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SEISMIC VULNERABILITY ASSESSMENT OF HOSPITALS IN NEPAL

Ramesh GURAGAIN[1], Amod Mani DIXIT[2]

SUMMARY

In the past, big 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. Though being a seismic country, earthquake-resistant standards have not been effectively applied and guidelines have not been published and practiced for hospital facilities in Nepal. The possibility of hospital buildings not being functional during a large seismic event is very high. National Society for Earthquake Technology (NSET) conducted two studies “Structural Assessment of Hospitals and Health Institutions of Kathmandu Valley” and “Non-structural Vulnerability Assessment of Hospitals in Nepal” in year 2001 and 2003. Systematic approach towards seismic assessment of hospitals in Nepal was developed while carrying out those assessments in major hospitals of Nepal. The necessity to develop such a methodology arose because of the non-applicability of similar methodologies used in other developed countries.

By assessing the structural and non-structural components against possible earthquakes, expected performances of hospital 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 and remaining 20% of the hospitals are at life safety to collapse prevention performance level. Recommendations were made to improve the seismic performance of different hospitals in priority basis. Fixing of all equipment and contents, strengthening of critical systems, training to hospital personnel and, provisions of some redundancies in critical systems were the proposed activities to implement in first phase. Seismic retrofitting of hospital buildings, further strengthening of critical systems and provision of extra redundancies in the systems were the activities for second phase implementation as proposed. Considering the opportunity of immediate implementation of non-structural risk mitigation, some examples of mitigation options to solve the problems were developed during the study.

INTRODUCTION

In the past, big 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, Rana [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

[1] Structural Engineer, National Society for Earthquake Technology , Email: rguragain@nset.org.np
[2] General Secretary, National Society for Earthquake Technology, Email: adixit@nset.org.np

Valley) estimated high potential losses and casualties including the potential losses of medical facilities during a large earthquake affecting Kathmandu Valley, Nippon Koei [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, Patton [3]. Although being a seismic country, earthquake-resistant standards have not been effectively applied and guidelines have not been published and practiced for hospital facilities in general, in Nepal. For this reason, there is a higher possibility of hospital buildings not being functional during a large seismic event.

National Society for Earthquake Technology-Nepal (NSET) conducted a project "Structural Assessment of Hospitals and Health Institutions of Kathmandu Valley" with WHO-Nepal and the Ministry of the Health, HMGN in 2001, WHO [4]. The assessment estimated that most of the 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 non-structural damage and one of the recommendations of the project was to conduct detailed non-structural 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 support from WHO-Nepal, NSET [5]. Both studies were envisaged by the Health Sector Emergency Preparedness & Disaster Response Plan Nepal prepared by the Disaster Health Working Group, Epidemiology and Disease Control Division (EDCD), Department of Health Services (DHS), the Ministry of Health and WHO-Nepal, DHWG [6].

Systematic approach towards assessment of structural and non-structural vulnerability of hospitals in Nepal was developed through implementation of such assessment work in about 20 major selected hospitals during the study. Appropriate measures for improving seismic performance of the selected hospitals were identified and the findings were disseminated in order to facilitate the implementation of the identified earthquake risk reduction measures. The methodology adopted, key findings and recommendations and mitigation measures identified during the study are described below.

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 assessment in different studies e.g. Johnson [7], WHO [8], NZS [9], NZS [10], FEMA [11] and FEMA [12]. It was necessary to develop such 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 the construction methodology. That information is the input parameters required for standard methodology primarily developed for developed countries in assessment works. The methodology developed in this study accounts the general unavailability of data on design and construction of health facilities. Also the participation of hospital staff and possible availability of primary data are 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.

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, was taken as basis while defining the different building typologies. The types of buildings considered 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)

Selection of Appropriate Fragility Function

The performance level of specific building type as described above was decided 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 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.

Vulnerability Factors Identification

The appropriate vulnerability factors for different types of buildings were selected using the set of appropriate checklists available in FEMA [12]. 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 of buildings and sites. Critical vulnerability factors that were necessary to check with quick calculations were identified in this step. Some specific vulnerability factors like integrity of different structural components, bonding between two wyths of stone masonry wall, flexible roofing and flooring system, interaction of structural/non-structural components were also checked in this step. In addition, provision of seismic detailing was also checked wherever detail construction drawings were available.

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, short column effect, soft-story effect etc. Those checks sometimes revealed the critical status of the building.

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 to 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 to the building.

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					

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 targeted 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.

Making Structural Safety Statement about the Building

The expected structural performance of hospital buildings during different levels of shaking measured in 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. Five grades of damage from damage grade 1 to 5 as defined in BCDP [13].

Table 2: Structural Safety of the Building at Different Intensities Earthquakes

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

Non-Structural Vulnerability Assessment
The major steps carried out for the non-structural assessment of hospitals are discussed below.

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, in each hospital which will be important for continued functionality of the hospital after an earthquake, were identified after visiting the hospital. Following steps were followed to identify the critical systems.
<u>Steps for Identifying the Critical Systems and Facilities</u>
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: Cross correlation among structural system, medical facilities and lifeline systems.

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.

