Methodology for assessing seismic vulnerabilities of health facilities

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Abstract

Assessment of health facilities' structural and nonstructural components safety against possible earthquakes was developed in Nepal in 2001–2004. It is clear that not all globally developed or accepted methodologies for seismic vulnerability assessment can apply to developing countries like Nepal. Based on the experience of the National Society for Earthquake Technology (NSET) in four studies on structural and nonstructural vulnerability of hospitals in Nepal, a guideline for seismic vulnerability assessment for hospitals was published in 2004 together with WHO. The seismic vulnerability assessment tool is mainly targeted to civil engineers and technicians who are responsible for ensuring stability of the hospital building structures and their contents during earthquakes, while nonstructural guidelines can also be used by health professionals and hospital administrators. The method developed and applied also assists in prioritization. This article outlines experience in the development and application of these methods as well as the initiatives that followed after its completion and dissemination. Some of these are applications for planning purposes, i.e. for identifying the priorities of intervention in hospital systems, training needs for health professionals and initiatives by hospitals that have been through assessment and worked on expanding their preparedness with plans and drills.

Introduction

In the past, major earthquakes in Nepal have caused huge numbers of casualties and damage to structures. The Great Nepal-Bihar earthquake in 1934 reportedly killed 8519 persons and damaged 80 000 buildings in Nepalese territory[1]. In recent years, the Kathmandu Valley Earthquake Risk Management Project (KVERMP) and other projects (e.g. The Study on Earthquake Disaster Mitigation in Kathmandu Valley) estimated high potential losses and casualties including the potential losses of medical facilities during a large earthquake affecting Kathmandu Valley[2]. Seismic performance evaluation studies, carried out by the National Society for Earthquake Technology-Nepal (NSET) for Bir Hospital, the largest hospital of Nepal, confirmed the prediction[3]. Although being a seismically active country, earthquake-resistant standards have not been effectively applied and guidelines have not been published and practiced for hospital facilities in general. Most buildings in Nepal and in developing countries are non-engineered ones, and earthquake considerations have not been integrated into the buildings even in seismic regions. This is reflected also in the construction of buildings to house health facilities. For this reason, there is a higher possibility of hospital buildings not being functional during a large seismic event. This realization has led to a series of activities and programmes in Nepal directed towards improving the seismic performance of hospitals and health facilities, summarized in Box 1. Effective reduction of disaster vulnerability of health facilities can be achieved and requires a long and comprehensive logical process that should target and engage all stakeholders, and utilize the knowledge that is available in-country and globally.

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In this process, NSET conducted a project, "Structural Assessment of Hospitals and Health Institutions of Kathmandu Valley" with WHO-Nepal and the Ministry of Health, in 2001[4]. At the initial stages of this effort, it became very clear that while the required level of knowledge existed in the country, there was an obvious lack of experience for conducting such assessments in the country as well as in the Region. The project, therefore, decided to use the experience of countries of the Pan-American Health Organization (PAHO), and utilized the services of an expert for the purpose of experience-transfer for a period of two months. The assessment estimated that most hospitals would withstand the occasional earthquake of MMI VII* without collapsing. It was found that 10% of the hospitals might be functional, 30% partially functional, and 60% out of service. The major cause of possible functional loss was considered to stem from nonstructural damage and one of the recommendations of the project was to conduct detailed nonstructural assessment of major hospitals.

As a recommended follow-up of the aforementioned study, another study called "Non-structural Vulnerability Assessment of Hospitals in Nepal" was carried out by NSET with financial support from WHO-Nepal[5]. Both the studies were envisaged by the Health Sector Emergency Preparedness & Disaster Response Plan, Nepal, prepared by the Disaster Health Working Group (DHWG), Epidemiology and Disease Control Division (EDCD), Department of Health Services (DHS), the Ministry of Health and WHO-Nepal[6], thus creating the background for effective national ownership of the methodologies and outcomes.

Structural vulnerability assessment: Doing a structural assessment refers to the estimation of the performance level of the structural system when subjected to earthquake loads of different intensities.

