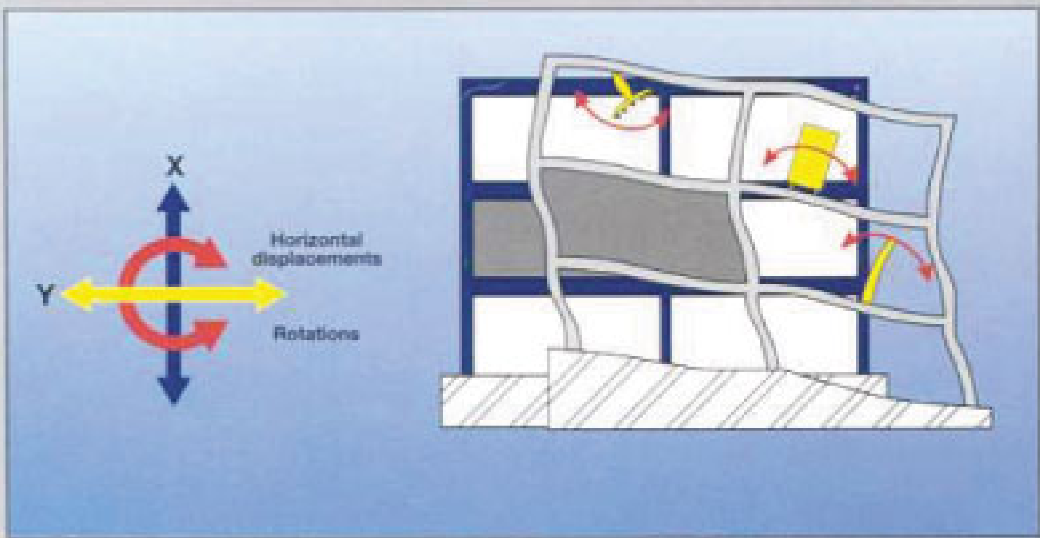
Mitigating Earthquake Risk
in Health Facilities

A Structural Vulnerability Assessment of Hospitals in Kathmandu Valley



World Health Organisation
Emergency & Humanitarian Action

Ministry of Health
Department of Health Services
Epidemiology & Disease Control Division

Kathmandu, Nepal
August 2002

Hon'ble Sharat Singh Bhandari
Minister for Health

His Majesty's Government
Ministry of Health
Ramshahpath, Kathmandu, Nepal

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Date: 6th Aug, 2002

Message from Honourable Minister of Health,
Mr. Sharat Singh Bhandari
Ministry of Health, Ram Shah Path

I congratulate the World Health Organization for producing this important study that helps us to realize the current health infrastructure in view of impending earthquake risk.

By detailing the seismic vulnerability of altogether 14 hospitals in Kathmandu Valley, the report provides valuable information for emergency planners. It is satisfying to know that almost all of the hospitals may withstand frequent earthquakes of small intensity without collapse and remain operational. However, when it comes to occasional earthquakes of moderate or high intensity the performance is a matter of great concern.

In order to counteract this threat, the Ministry of Health with the help of World Health Organisation have initiated a comprehensive emergency planning process through the Disaster Health Working Group. This study is in itself an outcome of the good collaboration. In the Ministry of Health a Focal Point for Disaster Management has been established so as to coordinate the inter-institutional activities in this regard.

I would like to assure that the Ministry of Health is committed to enhancing the emergency preparedness of the health sector.

To conclude, I extend my sincere appreciation to all for their valuable contribution to this important study.

Sharat Singh Bhandari
Ministry of Health

His Majesty's Government
Ministry of Health

HON'BLE MOHAN BAHADUR BASNET

State Minister

Personal Secretariat

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Ref.

Date : ....

26 July, 2002

Message from Honourable State Minister of Health
Mr. Mohan Bahadur Basnet,
Ministry of Health, Ram Shah Path.

I realize that this document has got immense value in initiating long-term measures aimed at reducing the seismic vulnerability of the health infrastructure in Nepal. I would like to thank the World Health Organisation and the Disaster Health Working Group for such an important study.

