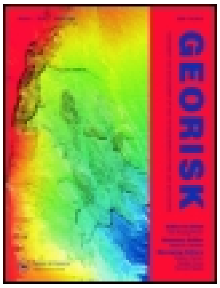

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The non-structural assessment of critical public facilities such as hospital buildings is very essential for earthquake disaster adaptation in earthquake prone regions. In Nepal, a devastating earthquake is inevitable in the long term and likely in the near future. So a non-structural earthquake vulnerability assessment study was carried out in the selected main hospitals of Nepal. This paper presents the findings of the assessment work. The results show an alarming situation and demand an immediate action in most of the hospital buildings so as to achieve a standard and acceptable level of safety. The study also recommends a gradual approach of increasing the safety level considering the socio-economic condition of the country and the fact that medium-level earthquakes are more frequent than the severe ones. Moreover, the non-structural component assessment study largely helped to convince the government officials and hospital authorities on the affordability and possibility of constructing earthquake-resistant non-structural components in the hospitals of developing countries such as Nepal, employing a slight improvement in the already employed methods of construction.

Keywords: disaster; earthquake risks; vulnerability analysis; non-structural safety; hospitals; Nepal

1. Introduction

Nepal faces a variety of natural hazards. The frequencies and intensities of these hazards are comparatively high. Earthquake is among the most significant natural hazards the entire country faces. This is because of the fact that the territory of Nepal sits astride the subduction boundary between the Indo-Australian plate in the south and the Eurasian plate in the north. Movement of the tectonic plates has caused several active faults, which are believed to be the main sources of future earthquakes. A total of 92 active faults have been identified throughout the country (BCDP 1994). During the past 100 years, three great earthquakes occurred along the Himalayan front (Bilham 2001). Nepal also has a long history of destructive earthquakes (Rana 1935; Dunn et al. 1939; Chitrakar and Pandey 1986,; Wyss 2005). From east to west, the destructive earthquake sequence includes the 1905 Kangra Earthquake (Ms $\sim$7.8), the 1934 Bihar–Nepal Earthquake (Mw = 8.1) and the 1950 Assam Earthquake (Mw $\sim$8.6). The Sikkim/Nepal Border Earthquake of 18 September 2011 is the latest earthquake (6.9 Richter Magnitude) in Nepal.

Earthquakes are unavoidable part of Nepal's geological history, and a major earthquake is likely to hit the country in near future (Ambraseys and Bilham 2000; Bilham et al. 1997). Despite the knowledge of historical seismicity and associated risk, public awareness on earthquake hazard and disaster risk was minimal until a few years back. It was only after massive destruction and fatal loss of 721 humans in the Udayapur Earthquake (Gupta 1988) of 1988 (Mw $\sim$6.6) that the need for an organised approach towards earthquake disaster risk management was realised and several innovative initiatives for the earthquake risk management were taken. The seismic record of Nepal, which exists from AD 1255, suggests that earthquakes of a size of the 1988 Udayapur Earthquake occur approximately every 50 to 100 years (JICA 2002). This indicates that a devastating earthquake is inevitable in the long term and likely in the near future. Nepal has been ranked as the 11th worst area in terms of relative vulnerability to earthquakes (BCPR 2004). A World Bank (Arnold et al. 2005) study has identified Nepal as a disaster hot spot, and the Global Earthquake Safety Initiative Pilot Project ranks Kathmandu Valley as the most at risk city in terms of potential death due to earthquake (GHI and UNCRD 2001). If the 1934 earthquake shaking is to occur again in the Kathmandu valley, it is estimated that including more than 100,000 deaths, the overall loss is estimated (data source: GHI and UNCRD 2001) as follows.

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(1) Death: 100,000
(2) Serious injury: 100,000
(3) Minor to moderate injury: 200,000
(4) Homeless population: 1,500,000–2,000,000
(5) Building damage: 60%
(6) Damage to infrastructures
  - Bridges impassable: >50%
  - Road length damaged: >10%
  - Water supply pipes damaged: >95%
  - Telephone Exchange Buildings: most
  - Telephone lines: >60%
  - Electric substations: most
  - Electric lines: 40%

These loss estimation data clearly indicate that the earthquake disaster risk scenario of Nepal is very alarming, and it is of utmost importance to prepare for an upcoming disaster.

Despite being a seismically active region, however, earthquake-resistant standards have not been effectively applied, and construction and planning guidelines have not been published and practised for the public buildings in Nepal. Most important public facilities such as hospitals are also not safe. There are greater possibilities that the hospital buildings will not function during and after a large seismic event. With this understanding, a non-structural earthquake vulnerability assessment of major hospitals of Nepal was done, and the research findings are presented in this paper.

