CONCEPTUAL DESIGN OF HOSPITALS IN THE FACE OF THE EARTHQUAKE HAZARD

RUBÉN BOROSCHEK
WHO/PAHO COLLABORATING CENTER
DISASTER MITIGATION IN HEALTH FACILITIES
UNIVERSIDAD DE CHILE

rborosch@ing.uchile.cl
www.hospitalseguro.cl

Introduction

The recent earthquakes in El Salvador 2001 - where more than 50% of the country hospitals suffered functionality loses and 28% of the health facilities are operating in tents or temporary housings two years after the events - is a direct consequence of poor design concepts for health facilities.

This short paper with its annex slide presentation gives an overview of minimum concepts and procedures to apply in the design process of health facilities.

Hospital Performance Objective

The first step in the design process is the definition of the desired performance objective for the health facility. The selection of the performance objective depends on the health services of the hospital and its relation with the national and local health networks. The are three main performance objectives:

1. The *Functional Protection Performance Objective* that considers the protection of life and investment in the facilities and limits the structural and non-structural damage so that the function in critical services or the whole hospital is maintained and any existing damage or disruption is easily and inexpensively overcome.

2. The *Investment Protection Performance Objective* that considers life preservation and preclude damage in selected services based on its investment value and difficulty of recovery.

3. The *Life Safety Performance Objective* that preserves life of the users and workers of the facilities but does not ensure the protection of functionality or the investment.

The different performance objectives require different design, construction and maintenance procedures that generally result in different process timeframes and professional skills.

The performance objective should be established based on the earthquake severity. Historically, hospitals have been designed for life safety performance objectives for seismic hazards associated with relative rare earthquakes, 10% probability of being exceeded in 50 years. This hazard level, together with the application of design codes that mainly consider the design of structural elements, has contributed to the limited current functional safety in hospitals.

Decision matrices like the one presented in table 1, (Vision 2000) indicate different performance objectives for different hazard levels.

Table 1. Building Performance Objective Based on Seismic Hazard (Vision 2000)

Seismic Hazard	***Performance Objective***			
	Operational	**Immediate Occupancy**	**Life Safety**	**Collapse Prevention**
Frequent (50%/30 years)	✕	NOT ACCEPTABLE	NOT ACCEPTABLE	NOT ACCEPTABLE
Occasional (50%/50 years)	◆	✕	NOT ACCEPTABLE	NOT ACCEPTABLE
Rare (10%/50 years)	■	◆	✕	NOT ACCEPTABLE
Very Rare (10%/100 years)		■	◆	✕

The performance objective could be applied to the facility as a whole or to independent hospital services. Typical hospital services are listed in table 2. It is not necessary for all services to be designed for the same performance objective, but it is highly recommended. Also, it is not possible to design highly dependent services with different performance objectives. Nevertheless, it should be recognized that in some cases it is not possible to assign high performance objective levels and a selection criteria should apply. This selection should be done based on characteristics of the national and local health network and the characteristics of the hospital services and its functional objectives.

Table 2. Typical Hospital Services.

• Trauma and Orthopedics • Intensive Care/Treatment Unit • Urology • Emergency Care • Sterilization • Diagnostic Imaging • Pharmacy • Nutrition • Transport • Recovery • Blood Bank • Outpatient Consultation/Admissions • Otorhinolaryngology • Dental Service • Therapy and Rehabilitation Internal Medicine • Gynecology and Obstetrics • Administration	• Pediatrics • Neonatology • Laboratory • Laundry Services • Hemodialysis • Respiratory Medicine • Neurology • Ophthalmology • Filing and Case Management • Dermatology • Psychiatry • Oncology • General/Plastic/Pediatric Surgery • Burns • Nuclear Medicine • Clinical Gases • Industrial Gases • Thermal Power Station

The Applied Technology Council (ATC - 40) developed some guidelines to help the designer and owner to select an appropriate performance objective, Table 3. Basically, the owner should select in the table with the help of the designer the maximum desired structural and non-structural damage and the time to recover the hospital and individual health services.

Due to the large amount of structural, non-structural and functional components and to the uncertainties in earthquake characteristics, it is difficult to accomplish the higher performance levels (operational and immediate occupancy) with the traditional earthquake resistant design procedures. Nevertheless, the introduction of new seismic protection technology, like base isolation, has made it possible to achieve the functional performance goal, Boroschek (2002).

Table 3. Decision Matrices (Based on ATC - 40)

RECOVERY

SEISMIC HAZARD	IMMEDIATE HOURS	SHORT WEEKS	MODERATE MONTH-YEAR	LONG MORE 1 YEAR	VERY LONG NEVER
FREQUENT					
DESIGN					
MAXIMUM					

STRUCTURAL PERFORMANCE DAMAGE LEVEL

SEISMIC HAZARD	SP-1 MINOR	SP-2	SP-3 MODERATE	SP-4	SP-5 SEVERE
FREQUENT					
DESIGN					
MAXIMUM					

NON-STRUCTURAL PERFORMANCE

SEISMIC HAZARD	NP-A MINOR	NP-B	NP-C MODERATE	NP-D SEVERE	NP-E NOT CONSIDERED
FREQUENT					
DESIGN					
MAXIMUM					

Design Codes

Traditional design codes generally have the following performance objectives:

1. No damage in frequent earthquake events.
2. No structural damage in moderate events.
3. Collapse prevention in severe events.