The report emphasises the importance of a reliable health infrastructure that can deliver curative care during and after various types of disasters.Although technical in nature, the report presents its findings in a non-technical manner that is easily understandable for laymen.

It is also satisfying to see that the report shares experiences from the Pan American Health Organization with us. All over the world, many hospital buildings have been damaged during earthquakes, leaving them non-functional for several months. In countries with scarce facilities such as Nepal, it is very important to ensure that hospitals remain operational during disasters.

It is up to the health planners to ensure that the recommendations are taken into serious consideration in future planning efforts so as to securing the lives during a disaster situation, especially in a situation like an earthquake.

I wish to assure His Majesty's Government's fullest commitments to support any initiative towards mitigating a disaster and also enhancing the preparedness capacity.

Mohan Bahadur Basnet
Hon'ble State Minister of Health

Minister of State for Health

His Majesty's Government

Ministry of Health

Phone: 2 - 62987 / 62590 / 62802 / 62706 / 62935 / 62862

Ref.No. ....

Ramshahpath, Kathmandu
Nepal

Date: 26 July, 2002

Message from the Health Secretary,
Mr. Mahendra Nath Aryal,
Ministry of Health, Ram Shah Path.

This report is once again a reminder of the fact that Nepal is located on top of a seismic fault that can produce a major earthquake at any given point of time. Emergency preparedness is much more cost-effective intervention than disaster relief activities.

The holistic study makes this report particularly interesting as it combines a structural analysis with a non-structural analysis and an evaluation of hospital emergency plans. Only when both structural performance and emergency services are taken into consideration, a reliable disaster response can be delivered. I am hopeful that all emergency planners in the health sector will take use of this report.

The risk of collapsing hospitals is serious issue. Therefore, immediate retrofitting of most critical facilities areas should be seriously considered. The report's recommendation of establishing an Earthquake Management System among hospitals deserves serious attention.

It is my sincere hope that these findings and recommendations will be fully utilised while enhancing the emergency preparedness of the health facilities in the country.

I express my heartfelt appreciation to all who are involved in the preparation of this report. This includes the World Health Organisation who has helped to initiate the assessment and disseminate the findings.

Mahendra Nath Aryal
Secretary, Ministry of Health

FOREWORD

The World Health Organisation is pleased to present the report *Structural Vulnerability Assessment of Hospitals in Kathmandu Valley* prepared in collaboration with the Ministry of Health and the National Society for Earthquake Technology – Nepal (NSET). The completion and documentation of this study is a major achievement as it provides critical information to the concerned authorities in Nepal. In addition, this path breaking study is likely to create a broader interest in the subject among hospital directors and health sector emergency managers in the South-East Asian Region.

A reliable health infrastructure is one of the keys to the successful management of emergencies. Health facilities play a critical role in maintaining life during and immediately following disasters. It is therefore important that hospitals remain functional throughout such emergencies. This report helps to develop an understanding of how to mitigate the consequences of earthquakes, which are broadly perceived as the major hazard confronting Nepal. As such, this study is a significant contribution to the ongoing emergency planning process in the country's health sector.

The experiences of the Pan-American Health Organisation have shown that the improvement of both the structural and non-structural aspects of hospital buildings produce high economic and social returns. The mitigation of risk not only increases the reliability of health services (and thus the number of lives saved) during emergencies but is also a highly cost-effective intervention compared to disaster response.

We have been fortunate to receive the assistance of structural engineer Mr. Jaime Argudo, who played a vital role in the transfer of knowledge from the Americas to Asia. For this study, he developed a unique and holistic approach to assess hospital vulnerability, resulting in this most useful document.

At the national level, we benefited from close collaboration with NSET – Nepal, an internationally renowned organisation working in the field of earthquake mitigation. NSET – Nepal assisted in the conceptualisation and implementation of the study. Without the dedication and expertise of the General Secretary, Mr. Amod M. Dixit, and his team of engineers, Mr. Ramesh Guragain, Mr. Ram Chandra Kanel and Mr. Sury Narayan Shrestha, this study would not have been possible.