A major issue of earthquake vulnerability analysis in hospitals is high complexity of structural and non-structural systems (Kuwata and Takada 2007; Iadanza et al. 2009). Along with the structural components, performance of a hospital depends intimately on the non-structural components, such as medical facilities, hospital management aspects, hospital emergency planning and technical maintenance (Miniati and Iasio 2012). In general, strengthening of the non-structural system always improves the disaster preparedness level of a hospital after a medium-scale earthquake. Several methodologies have been developed and applied for assessing the structural and non-structural earthquake risk in hospitals (Yao and Lin 2000; Kuwata and Takada 2007; Bayraktarli and Faber 2011). Various guidelines on earthquake vulnerability assessment for hospitals in both developing and developed nations were formulated in the last 10 years within the Safe Hospitals Campaign of the Hyogo Framework (UN/ISDR 2005). With this understanding, this study has been carried out considering the high seismic risk of Nepal and low level of preparedness in critical infrastructures, including health facilities. More recently, the Kathmandu Valley Earthquake Risk Management Project and various other projects have estimated higher potential losses and casualties, including the loss of medical facilities during a large earthquake shaking in the Kathmandu Valley. After the assessment, the estimated result for occasional earthquake of MMI VIII was found as most of the hospitals might withstand the earthquake without collapse (WHO 2002). It was found that, 10% of the hospitals might be functional, 30% partially functional and 60% out of services. The cause of possible functional interruption was considered mainly due to non-structural damage (WHO 2002).

The main objectives of this study are as follows:

- to develop an appropriate methodology for non-structural earthquake vulnerability assessment,
- to conduct the non-structural earthquake vulnerability assessment of selected major hospitals in Nepal,
- to identify appropriate measures for improving seismic performance of selected hospitals,
- to disseminate the findings for facilitating implementation of the identified earthquake risk reduction measures as recommendation of the research.

2. Structural and non-structural components

The structural components of a hospital building are those that take up gravitational forces, earthquake forces and wind and any other type of load. They generally include columns (posts and pillars), beams (girders and joists) and foundations (mat, spread footings and piles). In Nepal, for engineered constructions, the structure is typically designed and analysed in detail by a structural engineer, but for non-engineered constructions, masons or labour contractors construct these elements directly without any specific design in general.

On the other hand, the non-structural components include every part of the building and its contents excluding the structural components or the columns, floors, beams, etc. (Figure 1). The common non-structural components include false ceilings, windows, office equipment, computers, inventory stored on shelves, file cabinets, water tanks, generators, transformers, heating, ventilating and air conditioning (HVAC) equipment, electrical equipment, furnishings, lights, etc. Typically, the non-structural components are not analysed and designed by an engineer, but may be specified by an architect, a mechanical engineer, an electrical engineer and an

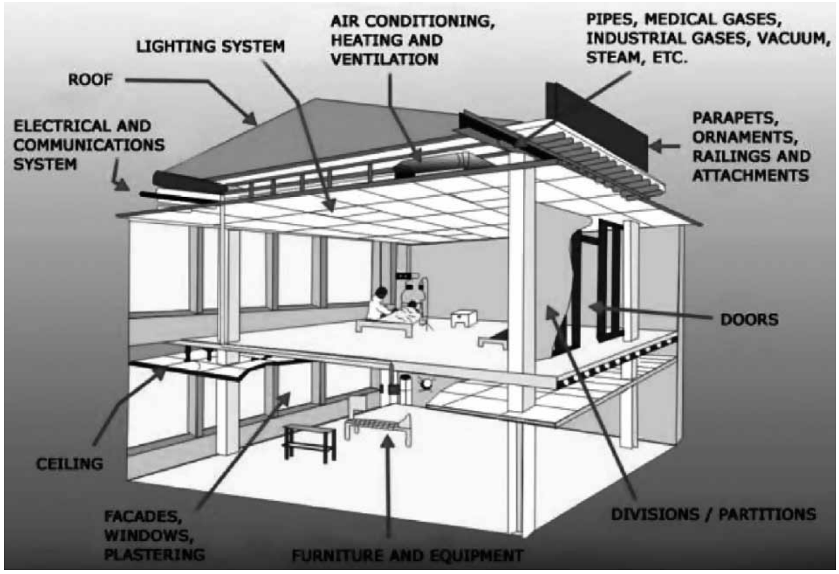

Figure 1. Non-structural components in a typical hospital of Nepal.

interior designer, or in most of the cases, they may be purchased without involving any design professional by the owners after construction of the structural components.

3. Causes of non-structural damage during earthquakes

Earthquake ground shaking primarily has three effects on the non-structural elements of buildings: (1) direct or shaking effect on the non-structural elements themselves, (2) effect of the structural components on the non-structural components and (3) the pounding effect at the interface between the adjacent structures. In general, the earthquake's inertial forces are greater if a building or an object within the building weighs more or if the acceleration or severity of the shaking is greater.