The structural performance of hospitals in an earthquake is measured in terms of the potential damage to the structural system in relation to existing vulnerabilities. The vulnerability of the structure is its susceptibility to damage at local level as well as its consequences for the stability of the building system when subjected to earthquake load.

Nonstructural vulnerability assessment: Assessment of nonstructural vulnerability is made in order to estimate the expected damage that these elements may suffer when subjected to earthquakes at different levels of intensity and the consequence to the functionality of the hospital. The cost of the nonstructural elements in a hospital may be much higher than that of the structure. Particularly in hospitals, it may reach up to 90% of the total facility value or even exceed it.

In summary, nonstructural vulnerability assessment and consequent implementation of mitigation measures in hospitals are justified on the following grounds:

(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 its functional collapse.

(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

* The Modified Mercalli Intensity scale compares earthquake effects from one location to another, or from one earthquake to another. It is based on the effects of the earthquake on buildings, objects and people.

approximately 60% of the value in housing and office buildings, in hospitals these values range from 85% to 90%, mainly due to the cost of medical equipment and specialized facilities.

Performance assessment: Based on the assessment of structural and non-structural vulnerabilities and also that of critical facilities, lifelines and in-place system of emergency response if any, the overall seismic performance of the hospital is evaluated for different levels of earthquake shaking. Priority-wise mitigation measures are then identified and recommended. The seismic vulnerability of different systems, technical and economic feasibility of implementing mitigation options, structural vulnerability and importance of the different critical systems and departments for operating the hospital after an earthquake shall be taken as a basis for the prioritization. In addition, the priority should follow some logical sequence of improving the functional status of the hospital after an earthquake.

History

Beginning in 2000 a dedicated emergency preparedness team from the Ministry of Health, WHO and NSET in Nepal initiated a programme of assessing the seismic vulnerability of national health facilities. The starting point was a structural assessment of 14 hospitals in Kathmandu Valley, supported by PAHO carrying out the structural assessment as well as imparting the knowledge and experience to the engineers in NSET. The following box elaborates the history of health facility risk reduction in Nepal.

Box 1: Brief history of health-sector disaster risk reduction efforts in Nepal

1. The Kathmandu Valley Earthquake Damage Scenario (1997) revealed massive potential for casualties surpassing the combined capacities of all major hospitals in Kathmandu Valley (injuries at IX MMI > 100 000 as against available total bed capacity of 5000).
2. A workshop on Health and Medical Implications of Earthquake Disasters in 1998 (OFDA, WHO, MOH) provided, for the first time, access to experience (and documentation) from PAHO and SEARO. Subsequently, WHO supported several workshops, training programmes, and simulations; an EHP profile was prepared. A Disaster Heath Working Group (DHWG), established after the 1993 floods in south-central Nepal was revitalized in 2000-2001.
3. DHWG discussed the earthquake damage scenario and prepared the National Health Sector Plan. According to the Plan structural assessment of major hospitals (structural vulnerability, qualitative + and quantitative) was conducted; technology / experience transferred from PAHO to Nepal.
4. Structural vulnerability assessment continued for other major hospitals. Non-structural vulnerability assessment methodology was developed and implemented in all 20 major hospitals.
5. Patan Hospital took the lead in implementing vulnerability reduction, revised existing plan, made mass casualty drill regular. Earthquake preparedness was institutionalized.
6. Hospital Preparedness for Emergencies (HOPE) course developed, implemented and institutionalized with preparation of a cadre of national/regional instructors as a part of the Programme for Enhancement of Emergency Response (PEER) supported by the US Office of Foreign Disaster Assistance (USAID/OFDA). HOPE focused on instructors' development and institutionalization of hospital preparedness in six Asian countries including Nepal. HOPE course was made multi-hazard in 2009.
7. Emergency Plans were developed in other hospitals and regular drills conducted an increasing number of hospitals including private ones.
8. Structural, Nonstructural and Functional vulnerability assessments were conducted for blood banks and Red Cross buildings.
9. A Growing number of hospitals implement structural and nonstructural vulnerability reduction measures. The need to support such efforts and to scale up the initiative has been included in the National Strategy for Disaster Risk Management of Nepal.