We deeply appreciate the efforts of Dr. R. P. Shrestha, Dr. M. B. Bista and Dr. G. P. Ojha of the Ministry of Health who had the vision to authorise this pioneering study. Without their invaluable support, Mr. Jaime Argudo and NSET – Nepal would not have been able to carry out the activities delegated by WHO, in response to a request made by His Majesty's Government of Nepal.

Although this report is a significant achievement, we are aware that it only represents the first stage of the implementation of long-term initiatives aimed at reducing the seismic vulnerability of the health infrastructure in Nepal.

Dr. Klaus Wagner
WHO Representative to Nepal

PREFACE

This report summarises the study and assessment of the structural vulnerability of hospitals in Kathmandu Valley, Nepal.

Chapter 1 introduces the background and Chapter 2, the objectives and goals of the study. Chapter 3 describes the approach, Chapter 4 the methodology, and Chapter 5 the seismic hazard and design ground motion with which the structural vulnerability assessment was carried out.

The results of the evaluation of the earthquake performance of 14 hospitals are presented in Chapter 6, and recommendations to improve the structural design of new hospitals and earthquake response in the health sector are addressed in Chapters 7 and 8.

In Chapter 9, a programme for improving the earthquake resilience of existing hospitals is proposed. The implementation of such a programme will contribute, to a large extent, to saving lives and mitigating earthquake risk in health facilities in Nepal. The programme was designed on a cost-effective basis.

This report also includes eleven appendices that provide information relating to additional works conducted by the consultant: building local capacities (Appendix 1), evaluation of the earthquake performance of ordinary buildings (Appendix 2), mass casualty simulation (Appendix 3), soil liquefaction and site effect evaluation (Appendices 4 and 5), definition of terms (Appendix 6), and a detailed structural vulnerability assessment of five major hospitals in Kathmandu Valley (Appendices 7 to 11).

Jaime F. Argudo
Structural Engineer and Consultant
Emergency & Humanitarian Action
World Health Organisation Nepal

DISCLAIMER

This report assesses the potential earthquake damage to health institutions in Kathmandu Valley. Since the timing, location and intensity of seismic events cannot be accurately predicted, some uncertainty regarding the actual consequences remains. The report is intended only for use in health sector planning, mitigation and preparedness. The publishers and contributors are not responsible for use beyond these purposes.

ACKNOWLEDGMENTS

The consultant expresses his sincere gratitude to the following institutions and people who supported the consultant's mission and contributed to the assessment and preparation of this report:

The Ministry of Health of Nepal, and its Epidemiology and Disease Control Division from the Department of Health Services (EDCD).

The World Health Organisation through The Pan-American Health Organisation (PAHO), The South East Asian Regional Office (SEARO), and its Representative Office in Nepal.

The National Society for Earthquake Technology – Nepal (NSET).

The Disaster Health Working Group of Nepal.

Directors, emergency chiefs, and maintenance engineers of hospitals in Kathmandu Valley.

Dr. Mahendra B. Bista (Director of EDCD) from the Department of Health Services.

Dr. Klaus Wagner (WHO Representative to Nepal), Dr. Luis J. Perez (PAHO - SEARO) and Mr. Erik Kjaergaard (Nepal) from the Emergency and Humanitarian Action Programme of the World Health Organisation (EHA).

Mr. Shiva B. Pradhanang (President), Mr. Amod M. Dixit (General Secretary), Mr. Mahesh Nakarmi (Project Manager), Mr. Ram Kandel (Civil Engineer), and Mr. Ramesh Guragain (Structural Engineer) from NSET.

Miss Lise Ganloese (intern) and Miss Trine Ladegaard (intern) from EHA Nepal.

Miss Helen Shipley (intern) and Mr. Erik Kjaergaard from EHA Nepal who edited the final manuscript in consultation with Dr. Lin Aung (SEARO) and Dr. Luis J. Perez (PAHO).

