a = C_{ma}$$

$$C_w = \frac{f_c}{200} * \frac{30 * \sum A_{m_1} + 20 * \sum A_{m_2} + 12 * \sum A_{m_3} + 10 * \sum A_{m_4}}{\sum_{j=i}^{n_p} W_j}$$

$$C_c = \frac{f_c}{200} * \frac{10 * \sum A_{c_1} + 7 * \sum A_{c_2}}{\sum_{j=i}^{n_p} W_j}$$

where:

f_c = Cylindrical resistance to compression exhibited by the concrete.

$\sum A_{mar}$ = Sum of the areas of the infilled brick walls on the floor under assessment in the direction under analysis.

$\sum A_{sc}$ = Sum of the area of short reinforced concrete columns on the floor under assessment.

$\sum A_{ma}$ = Sum of the areas of the confined brick walls on the floor under assessment in the direction under analysis.

$\sum A_{m_1}$ = Sum of the areas of the reinforced concrete walls on the floor under assessment with columns in both ends, with horizontal reinforcement greater than or equal to 1.2 % and wall thinness (HIL) greater than 2. In these walls the resistance to shearing is controlled by the resistance to crushing of the compressed diagonal due to the high level of horizontal reinforcement.[9]

$\sum A_{m_2}$ = Sum of the areas of the reinforced concrete walls on the floor under assessment with columns in both ends and a minimal amount of horizontal reinforcement. In these walls the resistance to shearing is provided mainly by the horizontal reinforcement.[10]

$\sum A_{m_3}$ = Sum of the areas of the reinforced concrete walls on the floor under assessment, without columns or with a column in some of its ends, a wall thinness less than or equal to 2 and minimum reinforcement. In these walls, the resistance to shearing is defined by the diagonal cracking load of the concrete due to its reduced level of reinforcement.[11]

$\sum A_{m_4}$ = Sum of the areas of the reinforced concrete walls on the floor under assessment, without columns or with a column in some of its ends and a wall thinness greater than 2. In these walls the resistance to shearing is provided by the ACI-318 standard equations.[12]

9 Wakabayashi, M., *Design of earthquake-resistant buildings*, Mc Graw-Hill Book Company, 1986.

10 Ibid.

11 Ibid.

12 ACI 318 (1984) "Building Code Requirements for Reinforced Concrete."

$\sum A_{c_1}$ = Sum of the areas of the reinforced concrete columns[13] where the relation between the vertical clearance (h) and the width (D) is less than 6.

$\sum A_{c_2}$ = Sum of the areas of the reinforced concrete columns[14] where the relation between the vertical clearance (h) and width (D) is equal to or greater than 6.

W_j = Weight of floor j.

τ_o = Basic resistance to shearing of masonry.

σ_o = Normal stress due to axial force produced by the weight of vertical loads and overloading.

L = Length of the wall.

H = Height of the floor if L is greater than or equal to 3 m, or the vertical clearance of the wall if L is less than 3 m.

In these equations the areas must be expressed in cm^2, the resistance and stress in kgf/cm^2 and weight in kg. The coefficients that accompany the areas correspond to the resistance to shearing exhibited by the different types of elements that form the seismically resistant system. The value of these coefficients is expressed in kgf/cm^2.

Calculation of S_D

This coefficient quantifies the influence of irregularities in the structural configuration and the distribution of stiffness and mass on the seismic behavior of the building.

Information needed to calculate S_D is obtained mainly from structural plans and is complemented by on-site visits. The characteristics of a building considered in the determination of this coefficient are: regularity of the floor plan, the length-width relation of the floor plan, contraction points in the floor plan, thickness of the expansion joints, dimensions and location of inner patios, existence of a basement, uniformity of height of the floors, eccentricity in the stiffness of the floor plan, irregularities in the distribution of mass, stiffness of the mezzanine of higher floors, etc.

Hirosawa proposes the following equation to calculate S_D when the first level of assessment of vulnerability is used:

$$S_D = \prod_{i=1}^{1=8} q_i$$

where:

$$q_i = \{1.0 - (1 - G_i) * R_i\} \ when \ i = 1, 2, 3, 4, 5, 7 \ and \ 8$$

$$q_i = \{1.2 - (1 - G_i) * R_i\} \ when \ i = 6$$

The values of G_i and R_i recommended by Hirosawa are shown in table A2.

13 Hirosawa, M. (1992) "Retroffiting and Restoration of Buildings in Japan" IISEE, Lecture Note of Seminar Course, Tsukaba, Japan.

