3 Methodology

One of the objectives of the study was to develop a methodology for seismic vulnerability assessment of hospitals in Nepal. This was done by adopting and adapting the provisions spelt out for such non-structural assessment in different documents.

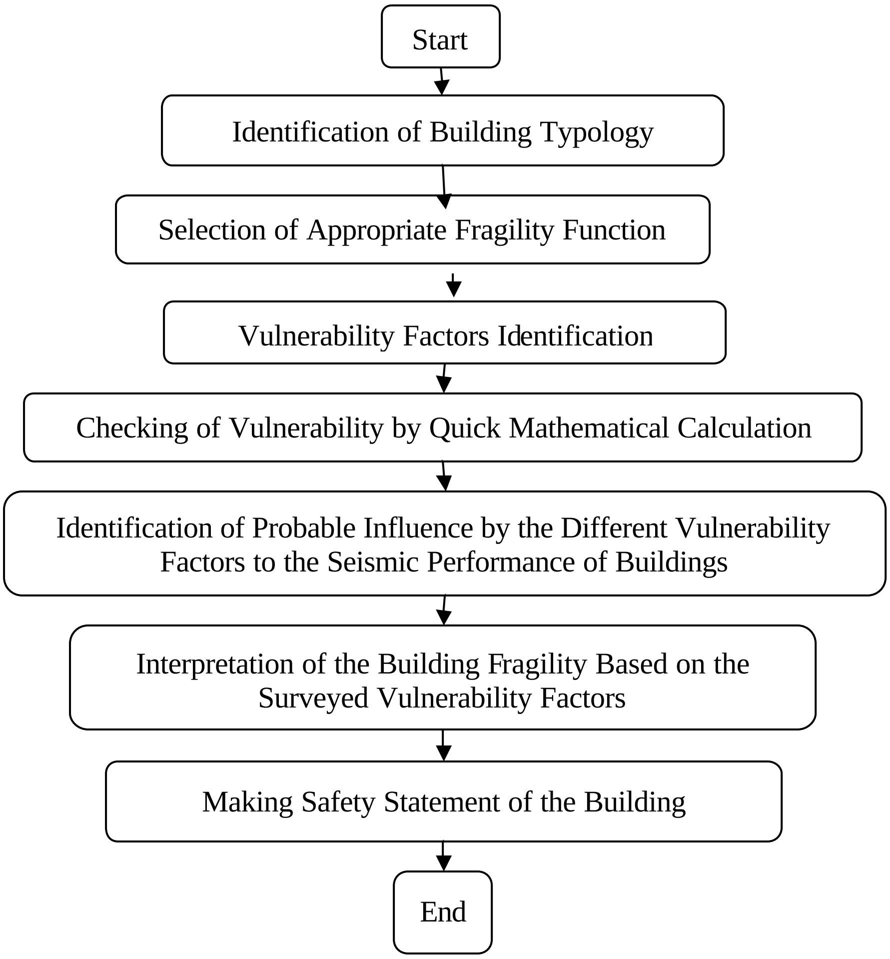
Seismic Reliability Assessment of Critical Facilities the technical report MCERR-99-0008, Protocol for Assessment of the Health Facilities in Responding to Emergencies by WHO, *New Zealand standards NZS 4104:1994* and *NZS 4219:1983* and *NEHRP Guidelines for the Seismic Rehabilitation of Buildings,* (FEMA-273) were all used as references and the methodology defined in these documents were used to some extent to develop the methodology for this study.

It was necessary to develop such a methodology because of the non-applicability of similar methodologies used in developed countries. In Nepal, there is a lack of data about the design and the construction methodology, and this data is normally used as input parameters in the established software used for making such assessments in developed countries. The methodology, which was developed and used for the study is described below.

3.1 Structural Vulnerability Assessment

The flowchart below shows the major steps of an assessment of a typical hospital in this study. The description of the different steps is presented in the following sections.

Fig 1: Flow Chart for Structural vulnerability Assessment (Qualitative)



3.1.1 Identification of Building Typology

The targeted hospital buildings were classified as below. This typology classification is global, and is based on the performance of different types of buildings during past earthquakes. Building typologies defined in *The Development of Alternative Building Materials and Technologies for Nepal: Seismic Vulnerability Analysis* (Appendix-C), a Nepal National Building Code document, were also considered when defining the different building types. The types of buildings are:

Type 1: Adobe, stone, adobe & stone, stone & brick-in-mud.