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Chapter 1

INTRODUCTION

Nepal is a country highly prone to earthquakes. According to historical evidence, Nepal has experienced nine major earthquakes during the last 700 years. Recurring earthquakes during the 20th century have claimed more than 11,000 lives[11].

The seismic record of the region extends back to 1255AD, and suggests that earthquakes like the Great Bihar-Nepal Earthquake in 1934 occur approximately every 75 years, indicating that a devastating earthquake is inevitable in the long run and likely in the near future. The Kathmandu Valley Earthquake Risk Management Action Plan (NSET & GeoHazards, 1999) estimates that as many as 60% of the buildings in Kathmandu Valley are likely to be heavily damaged if the shaking of the 1934 earthquake is repeated today.

The experiences of the Pan-American Health Organisation (PAHO)[13, 16, 23] in the Americas, have shown the high economic and social returns of improving the structural and non-structural behaviour of vulnerable hospital buildings. It is highly cost-effective to mitigate risk before an earthquake strikes. Structural retrofitting and non-structural measures can save lives and significantly increase the reliability of services in health facilities.

To start long-term initiatives addressing the reduction of seismic vulnerability in the health infrastructure of Nepal, the Emergency and Humanitarian Action programme of the World Health Organisation (EHA) and the Epidemiology and Disease Control Division, Department of Health Services (EDCD), Ministry of Health, decided to implement a comprehensive structural assessment of selected hospitals and to develop a programme for improving the earthquake resilience of the current health infrastructure.

EHA Nepal requested the South East Asian Regional Office of the World Health Organisation (SEARO) to appoint a consultant to conduct this study. SEARO in collaboration with PAHO, designated a structural engineer for a 2-month assignment in Nepal.

The assessment took place from October to December 2001 and was conducted by the consultant in collaboration with EHA Nepal and the National Society for Earthquake Technology (NSET).

Chapter 2

OBJECTIVES AND GOALS

In accordance with the consultant's terms-of-reference and the aim of the assessment, the following objectives and goals were planned and achieved:

a) Development of a programme to both improve the earthquake resilience of the existing health infrastructure and to identify appropriate measures for improving the structural and non-structural performance of existing buildings.

b) Dissemination of the findings at public seminars in order to facilitate the implementation of the identified earthquake risk reduction measures.

   The findings and recommendations were presented to the following focal groups: The Ministry of Health and hospital directors, the heads of UN agencies and the UN Disaster Management Team, the Disaster Health Working Group, the health sector (represented by emergency chiefs and maintenance engineers from 14 major hospitals), and the technical sector (represented by structural designers, university professors, and representatives from the engineering and architectural sectors).

c) Development of a comprehensive format covering all aspects of an assessment of the structural vulnerability of hospital buildings and health institutions in Nepal. A selection of the most critical hospitals / health institutions to be structurally assessed, and the implementation of a structural assessment of at least five major hospitals.

d) Compilation of a comprehensive report detailing procedures and presenting findings and recommendations.

e) Training of NSET engineers, transfer of technology and building of local capacity in the country.

f) Increase the awareness of the hospitals' structural vulnerability among politicians, city officials, hospital directors, emergency chiefs, hospital maintenance personnel, and representatives from engineering and architectural societies.

Chapter 3

APPROACH

The study's approach was systemic and holistic. Structures were assessed based on an understanding that they are connected to other hospital systems.

The structure is an essential part of hospital facilities. It acts like the skeleton of the human body, supporting non-structural components such as architectural elements (infill non-bearing walls, parapets, windows, etc.), equipment and lifeline systems (utilities, medical gases, etc.).

Most of the non-structural components are connected to building structure in such a way that the structural system transfers earthquake displacements and forces on to them. The structural behaviour of the buildings greatly influences non-structural performance.

All over the world, many hospital buildings have been designed to comply with a life-safety objective. However, the interaction between structural and non-structural systems is not usually evaluated and the assurance of hospital functionality is not a design objective. As a consequence, heavy non-structural damage is frequently experienced during earthquakes. The loss of hospital services for months or years is a common result.