In a hospital building, file cabinets, emergency-power generating equipment, freestanding book-shelves, office equipment, water tanks, flower pots and items stored on shelves or racks can all be damaged because of the inertial forces. When an earthquake shakes unstrained items, the inertial forces may cause them to slide, swing, strike other objects or overturn. The items may slide off the shelves and fall off to the floor. One misconception is that large and heavy objects are stable and not as vulnerable to earthquake damage as lighter objects, perhaps because we may have difficulty moving them. In fact, many objects are more vulnerable to earth-quake damage or overturning caused by inertial forces because inertial forces during an earthquake are proportional to the object mass.

During an earthquake, building structures distort or bend side to side in response to the earthquake forces. There have also been notable causes of structural and non-structural interaction in past earthquakes, when rigid, non-structural components have been the cause of structural damage or collapse. These causes generally involve rigid, strong architec-tural components, such as masonry infill, that inhibit the movement or the distortion of the structural framing and cause premature failure of column or beam elements.

Another source of non-structural damage involves pounding or movement across separation joints between adjacent structures. Damage to items cross-ing the seismic gaps is also a common type of earthquake damage, and if the size of the gap is insufficient, pounding between adjacent structures may result in damage to structural components, such as parapets, veneer or cornices on the facades of older buildings.

4. Approach and methodology

Assessment of major hospitals of Nepal for earth-quake vulnerability is the major goal of this research. To achieve this goal, nine major hospitals were selected for a detailed non-structural assessment. Four of them were among the 15 major hospitals of Kathmandu Valley and five were among regional and zonal hospitals from outside the valley. The locations of the selected hospitals within and outside the Kathmandu Valley are shown in Figure 2, and the detailed list is given in Table 1.

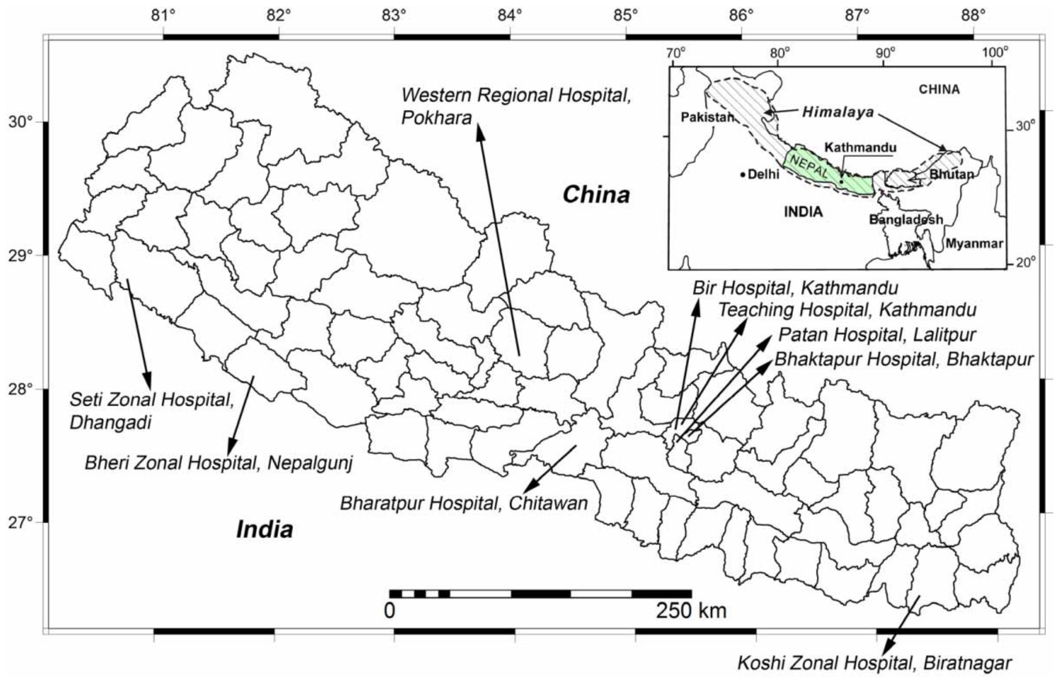

Figure 2. Locations of the selected nine hospitals in Nepal.

The criteria for selecting the hospitals within the Kathmandu Valley, where the capital city of Kathmandu is situated, were based on the recommendations of a structural assessment study conducted in 2001 (WHO 2002). As a qualitative structural assessment was already available, the non-structural assessment was considered more appropriate for these hospitals. Similarly, importance in terms of emergency management is also considered, and all selected hospitals are of general type and are four main hospitals in the Kathmandu Valley.

In selecting the hospitals outside of the Kathmandu Valley, general criteria such as number of beds and geographical distributions were considered. General structural assessment was also conducted prior to non-structural assessment because no structural assessment data were available for the hospital buildings outside of the Kathmandu Valley.