Type 2: Un-reinforced masonry made of brick in mud.

Type 3: Un-reinforced masonry made of brick in lime, brick in cement, and well-built brick in mud, stone in cement (well built brick in mud: with wooden bands, corner posts with very good wall / area ratio and proper connection; original courtyard type).

Type 4: Reinforced concrete ordinary-moment-resistant-frames (OMRF).

A: ORMF with more than three stories.

B: ORMF less or equal to three stories.

Type 5: Reinforced concrete intermediate-moment-resistant-frames (IMRF).

Type 6: Reinforced concrete special-moment-resistant-frames (SMRF).

Type 7: Other (must be specified and described).

3.1.2 Selection of Appropriate Fragility Function

The performance level of specific building types was decided upon based on the internationally available descriptions of seismic performance during past earthquakes. The description of both structural and non-structural damage was taken as basis. However, such descriptions are not available for all building types found in Nepal, and a combination of international and Nepalese Standards were therefore used. For this evaluation, the damage extent at different intensities was taken from fragility functions derived in *The Development of Alternative Building Materials and Technologies for Nepal: Seismic Vulnerability Analysis* (Appendix-C) and *European Micro-seismic Scale*, 1998.

3.1.3 Vulnerability Factors Identification

The right vulnerability factors for the different types of buildings were selected using the set of appropriate checklists available in FEMA 310, *Handbook for the Seismic Evaluation of Buildings*.

The basic vulnerability factors related to building systems, lateral force resisting systems, connections, diaphragms, geologic and site hazard, and non-structural hazards were evaluated based on visual observation. Critical vulnerability factors that were necessary to check with quick calculations were identified in this step.

3.1.4 Checking of Stress Conditions of Some Components by Mathematical Calculations

The severity of different vulnerability factors was checked by quick calculations wherever found necessary. These calculations were quick shear checks, strong column-weak beam condition etc., and they sometimes revealed the critical status of the building.

3.1.5 Identifying Probable Influence of the Different Vulnerability Factors on the Seismic Performance of Buildings

Based on the observations and short calculations, probable effects of different vulnerability factors were assessed. Table 1 provides a checklist of the vulnerability factors and their effects.

Table 1: Identifying Probable Influence of the Different Vulnerability Factors on the Seismic Performance of Buildings

Vulnerability Factors		**Increasing Vulnerability of the Building by different vulnerability factors**				
		High	**Medium**	**Low**	**N/A**	**Not known**
Building System	Load Path					
	Weak Storey					
	Soft Storey					
	Geometry					
	Vertical Discontinuity					
	Mass					
	Torsion					
	Deterioration of Material					
	Cracks in Infill Wall					
	Cracks in Boundary Columns					
Lateral Force Resisting System	Redundancy					
	Shear Stress Criteria					
Connection	Connectivity between different structural elements					
Others	Pounding Effect					

3.1.6 Interpretation of the Building Fragility Based on the Surveyed Vulnerability Factors

The probable damage to a building was judged using the general fragility curve chosen for the building combined with the assessed influence of different vulnerability factors. Based on this, the target building was classified as" average", "good" or " weak" for that particular typology. The classification “good” means that the building behaves better than average buildings of that type whereas a “weak” building behaves worse than an average building of that type.

3.1.7 Making Structural Safety Statement about the Building

The expected structural performance of hospital buildings during different MMI intensities was then figured out. The following table shows the format for making the safety statement about the building.

	Performance of the Building			
	MMI = VI	**MMI = VII**	**MMI =VIII**	**MMI = IX**
Structural Safety				

3.2 Non-Structural Vulnerability Assessment

The major steps carried out for the non-structural assessment of hospitals are described below.

3.2.1 Identifying Critical Systems and Facilities

Identification of critical systems and essential functions of hospitals was carried out based upon the functional requirements of the hospital during and after an earthquake. The main critical systems and facilities, which are important for continued functionality, were identified after visiting the hospital. The following steps were followed to identify the critical systems.

Steps for Identifying the Critical Systems and Facilities

Step 1: Visit the hospital and explain the scope of work to the hospital administration.