Generally, these codes only provide explicit recommendations for the third objective. No specific recommendations are given for hospitals, except for raising the level of demand, which will give higher strength to the designed elements, but generally they not require that a specific service must be preserved.

Performance Objective Codes are rare; however, some documents can be used as references:

1. ATC, “ATC-40: Seismic evaluation and retrofit of concrete buildings” Applied Technology Council, EEUU, 1996

2. FEMA, "FEMA 273: Guidelines for the rehabilitation of Buildings” de Federal Emergency Management Agency, EEUU 1997.

3. FEMA, “FEMA 356: Prestandard and Commentary for the Seismic Rehabilitation of Buildings”, November 2000.

Design Considerations

For the higher performance objectives, in-depth studies should be carried out in addition to those used in typical hospital design:

Seismic Hazard:

A seismic hazard appropriate for each performance objective should be established. National hazard maps are not always reliable for the site, so specific evaluation of seismogenic zones and reoccurrence characteristics should be established. Deterministic and probabilistic methods could be used. Nevertheless, the level of certainty in data in demand parameters should be clearly established.

Site characterization:

Geologic and geotechnical characterization should clearly indicate dangers to the buildings and the basic design parameters like soil dynamics amplification characteristics, collapse potential and bearing capacity.

Seismic Demand:

Based on the seismic hazard study and the site geologic and geotechnical characteristics, a design response spectrum should be established. The response spectra and associated reduction factors should consider the desired performance objectives. Specific response spectra should be established for equipment at ground level and in side structures. Vertical response spectra should be indicated when required by the seismic characteristics and by the structural and non-structural design needs.

In cases where time histories analysis are required, real and artificial earthquake records should be selected or developed that agree with the design response spectra and performance objectives.

Selection of building configuration and structural system.

Besides the selection of building location and determination of seismic demands important efforts should be made by the owner and designers to select the best building configuration and structural system that will satisfy the functional objectives of the health facility and the earthquake performance objective. When immediate occupancy objectives are present, several additional restrictions apply, such as the following requirements:

- Geometric plan regularity
- Geometric elevation regularity
- Vertical and horizontal mass regularity
- Horizontal and vertical stiffness regularity
- Safety considerations for adjacent buildings.
- Safety of non-structural components.
- Level of seismic strength to control damage.
- Level of seismic stiffness to control damage to non-structural elements.
- Level of seismic detailing to produce a safe failure in case expected loads are exceeded.

Some of these restrictions can be reduced when base isolation or other vibration control techniques are used.

Design of non-structural components and functional protection of the hospital

In hospitals, the performance objective defines the functional safety of each health service; thus an earthquake resistant design should be applied to the service and its structural and nonstructural components. Typical non-structural elements that require engineering design are presented in table 4.

It's important to design and protect the non-structural elements recognizing their dependencies. Because several professional specialties are responsible for different non-structural components, it's necessary to involve in the design project a vulnerability expert to coordinate and verify the design for the different specialties.

Analysis Procedures

Typically, linear elastic analyses are enough for designing new hospital buildings. Nevertheless, complex structures, buildings with innovative seismic protection techniques and the need to verify the performance objective for different levels of earthquake demands require non-linear analyses.

The complexity of the non-linear analysis is related to the uncertainties and design objectives selected for the project. In the professional community, it has been acknowledged that the static push over analyses could be enough; nevertheless, non-linear time history studies have been used to verify the design in complex hospital structures.

Table 4. Hospital non-structural elements

ARCHITECTURAL	EQUIPMENT	BASIC INSTALLATIONS
Interior partitions Facades Suspended Ceilings Roofs or decks Parapets Chimneys Plaster Glass windows Attachments (signs, antennae, etc) Ornaments Canopies Lighting system Railings Doors and exit routes Expansion joints	Medical equipment Laboratory equipment Industrial equipment Furniture Supplies	Medical gas piping Industrial gas piping Vacuum devices Steam Air-conditioning systems Heating Ventilation Electrical wiring Backup power Communications Drinking water Industrial water Sewerage Fire sprinklers Other pipelines Circulation (elevators, stairs)

Detailing Procedures

Structural and non-structural detailing should be applied not only to ensure life safety, but also to control the level of damage and behavior of the components and systems. At least two considerations should be taken into account in the design process of services with higher performance objectives than the life safety performance objective:

1. Structural and non-structural components should suffer limited damage that will not impair functionality, cause unnecessary concerns in the users and affect other building components.

2. Damage should be easily repaired in a short time and economically.

Extreme care should be taken when applying typical design codes with life protection performance objectives. When national codes are not appropriate a specific design criterion should be established for the project.

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