14 ACI 318 (1984) “Building Code Requirements for Reinforced Concrete”.

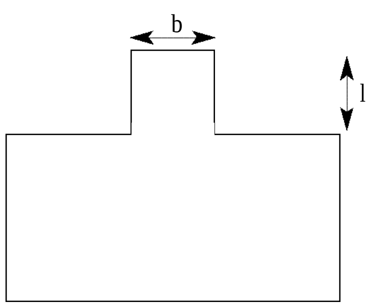
Table A2.
Values of Gi and Ri

ITEMS (q_i)	G_i			R_i
	1.0	0.9	0.8	
1.Regularity	Regular (a_1)	Median (a_2)	Irregular (a_3)	1.0
2.Length-width ratio	$B \leq 5$	$5 < B \leq 8$	$B > 8$	0.5
3.Contraction of the plan	$0.8 \leq c$	$0.5 \leq c \leq 0.8$	$c < 0.5$	0.5
4.Vestibule or interior patio	$R_{ap} = 0.1$	$0.1 < R_{ap} \leq 0.3$	$0.3 < R_{ap}$	0.5
5.Eccentricity of the vestibule or interior patio	$f_1 = 0.4$ $f_2 = 0.1$	$f_1 \leq 0.4$ $0.1 < f_2 \leq 0.3$	$0.4 < f_1$ $0.3 < f_2$	0.25
6.Basement	$1.0 \leq R_{as}$	$0.5 \leq R_{as} < 1.0$	$R_{as} < 0.5$	1.0
7.Expansion joint	$0.01 \leq s$	$0.005 \leq s < 0.01$	$s < 0.005$	0.5
8.Uniformity of height of floor	$0.8 \leq R_h$	$0.7 \leq R_h < 0.8$	$R_h < 0.7$	0.5

Following is the description of each one of the characteristics.

1. Regularity a_i

a_1: The floor plan is symmetrical in each direction, and the area of projections is less than or equal to 10% of the total area of the plan. These projections are considered where $l/b \geq 0.5$.



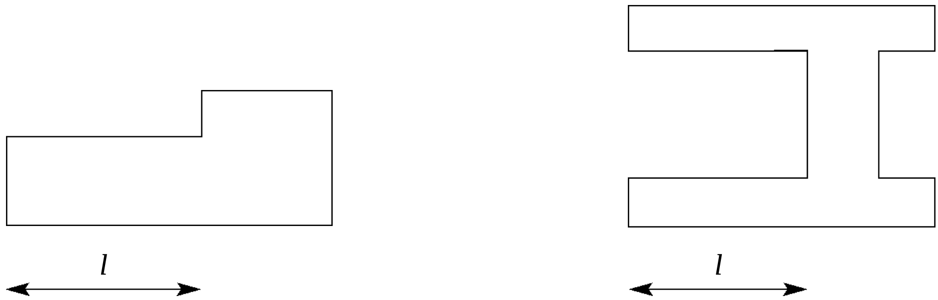
a_2: The plan is irregular, and the area of projections is less than or equal to 30% of the total area of the plan. This includes plans with L, T, U, and other shapes.

a_3: The floor plan is more irregular than in a_2, and the area of projections is greater than 30% of the area of the floor plan.

2. Length-width ratio, B:

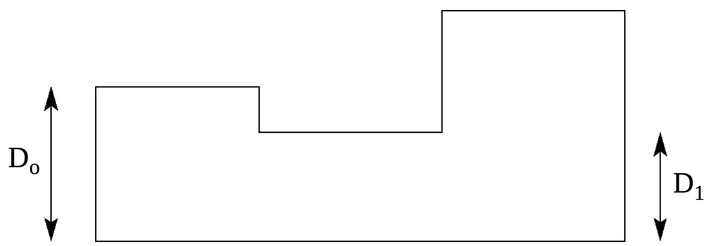
Ratio of the greater and lesser dimensions of the floor plan.

In floor plans of type L, T, U and others, the longer side is considered 2*l, with l shown in the figure below.



3. Contraction of the floor plan, c:

$$c = \frac{D_1}{D_o}$$



4. Vestibule or inner patio, R_{ap}:

This is the ratio of the area of the vestibule or patio to the total area of the plan, including the area of the patio/vestibule. Nevertheless, a flight of stairs constructed with reinforced concrete walls is not considered in this analysis.

5. Eccentricity of vestibule or inner patio, *f*:

f_1: Ratio of the distance from the center of the floor plan to the center of the vestibule, and the shorter length of the floor plan.

f_2: Ratio of the distance from the center of the floor plan to the center of the vestibule, and the greater length of the floor plan.

6. Basement, R_{as}:

Ratio of the mean area of the floor plan of the basement levels to the mean area of the building's floor plan.

7. Expansion joints, *s*:

This criterion is applied to buildings that have expansion joints. It is the ratio of the thickness of the seismic expansion joints to the height where the joints are located.

8. **Uniformity of height of floor, R_h:**
Ratio of the height of two contiguous floors (height of the floor above the floor under analysis to the height of the floor being considered). For the case of the highest floor, the floor immediately above in this ratio is replaced by the floor immediately below.

According to Hirosawa, the value of S_D is calculated by using the least favorable value among those obtained for the characteristics of different floors, a value that is assumed to be representative of the entire building.

Calculation of T

This index quantifies the effects produced by the deterioration of the building over time, effects of previous earthquakes or other events. The index is calculated from information obtained from on-site visits and from the information provided by the owner.