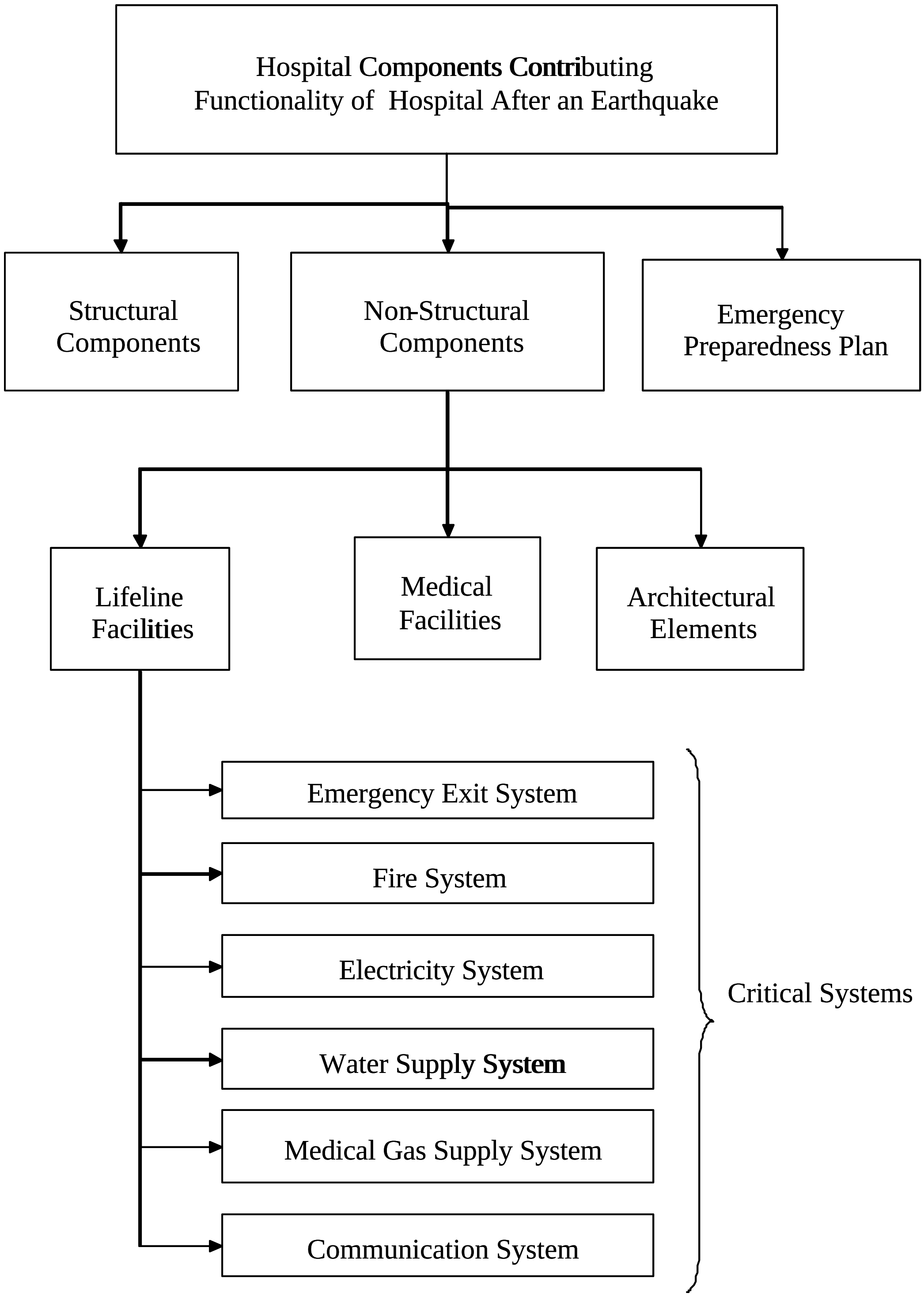
Step 2: Collect information.

Step 3: Visit essential and critical facilities (after collecting information).

Step 4: Visit lifeline facilities (after collecting information).

Step 5: Cross correlation among structural system, medical facilities and lifeline systems.

Fig 2: Major Systems of the Hospital



3.2.2 Assessment of Individual Components

All the identified critical systems and facilities were visited to evaluate the vulnerability of the individual components. All equipment and components were rated against two earthquakes, i.e. a medium size earthquake (MMI VI-VII) and a severe earthquake (MMI VIII-IX), in terms of different levels of damage; very high, medium and low. Vulnerability reduction options, implementation priority and cost estimation for implementation of mitigation options were identified for all equipment.