A holistic and systemic vision implies that the final outcome of the structural assessment should be a qualification of both building performance and the reliability of hospital services, not simply an assessment of the capacity of structures to withstand earthquakes.

To qualify building performance, a brief non-structural vulnerability assessment was conducted in hospitals. This assessment mainly focused on the reliability of lifeline systems, and was later combined with the structural vulnerability assessment to qualify the reliability of hospital services after earthquakes.

A non-structural assessment evaluates the expected damage to lifeline systems, architectural elements (infill non-bearing walls, parapets, etc.) and equipment. The damage to lifeline systems depends on many factors, but most of these factors are related to structural behaviour, elements at risk (the main features of the lifeline systems), maintenance quality during normal operation time, and external factors such as the reliability of the city utilities networks.

PAHO[23] recommends a fully-operational performance level for the design basis ground motion - a rare and big earthquake that has a 10 percent probability of being exceeded within 50 years of a building's occupancy.Such a design ground motion corresponds to an intensity MMI = IX earthquake in Kathmandu Valley. Particular earthquake levels for which a building's performance is to be attained were selected according to the valley's seismic hazard and are presented in Chapter 5.

The following standard performance level definitions from Vision 2000, proposed by the Structural Engineers' Association of California (SEAOC), were used to qualify hospital building performance:

Standard Performance Level Definitions According to Vision 2000 (SEAOC, 1995) [19,20,21,22]

Designation	Description
Fully Operational	Only very minor damage has occurred. The building retains its original stiffness and strength. Non-structural components operate, and the building is available for normal use. Repairs, if required, may be instituted at the convenience of the building users. The risk of life-threatening injury during the earthquake is negligible.
Functional	Only minor structural damage has occurred. The structure retains nearly all its original stiffness and strength. Non-structural components are secure, and if utilities are available, most would function. Life-safety systems are operational. Repairs may be instituted at the convenience of the building users. The risk of life-threatening injury during the earthquake is very low.
Life Safety	Significant structural and non-structural damage has occurred. The building has lost a significant amount of its original stiffness, but retains some lateral strength and margin against collapse. Non-structural components are secure, but may not operate. The building may not be safe to occupy until repaired. The risk of life-threatening injury during the earthquake is low.
Near Collapse	A limiting damage state in which substantial damage has occurred. The building has lost most of its original stiffness and strength, and has little margin against collapse. Non-structural components may become dislodged and present a falling hazard. Repair is probably not practical.

The performance level recommended by PAHO should only be applied to the design of new hospital buildings. In this assessment the performance of the buildings of each hospital is qualified according to the expected behaviour of structural and non-structural systems.

The building-performance of hospitals in Kathmandu Valley was found to be far below the performance level recommended by PAHO. In many cases it was found to be similar or slightly better than that of ordinary buildings, and in some cases below the acceptance level (near collapse).

Chapter 4

METHODOLOGY

The assessment methodology is summarised as follows:

1. Definition of seismic hazard and design basis ground motion based upon previous studies and building design codes (Chapter 5).

2. Evaluation of soil condition. Soil liquefaction and site-amplification effects were studied (Appendices 4 and 5).

3. Reconnaissance of 14 hospitals. More than 30 hospital buildings were inspected in order to conduct the vulnerability assessments.

   There are approximately 50 hospitals in Kathmandu Valley, including private facilities. The selected group is composed of every hospital with 50 or more beds and essential facilities (an emergency department and operating theatres).

   After inspecting this large number of hospitals, it was possible to select the five most critical facilities (the most important facilities from a disaster management perspective) to be structurally assessed in detail.

4. Identification of building design criteria and structural systems. Calculation of design shear forces and checking of stress in ground floor columns or bearing walls.

   Identification of structural vulnerability factors in hospitals, such as problems related to seismic joints, plan and vertical irregularities, and lack of strength in the ground floor level, among others.

5. General evaluation of the earthquake performance of hospitals in Kathmandu Valley. In a comprehensive format, a general reliability assessment of 14 hospitals in Kathmandu Valley was carried out (Chapter 6). Each hospital's building-performance was determined according to Vision 2000 [21, 22] definitions, through which the reliability of services in hospitals was finally evaluated.