Methodology

Developing a sound methodology for seismic vulnerability assessment of hospitals in Nepal was one of the main targets of the study. This was done by adopting and adapting the provisions spelt out for such assessment in different studies[7,8,9,10,11,12]. 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 information about the design and construction methodology which provides the input parameters required for standard methodology primarily developed for developed countries in assessment works. Also, the participation of hospital staff and possible availability of primary data have been taken into account in developing the methodology. The methodology, which was developed and used for the study is discussed below.

Structural vulnerability assessment

The description of the different steps of qualitative structural assessment methodology developed for the study is presented in the following sections.

1. Identification of Building Typology

The typology classification in this study is global, and is based on the performance of different types of buildings during past earthquakes. Building typologies defined in BCDP [13] a Nepal National Building Code document, were taken as a basis while defining the different building typologies. The types of buildings considered are:

Type 1: Adobe, stone, adobe and stone, stone and 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: OMRF with more than three stories

B: OMRF 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)

2. Selection of appropriate fragility function

The performance level of specific building types as described above was decided based on the internationally available descriptions of seismic performance during past earthquakes. The description of both structural and nonstructural damage was taken as the basis for performance evaluation. However, such descriptions are not available for all building types found in Nepal, and a combination of international and Nepalese standards were therefore used to define fragility function. For this evaluation, the damage extent at different intensities was taken from fragility functions derived in BCDP[13] and European Macro-seismic Scale, 1998.

3. Vulnerability factors identification

The appropriate vulnerability factors for different types of buildings were selected using the set of appropriate checklists available in Federal Emergency Management Agency (FEMA)[12]. The basic vulnerability factors related to building systems, lateral force resisting systems, connections, diaphragms, geologic and site hazard, and nonstructural hazards were evaluated based on visual observation of buildings and sites. Critical vulnerability factors that were necessary to check with quick calculations were identified in this step.

Table 1: Checklist for identifying probable influence of different vulnerability factors on the seismic performance of buildings

Vulnerability factors		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					

Some specific vulnerability factors like integrity of different structural components, bonding between two widths of stone masonry wall, flexible roofing and flooring system, interaction of structural/nonstructural components were also checked in this step. In addition, provision of seismic detailing was also checked wherever detailed construction drawings were available.

4. Checking of stress conditions of some components by mathematical calculations

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

5. Identifying probable influence of the different vulnerability factors on the seismic performance of buildings

Based on the observations and quick checks, probable effects of different vulnerability factors on the targeted building were assessed in this step. Increase in vulnerability by all these vulnerability factors was assigned as high, medium, low, not applicable and unknown to the building. Table 1 provides a checklist of the vulnerability factors and their effects on the building.

6. Interpretation of the building's 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 targeted building was classified as" average", "good" or " weak" for that particular typology. The classification "good" means that the building is better than average buildings of that type whereas a "weak" building is worse than an average building of that type.

***Table 2:** Format for structural safety of the building at different intensities of earthquakes*

	Performance of the building			
	MMI VI	MMI VII	MMI VIII	MMI IX
Building#1				

7. Making structural safety statement about the building

The expected structural performance of hospital buildings during different levels of shaking measured on the MMI scale was figured out based on the interpretation of building fragility. Table 2 shows the format for making the safety statement about the building. There are five grades of damage from grade 1 to 5 as defined in BCDP[13].

Nonstructural vulnerability assessment

The major steps carried out for the nonstructural assessment of hospitals are discussed below.

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, for continued functionality of the hospital after an earthquake were identified. Following steps were followed to identify the critical systems.

The steps for identifying the critical systems and facilities were as follows:

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

Step 2: Collect information on buildings, lifeline systems and facilities

Step 3: Visit essential and critical facilities

Step 4: Visit lifeline facilities

Step 5: check correlation between the structural system, medical facilities and lifeline systems.