Seismic Reliability Assessment of Critical Facilities (Johnson et al. 1999), Protocol for Assessment of the Health Facilities in Responding to Emergencies (WHO 2000), New Zealand Standards – NZS 4104:1994 (NZS 1994), NZS 4219:1983 (NZS 1983) and NEHRP Guidelines for the Seismic Rehabilitation of Buildings (FEMA 1997) were used as references to adopt an international approach for earthquake vulnerability assessment of the hospital buildings. Some modifications in the approaches and methodologies available in those documents were made as per the site conditions, which were necessary considering the non-applicability of the exactly similar methodologies used in the developed countries mainly because of lack of data related to design and construction methodology that go as input parameters on the established software for such assessment. The methodology developed and used in the study is described in the following subheadings.

The non-structural assessment of the hospitals is carried out in four aspects. At first, critical systems and facilities are identified within the hospital system. Then, individual, non-structural components are assessed for their vulnerability to earthquakes. Finally, total performance of the each hospital is assessed. The methodology developed and used in the study and the detail procedures for the assessment are described in following subheadings.

4.1. Identifying critical systems and facilities

Identification of the critical systems and essential functions of a hospital (Figure 3) is carried out on the basis of the functional requirements of the hospital during and after an earthquake. The main critical systems and facilities, which are important for continued functionality are identified after visiting the hospital. The following steps are tracked to identify the critical systems.

Step 1: Visit the hospital and explain the scope of work to hospital administration
Step 2: Collect information

Table 1. List of the selected hospitals and their characteristic features.

				Location								
S. no.	Name of the hospitals	Type	District	Municipality	Ward no.	Place	Structural type	Number of storeys	Date of completion	No. of beds	Total doctors	Total nurses
1	Bir Hospital	General	Kathmandu	Kathmandu	30	Mahaboudda	RC	5	1985	392	180	210
							BM	4	1968			
							BM	3	Not known			
2	Patan Hospital	General	Lalitpur	Lalitpur	5	Lagankhel	RC	4	1982	200	60	250
3	Bhaktapur Hospital	General	Bhaktapur	Bhaktapur	17	Dudhpati	BC	3	1978	50	11	25
							RC	1	2001			
4	Teaching Hospital	University Hospital	Kathmandu	Kathmandu	3	Maharajgunj	RC	2 and 4	1984	401	200	350
5	Western Region Hospital	General	Kaski	Pokhara	15	Ram Ghat	SC	1 and 2	1978	230	40	162
							RC	2				
6	Koshi Zonal Hospital	General	Morang	Biratnagar	4	Rangeli Road	BC	1, 2 and 3	1974	150	35	175
							RC	1 and 2				
7	Seti Zonal Hospital	General	Kailali	Dhangadhi	7	Main Road	BC	1 and 2	1987	75	18	90
							RC	2				
8	Bhrei Zonal Hospital	General	Banke	Nepalgunj	11	New Road, Nepalgunj	BC	1 and 2	1985	150	28	115
9	Bharatpur Hospital	General	Chitawan	Bharatpur	10	Bharatpur	BC	1 and 2	1988	140	30	122
							RC	1				

RC, reinforced concrete frame; BC, brick in cement; BM, brick in mud; SC, stone in cement.

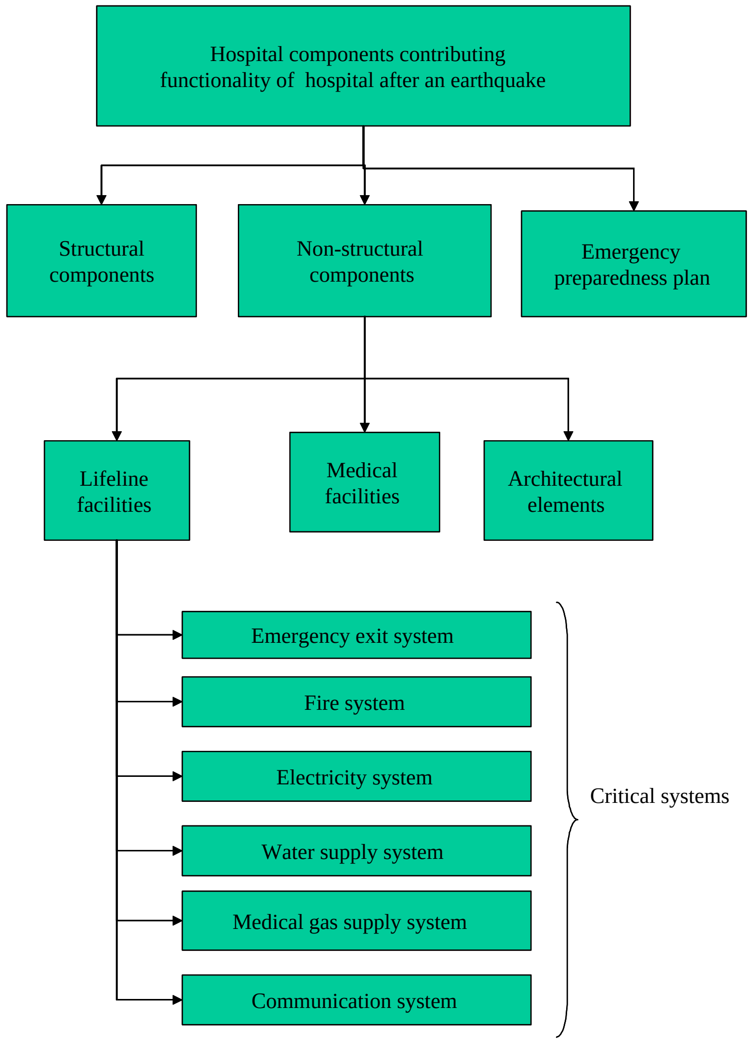

Figure 3. Major systems of the hospital designing detailed assessment.