3.2.3 Assessment of Systems' Vulnerability

Based on the assessment of the individual components of the respective systems, the critical systems and medical facilities were examined to find out the possible level of damage in the two earthquake scenarios. The different levels of potential damage and its consequences for the performance of the individual components and the systems are given in Table 3.

Mitigation options for each system were identified and critically evaluated in terms of ease and cost of implementation and of their expected efficiency regarding vulnerability reduction.

The feasibility of implementing mitigation options are defined as either: easy to implement or difficult to implement.

Easy to Implement: *The maintenance division of the hospital can implement the mitigation options after a short training from outside. The materials necessary for implementing mitigation options are available at local market.*

Difficult to Implement: *Experts from outside the hospital are necessary to implement the mitigation options. The materials necessary for implementing mitigation options are not available at local market.*

The terms used to define the cost involvement for implementing the mitigation options to reduce the risk are described as low and high cost as defined below.

Low Cost: *The cost involvement is less than NRs. 100,000 (The hospital administration / maintenance division can allocate the budget to implement the mitigation option).*

High Cost: *The cost involvement is more than NRs. 100,000 (The hospital administration / maintenance division can not allocate the budget to implement the mitigation option and needs external financial support.*

3.2.4 Performance Assessment of Hospital

The performance of the hospital in terms of non-structural vulnerability is evaluated at five distinct levels of damage to different critical systems and facilities that the hospital might sustain. The performance levels used here are defined in Table 3. The structural safety of the hospital is also considered while assessing the performance level.

Table 3: Non-structural Performance Levels and Damage Descriptions (Adapted from *NEHRP Guidelines for the Seismic Rehabilitation of Buildings*, FEMA-273)

Performance Levels and Overall Damage	Expected Levels of Damage to the Different Systems		
	Critical Systems / Components	**Contents and Equipment of Medical Facilities**	**Architectural Elements**
Operational (Slight Damage)	Lifts operate; ducts and piping sustain negligible damage; the fire response system is functional; transformer / generators are functional and electricity can be provided; water can be provided.	Medical equipment on floors and walls are secure and operable; power is available; equipment on rollers slide but do not tip and do not impact with anything; cupboards, racks cabinets and book shelves do not tip; negligible damage to chemical bottles in the lab; oxygen cylinders and blood stands are not tipped over.	Negligible damage to false ceilings, chimneys, light fixtures and stairs; minor damage to parapets and doors; minor cracks in cladding and partitions.
Immediate Occupancy (Slight to Moderate Damage)	All system components are secured; generators start but may not be adequate to service all power requirements; minor leaks in some joints of water supply pipelines; fire systems and emergency lighting systems are functional; medical gas supply systems are secure and functional if electricity is available, lifts are operable and can be started when power is available.	Medical equipment on floors and walls are secure but power may not be available; some equipment on rollers slide and impacts with something; cupboards, racks cabinets and book shelves do not tip; negligible damage to chemical bottles in the lab; blood stands may tip.	Minor damage to ceilings, chimneys, light fixtures, doors; some window glasses crack; some cracks to partition walls.
Life Safety (Moderate to Heavy Damage)	Lifts out of service, some breakages to pipelines and ducts; some fixtures broken; electrical distribution equipment shifts and may be out of service; breakages in medical supply systems near heavy equipment.	Medical equipment shift and disconnect from cables but do not overturn; most equipment on rollers slide; some cupboards, racks cabinets and book shelves tip; some damage to chemical bottles in the lab; lab equipment slide from table.	Extensive cracked glass, some broken glass; severe cracks in partitions and parapets; doors jammed; some fracturing to cladding.
Hazards Reduced Levels (Heavy to Very heavy Damage)	Some critical systems equipment slide or overturn; some piping lines rupture; generators will be out of function; some damage to the fire response system.	Equipment roll, overturn, slide, and cables are disconnected; some equipment require reconnection and realignment; sensitive equipment may not be functional; cupboards, cabinets and racks overturn and spill contents; severe damage to lab chemicals.	Generally shattered glass and distorted frames; widespread falling hazard; damage to partitions and parapets; severe damage to claddings; extensive damage to light fixtures.