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. Four levels of damage – very high, high, medium and low were taken in this case. Vulnerability reduction options, implementation priority and cost estimation for implementation of mitigation options were identified for all equipment.

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

The feasibility of implementing mitigation options are defined as either easy-to-implement or difficult-to-implement. Easy-to-implement means the maintenance division of the hospital can implement the mitigation options after a short training from experts and the materials necessary for implementing mitigation options are available locally. While difficult-to-implement means external experts are necessary to implement the mitigation options and the necessary materials are not available locally.

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* A level VIII on the Mercalli scale puts damage as slight in specially-designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures.

An intensity of IX describes considerable damage in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations.

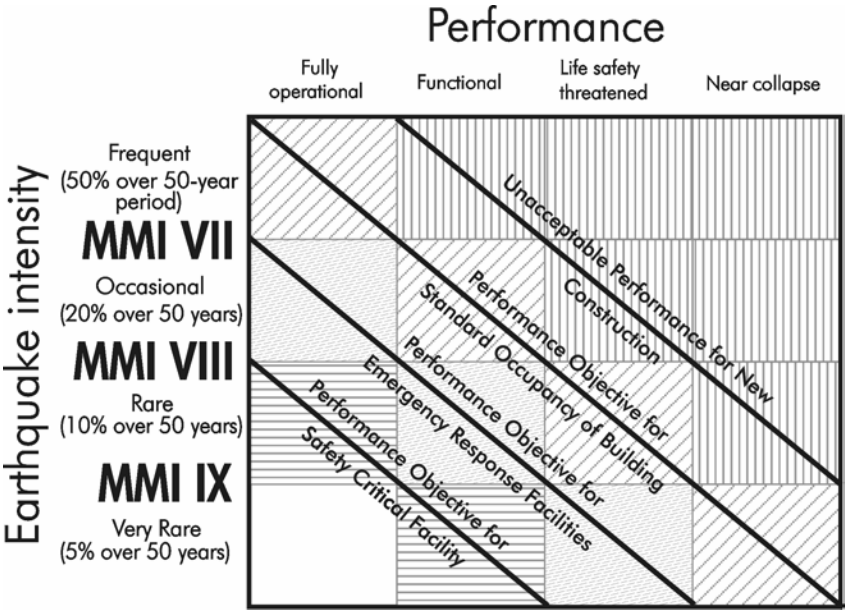
The terms used to define the cost for implementing the mitigation options to reduce the risk are described as low and high cost. These are basically relative terms. Low-cost-involvement means the cost involvement is less than 100 000 Nepali rupees (NRs.) or the hospital administration/maintenance division can allocate the budget to implement the mitigation option. High-cost-involvement means the cost involvement is more than NRs. 100 000 or the hospital administration/ maintenance division cannot allocate the budget to implement the mitigation option and needs external financial support.

Performance assessment of hospital

Based upon the structural and nonstructural vulnerability assessment of the hospital buildings and different critical systems and facilities, the functional assessment of the hospitals was made for two earthquake scenarios.

The hospital was then compared with the following risk acceptance matrix, proposed by Structural Engineers Association of California (SEAOC)[14]. Each assessed hospital was plotted in this matrix to compare the existing safety level to the standard expected safety level. The Figure shows the risk acceptance matrix used for the study.

Figure: Risk acceptance matrix used for the study



Identification of vulnerability reduction measures

Considering the opportunity for immediate implementation of nonstructural risk mitigation measures, some examples of mitigation options to solve the problems were developed. The purpose was to guide the hospital maintenance division to start implementation. Some representative problems from different hospitals were taken and solutions were provided using illustrative graphics. The following is one of the examples prepared during the study.

Improving safety of operating theatres

Almost all equipment in the operation theatres in Nepalese hospitals was on rollers or roller trolleys and therefore highly vulnerable.