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.

4.2. Assessment of individual components

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

4.3. Assessment of system vulnerability

Based on the assessment of individual components of respective systems, the critical systems and medical facilities are examined to find out the possible level of potential damage for the scenario earthquakes. The different level of possible damage and its consequences on the performance of the individual components and the systems are given in Table 2. Feasibility of mitigation options in terms of easiness and cost involvement to implement is also explored in each system. Mitigation options are identified and critically evaluated in terms of ease and cost of implementation, and their expected efficiency in vulnerability reduction.

The easiness of implementing the mitigation options is assessed in terms of easy-to-implement and difficult-to-implement. If the maintenance division of hospital can implement the mitigation options after a short training outside, it is an easy-to-implement

Table 2. Non-structural performance levels and damage descriptions [adopted as per FEMA (1997)].

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; fire response system is functional, transformer/generators are functional and electricity can be provided; water can be provided	Medical equipment on floor and wall are secure and operable; power available; equipment on roller slide but do not tip and do not impact to anything; cupboards, racks cabinets and book shelves do not tip; negligible damage to chemical bottles at lab; oxygen cylinders and blood stands are not tipped	Negligible damage to false ceilings, chimneys, light fixtures and stairs; minor damage to parapets and doors; minor cracks on cladding and partitions
Immediate occupancy (slight to moderate damage)	All systems' components are secured, generators start but may not be adequate to service all power requirements, minor leaks to 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 floor and wall are secure, but power may not be available; some equipments on roller slide and impacted to something; cupboards, racks cabinets and book shelves do not tip; negligible damage to chemical bottles at lab; blood stands may tip	Minor damage to ceilings, chimneys, light fixtures, doors; some window glasses cracked; some cracks to partition walls
Life safety (moderate to heavy damage)	Lifts out of service, some breakages to pipelines and ducts, and some fixtures broken; electrical distribution equipment shifts and may be out of service; there were breakages to medical supply systems near equipment	Medical equipment shift and disconnect from cables but do not overturn; most equipment on roller slide; some cupboards, racks cabinets and book shelves tip; some damage to chemical bottles at lab; lab equipment slide from table	Extensive cracked glass, little broken glass; severe cracks to partitions and parapets; doors jammed; some fracturing to cladding
Hazards reduced levels (heavy to very heavy damage)	Many equipments of critical systems slide or overturn; some piping lines rupture and generators will be out of function; some damage to fire response system	Equipment roll, overturn, slide, disconnect cables; 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	General shattered glass and distorted frames; widespread falling hazard; damage to partitions and parapets. severe damage to claddings and extensive damage to light fixtures

mitigation option. In this case, the materials necessary for implementing mitigation options are available at local market. A difficult-to-implement option refers to a situation when experts from outside the hospital need to be called to implement the mitigation options, and the materials necessary for implementing the options are not available in the locality.

Similarly, the terms used to assess the cost involvement in implementing the mitigation options to reduce the risk are low cost and high cost. A low-cost option refers to the cost involvement of less than NRs. 100,000 (1US$ = NRs 88), which the hospital administration/maintenance division can allocate in its budget to implement the mitigation option. A high-cost option refers to the cost involvement of more than NRs. 100,000, which the hospital administration/maintenance division cannot allocate in its budget and needs a financial support from external sources.

For the assessment of vulnerability system, a checklist was prepared and a team of experts visited the site with the checklist to perform the evaluation. The available structural maps, architectural maps, utility maps, and so on were also collected and evaluated. The non-structural performance levels were assessed as per FEMA (1997) (Table 2).

4.4. Performance assessment of each hospital

The performance of a hospital in terms of non-structural vulnerability is evaluated at five different levels of damage of the different critical systems and facilities that the hospital might sustain. The performance levels used in this study are described in Table 2. The structural safety of the hospital was also considered while assessing the performance level.

5. Result of assessments

Based on the structural and non-structural vulnerability assessment of the selected hospital buildings and different critical systems and facilities, the functional assessment of the hospitals was also done for two scenario earthquakes. The expected seismic performance of the assessed hospitals during the scenario earthquakes are presented in Table 3.