The index T is determined using table A3. When a unique value for T is used for the building, this value must correspond to the smaller value obtained in table A3.

Table A3.
Values of the index T for different causes and types of deterioration

Permanent deformation (T_1)	
Characteristics	**T_1**
The building is leaning due to differential settling	0.7
The building is constructed on landfill	0.9
The building has been repaired due to previous deformations	0.9
Visible deformation of beams or columns	0.9
Does not exhibit any signs of deformation	1.0

Cracks in walls or columns due to corrosion of the reinforced steel (T_2)	
Characteristics	T_2
Signs of leaking with visible corrosion of reinforcement	0.8
Visible slanted cracks in columns	0.9
Visible cracks in walls	0.9
Signs of leaking but without corrosion of reinforcement	0.9
None of the above	1.0

Fires (T_3)	
Characteristics	T_3
It has undergone fire but was not repaired	0.7
It has undergone fire and was suitably repaired	0.8
Has not undergone fire	1.0

Use of the body or block (T4)	
Characteristics	T4
It stores chemical substances	0.8
Does not contain chemical substances	1.0

Type of structural damage (T_5)	
Characteristics	T_5
Severe structural damage	0.8
Major structural damage	0.9
Slight structural damage or nonstructural damage	1.0

The criterion for the classification of earthquake damage is shown in table A4.

Table A4.
Classification of damages caused by earthquake

Type of damage	*Description*
Non-structural	Damage only in non-structural elements
Light structural damage	Cracks less than 0.5 mm wide in reinforced concrete elements. Cracks less than 3 mm wide in masonry walls
Major structural damage	Cracks 0.5 to l mm wide in reinforced concrete elements. Cracks 3 to 10 mm wide in masonry walls.
Severe structural damage	Cracks more than 1 mm wide in reinforced concrete elements. Openings in masonry walls.Collapse of concrete, breakage of stirrups and buckling of reinforcement in beams,columns and walls of reinforced concrete.
Cracking of capitals and consoles	Collapse of columns.Collapse of more than 1% of building height.Building settles more than 20 cm.

Source: Iglesias,J.,The Mexico Earthquake of September 19,1985 – Seminar zoning of Mexico City after the 1985 earthquake, *Earthquake Spectra*,Vol.5,No1,1989.

Calculation of index I_{SO}

This index is calculated using the following equation:

$$I_{so} = E_{so} * Z * G * U$$

where:

E_{SO} = Required basic seismic resistance

Z = Seismic zone factor; its value depends on the seismic hazard of the place where building is located ($0.5 \leq Z \leq 1$)

G = Influence of the topographical and geotectonic conditions

U = Importance of building according to its use

Basic seismic resistance (E_{SO}) was determined based on the study of building damage during an earthquake.[15] For the purpose of other studies, it is recommended that this resistance be established based on requirements for elastic strength under the current norms in the greatest seismic hazard zone (epicenter), reduced by a factor of reduction (R) whose value must be determined given that the damage does not impede function of the facility.

Factor G is equal to 1.0 for topographical conditions without slope, and is equal to 1.1 for zones with slope.[16]

The importance factor, U, is equal to 1.0 given that the required conditions for use of the building are considered when establishing the value of E_{SO}.

15 Hirosawa, M., "Retrofitting and Restoration of Buildings in Japan". IISEE Lecture Note, Seminar Course, Tsukuba, Japan, 1992.

16 Ibid.

In a period of only 15 years, between 1981 and 1996, 93 hospitals and 538 health care centers in Latin America and the Caribbean were damaged as a consequence of natural disasters. This resulted in the loss of service of some 24,000 beds. The direct cost of these disasters has been enormous; just as devastating has been the social impact of the loss of these critical facilities at a time when they were most needed.

Hospitals and health centers are complex; they have high occupancy levels and play a critical role in disaster situations. For these reasons, special consideration must be given to disaster planning for these facilities. Assessing and reducing their vulnerability to natural hazards is indispensable.

Principles of Disaster Mitigation in Health Facilities is an updated compilation of various documents on the topic already published by PAHO/WHO. Sections of previous publications have been revised to address the needs of professionals from a variety of disciplines, particularly those involved in health facility planning, operation and maintenance. It does not attempt to address the more technical and specialized aspects of disaster mitigation. Figures and photographs illustrate situations that can increase disaster vulnerability in health facilities. Examples are given of how countries in Latin America have conducted vulnerability assessments and applied specific disaster mitigation measures in their hospitals and health centers.

The book focuses on problems encountered in areas at high risk for seismic events. It introduces the essential aspects of carrying out vulnerability assessments and applying practical measures to mitigate damage in hospitals, addressing structural and nonstructural aspects, as well as administrative and internal organization.

Also published by PAHO/WHO:

Natural Disaster Mitigation in Drinking Water and Sewerage Systems—Guidelines for Vulnerability Analysis, Washington, D.C., 1998

This publication can be downloaded from the Internet at:
www.paho.org/disasters/

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