   This assessment provided suitable data for the formulation of recommendations for improving the structural design of new hospitals and earthquake response in the health sector (Chapters 7 and 8), and to develop a programme for improving the earthquake resilience of the existing health infrastructure (Chapter 9).

6. To understand the potential size of medical-care demand after an earthquake, estimation of damage to building stock and mass casualty simulations were conducted for a number of earthquakes of different intensities (Appendices 2 and 3).

7. Evaluation of the earthquake performance of major hospitals in Kathmandu Valley. The five most important hospitals (Bir, Army, Teaching, Patan and Bhaktapur) were selected and detailed qualitative structural assessments were conducted.

   Comprehensive reports were issued detailing the findings and recommendations for the selected hospitals. These reports are presented in Appendices 7 to 11.

8. Training of engineers from NSET, transfer of technology and building of local capacity in the country. A quantitative analysis of Bir Hospital was carried out by NSET engineers under the consultant's guidance. This numerical analysis provides suitable data for designing the structural retrofitting of Bir Hospital (Appendix 1).

9. Development of a programme for improving the earthquake resilience of the existing health infrastructure (Chapter 9).

   Future steps and priorities to reduce seismic vulnerability in the health infrastructure of Kathmandu Valley are identified. Appropriate measures for improving the structural and non-structural performance of existing buildings are recommended for the five major hospitals (Appendices 7 to 11).

10. Finally, this report is issued, detailing procedures and presenting the findings and recommendations in a comprehensive format.

Chapter 5

SEISMIC HAZARD AND DESIGN GROUND MOTION

SEISMIC HAZARD

There are two detailed studies assessing seismic hazard in Kathmandu Valley:

a) Seismic Hazard Mapping and Risk Assessment for Nepal (UNDP / UNCHS (Habitat), 1994); and,

b) The Study on Earthquake Disaster Mitigation in the Kathmandu Valley, Kingdom of Nepal (Nippon Koei & Oyo, 2001).

Although the results from both studies are not exactly the same, they are very similar in terms of seismic zoning. Kathmandu Valley should be considered as lying in Zone 4 according to the Uniform Building Code, 1997 (UBC-97)[10].

It would be very liberal to classify the area as Zone 3 considering the high historical seismic activity and the soil dynamic characteristics within the valley. Combining information from different studies, the Kathmandu Valley seismic hazard is summarised in the following table:

Kathmandu Valley Seismic Hazard

Earthquake Intensity Modified Mercalli Scale (MMI)	Probability of Occurrence within the Next 50 Years	Mean Return Period (Years)	Peak Ground Acceleration (%G)
VI	More than 66%	10 – 50	3 – 9
VII	30 to 66%	50 – 100	9 – 20
VIII	10 to 30%	100 – 475	20 – 35
IX	Equal or less than 10%	More than 475	> 35

In the past recorded intensities were larger, for example the MMI = X recorded during 1934's earthquake. World-wide, historical records have usually overestimated earthquake intensities by one degree as a result of the wrong application of the Mercalli intensity rules. Extreme damage rather than statistical damage has been used to quantify earthquake intensities.

DESIGN BASIS GROUND MOTION

This is the ground motion that has a 10 percent probability of being exceeded within 50 years, as determined by a site-specific hazard analysis or from a hazard-zoning map.