During the assessment of the selected hospitals, all available non-structural components such as Pharmacy, Surgical Out Patient Department (OPD), Medical OPD, Paediatric OPD, Eye OPD, Gynaecology OPD, Skin OPD, Ortho OPD, Ultrasound room, Dental OPD, Nero psychiatry, ECG Room, Endoscopic Department, Intensive Care Unit/Coronary Care Unit (ICU/CCU), Operation Theaters (OT), Recovery Room, Surgical Ward, Maternity Ward, Emergency Ward, ENT (ear, nose, and throat) Room, X-ray, Medical ward, Central Sterile Supply Department (CSSD), laboratories and administration are examined for earthquake vulnerability. Out of the nine hospitals, only two hospitals: Teaching Hospital, Kathmandu and Patan Hospital, Laltitpur, were found to be functional after the moderate earthquake (MMI VI – MMI VII) as well as the severe earthquake (MMI VIII – MMI IX). All nine hospital buildings were found to be partially operational after the moderate earthquake scenario, but seven of them were found to be useless after the severe earthquake scenario. Table 3 gives a glimpse of the expected damage and probable mitigation feasibility of the Western Regional Hospital in Pokhara.

As presented in Table 4, the situation of other hospitals is also more or less the same, but only the Teaching Hospital and Patan Hospital have relatively less damaged situation. A comparison of expected seismic performances of the hospitals with standard risk assessment matrix shows that about 80% of the assessed hospitals will be partially operational after a moderate earthquake, while they will be out of service after a severe earthquake. The remaining 20% of the hospitals will be partially operational after severe earthquakes (Figure 4). Figure 4 clearly illustrates that the seismic performance of non-structural components of the hospitals in Nepal is not in acceptable range. It suggests that about 80% of the hospitals will be non-functional, unsafe and near to collapse stage after MMI XI level of earthquake. Conversely, Figure 4 also suggests that about 80% of the hospitals will be functional, safe and will not collapse during MMI VII level of earthquake.

5.1. Major problems in non-structural components

Based on both structural and non-structural assessments of the hospitals in this study, various serious problems in relation with the non-structural components were identified. It was also understood that mitigating the risk of these problems may help to operate the hospitals even after an earthquake event.

In Bir Hospital of Kathmandu, it was observed that fixing of all equipment and contents is very urgent. There was also no provision of extra fuel storage for the generator to be used in emergency power backup. Similarly, the maintenance staffs, medical staffs, and administrative staffs were not found to be aware of the non-structural safety in the hospital. None of the glass window panes of the hospital buildings were found to have plastic lamination, and there was no bracing for the partition walls in various wards as well as in the administrative floor. More importantly, the problem of flexible couplings in water supply system and electricity system was found to be severe. The provision of redundancy in the critical system, such as extra generator, spare pumps, and so on, was also imperfect.

In Teaching Hospital of Kathmandu also, fixing of all equipment and contents is of prime importance. Here also, all maintenance staffs, medical staffs, and administrative staffs were not found to be aware of the non-structural safety. Only a few glass window panes were found to have plastic lamination. The hospital was found to have a weak supply of power into CSSD and X-ray system in case of emergency. The water supply system was also not good and needed a prompt action for a regular supply of water.

The performance of Patan Hospital, on the other hand, was found to be comparatively good during an earthquake. However, it also has some problems in non-structural components, which were exactly the same as in Bir Hospital and Teaching Hospital. Prompt actions were necessary in flexible coupling of medical gas system and solar heater system.

In Bhaktapur Hospital, the problems in non-structural components were exactly the same as Bir Hospital. The water supply system of this hospital

Table 3. Expected seismic performance of the assessed hospitals at two different scenario earthquakes.

