Structural Retrofitting
For
Earthquake Resistance

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Introduction

The need for structural retrofitting arises from several possible situations: earthquake damage, change in code requirements and change in performance objectives of the hospital.

In order to establish the need for retrofitting, a vulnerability study should be undertaken to identify existing conditions, vulnerability and expected behavior for different expected earthquake demands. The following are the basic steps in a retrofitting process:

- Preliminary vulnerability study
- Identification of structural characteristics
- Identification of existing damage
- Determination of site seismic hazard
- Determination of site characteristics
- Establishing occupancy requirements
- Identification economic restrictions
- Establishing social issues
- Consideration of historic status and local jurisdiction requirements
- Establishing possible target building performance levels
- Selection the rehabilitation method (Iterative procedure)

Preliminary Vulnerability Study

The vulnerability study should be able to identify the main weaknesses and strengths of the structure, its expected performance for the regional seismic hazard, a description of damage severity and functional disruption for each health service and the convenience of a functional, structural and non-structural retrofit.

There are several procedures to perform vulnerability studies. If the need for retrofitting is already known, a detailed vulnerability analysis that considers the geologic, geotechnical and seismic hazards, detailed information on structural and non-structural characteristics should be undertaken. The analysis methods should include as much information as possible, so they can be used later to develop, design and qualify the retrofitting.

In cases where no decision on retrofitting has been made, a more general vulnerability study can be undertaken, which identifies the needs and characteristics of a possible retrofit.

Selection of Performance Objectives.

Once it has been established that a hospital should be retrofitted, a clear statement about expected performance for different seismic hazards should be made. Traditionally, hospitals were design for life safety performance objective; nevertheless, a current trend is to evaluate the possibility of increasing its earthquake resistance performance to objectives like:

- Immediate Occupancy: where damage is minor and functionality is preserved at least in selected health services. If the damage occurred it is easily and rapidly repaired.

- Damage Control or Investment Preservation: where damage is localized according to pre-established criteria, protecting investment and reducing the cost of recovery.

There are several documents that present performance-based design and retrofit procedures:

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

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

3. “FEMA 310: Handbook for the Seismic Evaluation of Existing Buildings”.

4. “FEMA 356: Pre-standard and Commentary for the Seismic Rehabilitation of Buildings”, November 2000.

5. “FEMA 276: Guidelines for the Seismic Rehabilitation of Buildings: Example Applications”.

6. “FEMA 156 and 157: Typical Costs for Seismic Rehabilitation of Existing Buildings”

7. “FEMA 275: Planning for Seismic Rehabilitation Societal Issues”

Site Characteristics

Site characterization should include geologic and geotechnical components. Special attention should be given to all possible site effects that could impact the building response. Information on soil dynamic characteristics for the appropriate definition of a design response spectrum should be derived. Special attention should be given to actual foundation characteristics and possible limitations for the future retrofit project.

Soil parameters required for the complete modeling of the original and retrofitted building should be established and indicated to the analyst.

When seismic demand is not appropriately defined for performance-based analysis, specific seismic hazard studies should be undertaken. They should identify seismogenic sources and their characteristics. A deterministic and probabilistic description of the demand should be established.

Building Characteristics

A detailed description of the structural and non-structural characteristics is required.

It should include at least the following:

- Field Observations
- Documents: construction, engineering, soil characteristics, maintenance, others
- Code standards for the period of construction
- Destructive and non-destructive testing.
- Building earthquake behavior
- Building configuration: geometry, structural system.
- Definition of primary and secondary elements.
- Load path

- Identification of irregularities

Additionally, all structural elements should be described, at least with the following:

- Capacity, deformability and ductility.
- Classification as force-controlled or displacement-controlled.
- Condition.
- Level of knowledge about the element or system.

Selection of Retrofitting Procedure

The most important aspect in a retrofitting design for hospitals is that the functional performance objective of the health system should be achieved. If a high performance objective, like immediate occupancy has been selected, structural and non-structural design and retrofitting should be carefully selected. The technical and economic feasibility of the final retrofitted project has to be carefully studied. In some instances, due to the existing building conditions or political or health network characteristics, high levels of performance objectives are not possible or not convenient. In these cases, if the building preserves its health service characteristics, the minimum acceptable performance objective should be life preservation.

In several occasions there is no alternative health system to temporary transferring the services during the construction, so the retrofitting and construction procedure should consider the preservation of the functionality of the hospital.

Typical retrofitting techniques are:

SYSTEM	BENEFIT	INCONVENIENCE
Interior and perimeter walls	Increased strength and drift reduction.	Increased acceleration. Relative high construction disruption.
Interior and perimeter diagonal bracing	Increased strength and drift reduction.	Increased acceleration. Relative low construction disruption.
Perimeter frame	Increased strength and relative low drift reduction.	Intermediate construction disruption.
Exterior buttresses	Increased strength and drift reduction.	Limited by overturning of buttresses. Relative low construction disruption.
Base Isolation	Reduced drift and acceleration in superstructure	High construction disruption. Requires retrofitting of superstructure.

Analysis Techniques.

Basic linear elastic analysis is required for the design of the retrofit. Verification should be done using non-linear analysis if critical components are not retrofitted or if damage can affect performance objective.

Typically, static push over analyses are recommended, but non-linear time history should be done, when possible, to verify the final design.

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