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 expert and the materials necessary for implementing mitigation options are available at local market. While difficult-to-implement means experts from outside the hospital are necessary to implement the mitigation options and 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. These are basically relative terms. Low-cost-involvement means the cost involvement is less than NRs. 100,000.00 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. 100,000.00 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 non-structural vulnerability assessment of the hospital buildings and different critical systems and facilities, the functional assessment of the hospitals was made for two different scenario earthquakes.

The hospital is then compared with the following risk acceptance matrix, proposed by SEAOC [14]. Each assessed hospital was plotted in this matrix to compare the existing safety level to the standard expected safety level. Figure 1 shows the risk acceptance matrix used for the study.

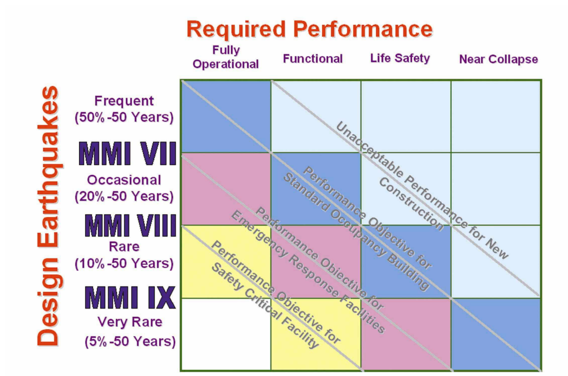


Fig 1: Risk acceptance matrix used for the study

IDENTIFICATION OF VULNERABILITY REDUCTION MEASURES

Considering the opportunity of immediate implementation of non-structural 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. Following is one of the examples prepared during study.

Improving Safety of Operation Theatres

Almost all equipment in the operation theatres of Nepalese hospitals were found to be on rollers or roller trolleys without any fixity and are 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 numbers 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 to the operation table during the operation. By providing anchor bolts in the ceiling and in the floor of the room the equipment rack can be placed in position 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 placed when not used.

Problem Identification Solution Provided as an example

Fig 3: Improving Safety of Operation Theatres

KEY FINDINGS AND RECOMMENDATIONS

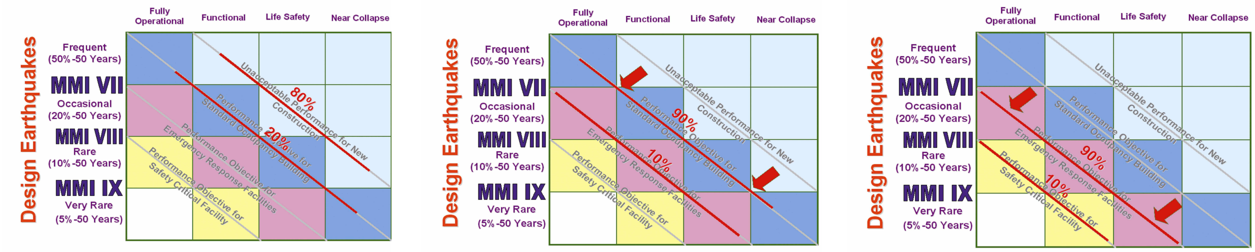
The comparison of the expected seismic performance of the hospitals with the risk assessment matrix gave the result that about 80% of the hospitals assessed falls in the unacceptable performance area for new construction i.e. they are in the situation beyond the Collapse Prevention Building Performance Level, FEMA [15], in severe earthquake and remaining 20% of the hospitals pose life safety to collapse prevention performance level.

The result shows an alarming situation and demanded immediate reconstruction of most of the hospital buildings to achieve standard acceptable level of safety. However the study project recommended the approach of gradual level of increasing safety considering the socio-economic condition of the country and the fact that medium level earthquakes are more frequent than the severe ones. Thus, priority-wise recommendations are made to improve the seismic performance of each hospital. The seismic vulnerability of different systems, technical and economical 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 are taken as basis for the prioritization of recommended actions. Moreover, the possibilities of implementing different mitigation options were also discussed with hospital administration before finalizing the priority. Technical feasibility of implementing mitigation options were discussed in a workshop inviting engineering professionals. Table 3 shows the phase wise recommendations made by the study.

Table 3: Recommendations of the study

Phase and Objective	Activities	Cost Estimate
Phase I: To expect the Hospitals Fully Operational after a Moderate Earthquake	• Fixing of all equipment and contents • Strengthening of critical systems • Training to hospital personnel and • Provision of some redundancies in critical systems	US$150,000.00 to phase I recommendations in assessed 9 hospitals
Phase II: Additional Recommendations for Improving Performance of the Hospital to a Desirable Level after a Severe Earthquake	• Seismic retrofitting of hospital buildings • Further strengthening of critical systems and • Provision of extra redundancies in the systems	US$5,200,000.00 to implement structural and non-structural mitigation options in assessed 9 hospitals

Expected seismic performance of the hospitals after implementation of phase I and phase II were again compared with the above mentioned risk acceptance matrix. Figure 2 shows the existing situation of assessed hospitals and the expected improved situation after implementation of phase I and phase II recommendations.



a) Existing Safety

b) Expected Safety after implementation of Phase I recommendations
Total cost required = US$ 150,000.00

c) Expected Safety after implementation of Phase II recommendations
The cost required = US$ 5,200,000.00

Fig 2: Existing and expected improved situation of hospitals

CONCLUSION

The available methodologies of assessment as well as mitigation options for assessment of hospitals in Nepal were 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 local situation helped build- upon the consensus among government authorities and hospital professionals.

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