Hospitals	Scenario earthquakes: Moderate earthquake (MMI VI – MMI VII)	Scenario earthquakes: Severe earthquake (MMI VIII – MMI IX)
1. Bir Hospital, Kathmandu	*Out of service for some time* • Severe damage to water supply, electricity and medical gas system • Many partition walls will fail • Most of the medical facilities will not operate • Some OPD may be functional after some hours of maintenance	*Out of service* • Critical systems and most of hospital departments will be out of service for a long time • There will be heavy structural and non-structural damage
2. Teaching Hospital, Kathmandu	*Partially operational* • All the critical systems will be functional • There may be quite less electric power and some damages to medical gas system may occur • The labs and operation theatres may not be functional	*Partially operational after some time* • There will be moderate damage to medical gas supply system • Many medical facilities might be functionless for some time, some hours or even days
3. Patan Hospital, Laltitpur	*Partially operational* • Most of the critical systems, OPD, Emergency Department, X-ray and CSSD may be operational after some hours	*Partially operational or out of service* • Some critical systems and most of hospital departments will be out of service for a long time
4. Bhaktapur Hospital, Bhaktapur	*Partially operational* • Some medical facilities such as OPD, Emergency Department and CSSD may be operational after some hours • The electricity and water supply systems may be out of order for long time	*Out of service* • Critical systems and most of hospital departments will be out of service for a long time
5. Western Regional Hospital, Pokhara	*Partially operational* • There is a possibility of interruption to electricity and water supply systems • There is a possibility of heavy damage to laboratory, maternity and some part of OPD • Most of the wards and OPD will be functional after some hours	*Out of service* • All critical systems and most of hospital departments will be out of service for long time • There will be heavy damage to most of the facilities
6. Koshi Zonal Hospital, Biratnagar	*Partially operational* • Water supply system will be functional and electricity system may be partially operational • X-ray, CSSD and some wards may be operational after some hours • OPD and laboratory block, Intensive Care Unit (ICU) block and maternity cabin block may have heavy damage	*Out of service* • All critical systems and most of hospital departments will be out of service for long time • There will be heavy damage to most of the facilities • Some buildings may be destructed
7. Bheri Zonal Hospital, Nepalgunj	*Partially operational* • Electricity system may not be functional • X-ray, CSSD and some wards may be operational after some hours • OPD and laboratory block, ICU block and maternity cabin block may have heavy damage	*Out of service* • All critical systems and most of hospital departments will be out of service for a long time • There will be heavy damage to most of the facilities • Some buildings may be destructed
8. Seti Zonal Hospital	*Partially operational* • There is a possibility for interruption to water supply system • Electricity system may work • X-ray and OPD may be operational after some hours	*Out of service* • All critical systems and most of hospital departments will be out of service for a long time • There will be heavy damage to most of the facilities

Table 3. (*continued*).

Hospitals	Scenario earthquakes: Moderate earthquake (MMI VI – MMI VII)	Scenario earthquakes: Severe earthquake (MMI VIII – MMI IX)
9. Bharatpur Hospital	*Partially operational* • There is a possibility interruption to electricity and water supply systems • X-ray, CSSD and lab will be out of function for several hours • Some part of hospital like general store may have severe damage	*Out of service* • All critical systems and most of hospital departments will be out of service for a long time • There will be heavy damage to most of the facilities

Table 4. Expected damage and probable mitigation feasibility of Western Regional Hospital.

Critical systems and facilities		Moderate earthquake (MMI VI – MMI VII): Expected damage	Moderate earthquake (MMI VI – MMI VII): Mitigation feasibility	Severe Earthquake (MMI VIII – MMI IX): Expected damage	Severe Earthquake (MMI VIII – MMI IX): Mitigation feasibility
1. Electricity system		Heavy	Easy to implement and low cost involvement	Heavy to very heavy	Easy to implement and high cost involvement
2. Water supply system		Heavy to very heavy	Easy to implement and low cost involvement	Very heavy	Difficult to implement and high cost involvement
3. Fire response system		Slight	Easy to implement and high cost involvement	Slight	Easy to implement and high cost involvement
4. Communication system		Moderate to heavy	Easy to implement and low cost involvement	Heavy	Easy to implement and low cost involvement
Important departments and wards	5. CSSD	Heavy to very heavy	Easy to implement and low cost involvement	Very heavy	Easy to implement and low cost involvement
	6. X-ray	Slight to moderate	Easy to implement and low cost involvement	Moderate to heavy	Easy to implement and low cost involvement
	7. Laboratory	Very heavy	Easy to implement and low cost involvement	Very heavy	Easy to implement and low cost involvement
	8. OPD	Slight to moderate	Easy to implement and low cost involvement	Moderate to heavy	Easy to implement and low cost involvement
	9. Wards	Slights to moderate	Easy to implement and low cost involvement	Moderate to heavy	Easy to implement and low cost involvement
	10. Operation theatre	Moderate to heavy	Difficult but low cost	Heavy to very heavy	Difficult but low cost
	11. Emergency department	Moderate to heavy	Easy to implement and low cost involvement	Heavy to very heavy	Easy to implement and low cost involvement
	12. Administration	Moderate to heavy	Easy to implement and low cost involvement	Heavy to very heavy	Easy to implement and low cost involvement

was found to be in an urgent need of repair for a smooth performance during and after an earthquake.

Regarding the hospitals outside the valley, almost all including the Western Regional Hospital, Koshi Zonal Hospital, Bheri Zonal Hospital and Seti Zonal Hospital have the same problems with the non-structural components. As in the hospitals of the Kathmandu Valley, these hospital buildings also need fixing of all equipment and contents in all wards and departments. None of these hospitals were found to have any provision of extra fuel tank for the backup power generators. The staffs were also not found to have been aware of earthquake vulnerability of the non-structural components in various wards and