However, for everyday use this equipment must be flexible and mobile and cannot be permanently fixed. Thus, a special system for anchoring the equipment is necessary; anchoring which can fix the equipment during operations and can be removed afterwards. The system can be a steel frame consisting of vertical and horizontal angles attached to the equipment rack. The system should have a number of chains, straps, hooks and guide bars in the rack for fixing and securely placing the equipment in the rack. The frame can then be fastened in a location near the operation table during the operation. By providing anchor bolts on the ceiling and on the floor the equipment rack can be positioned near the OT table. Similarly, anchor bolts should be provided in the walls in appropriate locations so that the equipment can be removed and fixed in a safe place when not used.

Key findings and recommendations

By assessing the structural and nonstructural components against possible earthquakes, the expected performance of hospitals were evaluated and compared with standard risk acceptance matrices. The results show that about 80% of the hospitals assessed in the study fall in the unacceptable performance level for new construction. The remaining 20% are at the level of risk to life safety or near collapse. Recommendations were made to improve the seismic performance of different hospitals on priority basis. Fixing of all equipment and contents, strengthening of critical systems, training hospital personnel and provision of some redundancies in critical systems were the proposed activities in the first phase. Seismic retrofitting of hospital buildings, further strengthening of critical systems and provision of extra redundancies in the systems were the activities proposed in the second phase of implementation. Considering the opportunity for immediate implementation for nonstructural risk mitigation, some examples of mitigation options to solve the problems were developed during the study.

The results of the study show an alarming situation where immediate reconstruction of most of the hospital buildings to achieve the standard acceptable level of safety is necessary. However, the study recommended the approach of gradually increasing safety considering the socio-economic condition of the country and the fact that medium-level earthquakes are more frequent than severe ones. Thus, priority-wise recommendations have been made to improve the seismic performance of each hospital. The seismic vulnerability of different systems, technical and economic feasibility of implementing mitigation options, structural vulnerability and importance of the different critical systems and departments in order to operate the hospital after an earthquake have been taken as a basis for the prioritization of recommended actions. Moreover, the possibilities of implementing different mitigation options were also discussed with the respective hospital administration staff before finalizing the priority. The technical feasibility of implementing mitigation options were discussed in a workshop attended by engineering professionals. Table 3 shows the phase-wise recommendations made by the study.

The expected seismic performance of the hospitals after implementation of Phase I and Phase II recommendations were again compared with the above-mentioned risk acceptance matrix to determine the expected improved situation after implementation of Phase I and Phase II recommendations. After the implementation of Phase I recommendations (at an estimated cost of $US 150 000), 90% of facilities would meet the performance objectives for standard occupancy of buildings defined in the matrix (refer to Figure 1, p. 28), while 10% would reach the level for emergency response facilities. The implementation of Phase II recommendations (at an estimated cost of $US 5 200 000) would mean that 90% of facilities would meet the performance objectives for emergency response facilities, while 10% would reach the highest level, that of the performance objectives for safety critical facilities.

Table 3: Recommendations of the study

Phase and objective	Activities	Cost estimate
Phase I: To expect the hospitals to be fully operational after a moderate earthquake	• Fixing of all equipment and contents • Strengthening of critical systems • Training hospital personnel • Provision of some redundancies in critical systems	US$ 150 000 for Phase I recommendations in the nine assessed hospitals
Phase II: Additional recommendations for improving the performance of the hospital to a desirable level after a severe earthquake	• Seismic retrofitting of hospital buildings • Further strengthening of critical systems • Provision of extra redundancies in the systems	US$ 5 200 000 to implement structural and nonstructural mitigation options in the nine assessed hospitals

Conclusions

The available methodologies for assessment as well as mitigation options of hospitals in Nepal are not suitable to the local environment largely because of the difference in the typologies of the construction resulting from the preference of certain construction materials by the community. Appropriate methodologies were developed and tested to ensure that the local problems could be addressed properly. The development of practical methods applicable to the local situation helped in the consensus-building among government authorities and hospital professionals.

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