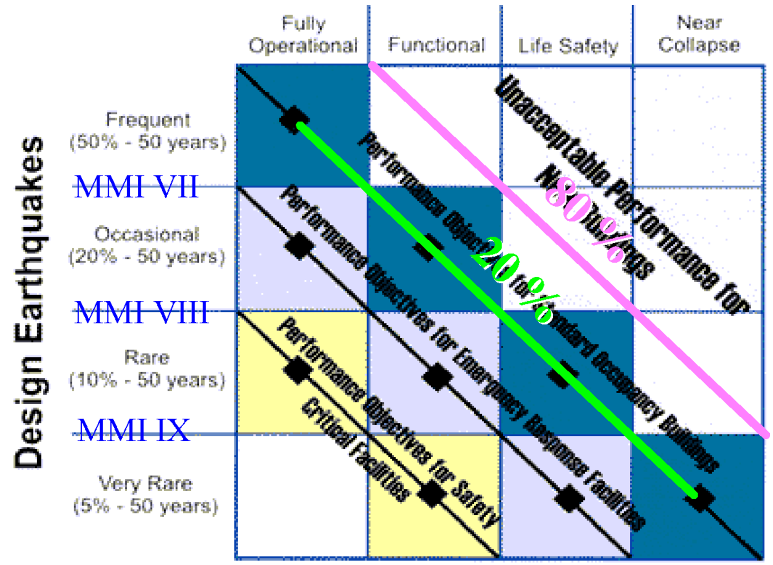

Figure 4. Risk assessment matrix for vulnerability assessment of major nine hospitals in Nepal (risk matrix modified after SEAOC 1995). This figure is prepared with the scenario earthquake and possible damage investigated during this work. Data in Table 4 is used for one hospital and similar data are used for other selected hospitals.

departments. Glass window panes were also not laminated and bracing of partition walls was not observed. Couplings in electricity and water supply systems were very weak. In all four zonal hospitals, there was no provision of redundancy in the critical system (i.e. extra generator, spare pumps, and so on).

The analysis also suggests that if an immediate action is taken to improve the abovementioned common non-structural issues of all nine hospitals, according to standard risk assessment matrix, the performances of the hospitals will be increased significantly (Figure 5). The analysis shows that about 90% of the assessed hospitals will be functional after a moderate earthquake but will go out of service after a severe earthquake, while 10% will be fully operational after a moderate earthquake and functional after a severe one. Figure 5 illustrates that the seismic performance of non-structural components of the hospitals in Nepal will be in acceptable range after enhancing the common non-structural issues of all

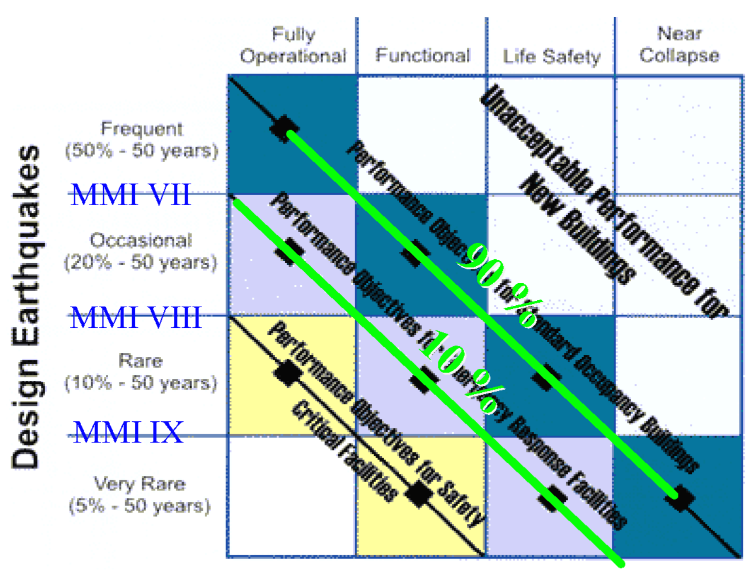

Figure 5. Estimated risk assessment matrix after improvement in common non-structural issues of all the nine hospitals (risk matrix modified after SEAOC 1995). This figure is prepared as per investigated results of scenario earthquakes and suggested improvement in non-structural components.

nine hospitals. Only, about 10% of the hospitals will be non-functional, unsafe and near to collapse stage after MMI XI level of earthquake and about 90% of the hospitals will be functional, safe and will not collapse during MMI VII level of earthquake.

6. Concluding remarks

A study of the earthquake catalogue in Nepal indicates that a devastating earthquake is inevitable in the long term and likely in the near future. Therefore, the non-structural assessment of critical public facilities such as hospital buildings is very important for an earthquake safe life in Nepal. This paper presented the findings of a non-structural earthquake vulnerability assessment and also discussed some important issues of non-structural components of nine major hospitals in Nepal.

The results showed an alarming situation and demanded an immediate action in most of the hospital buildings so as to achieve the standard acceptable level of safety. The study certainly helps to recommend a gradual approach of increasing the safety level considering the socio-economic condition of the country and the fact that medium-level earthquakes are more frequent than the severe ones.

This non-structural component assessment study largely helped to convince the government officials, hospitals authorities and political leaders on the affordability and possibility of constructing earthquake resistant non-structural components in the hospitals of Nepal using slight improvement in the already employed methods of construction.

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