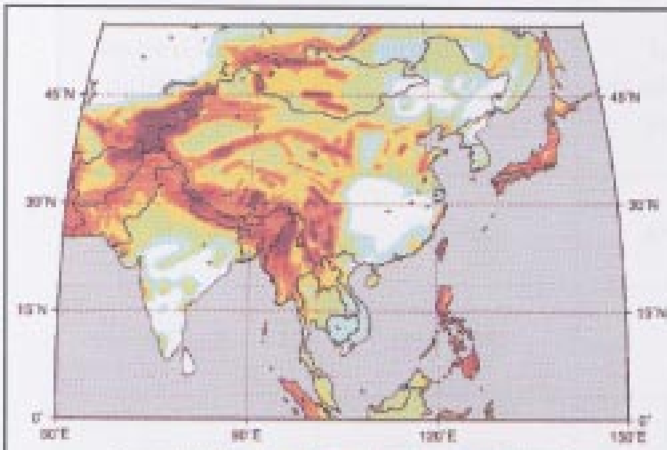
SEISMIC ZONING OF KATHMANDU VALLEY

According to UBC-97[10], Seismic Zone 4 necessitates the use of a peak ground acceleration of 0.4 g (3.924 m/s^2) when designing earthquake resistant structures against the design basis ground motion.

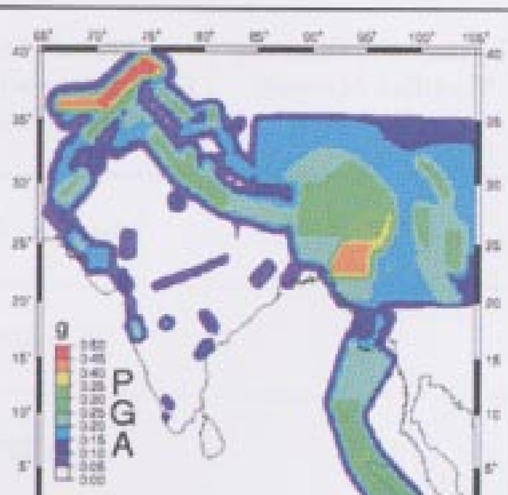
Various earthquake zoning studies assign Kathmandu Valley peak ground accelerations ranging from 0.3 g to 0.45 g, which corresponds to a Modified Mercalli Intensity MMI = $VIII^{+}$-IX^{-}.

From the Munich Re. Group database[8] it can be concluded that MMI = IX is the maximum intensity that can be expected on Kathmandu Valley fluvio-lacustrine-deposits, and MMI = VIII should be assumed on bedrock surrounding the Kathmandu metropolitan area.

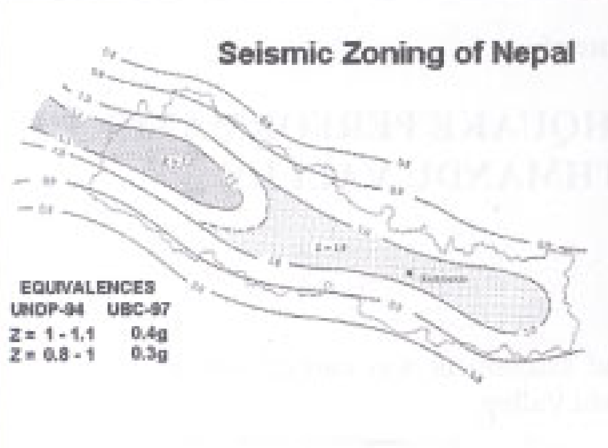
Seismic Zoning of South East Asia



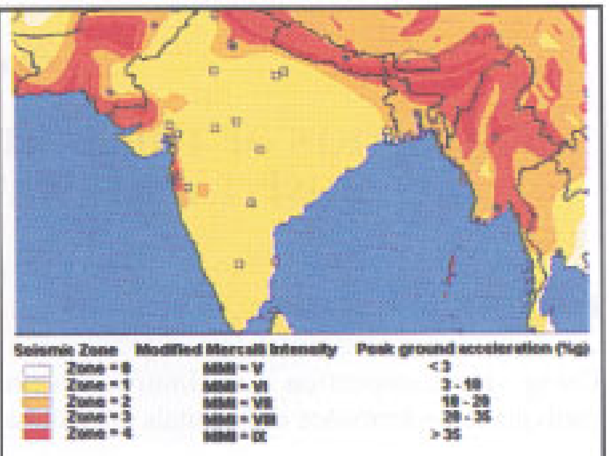
Source: International Lithosphere Programme (ILP), 1999.



Source: National Geophysical Research Institute, Hyderabad, India.



Source: UNDP / UNCHS (Habitat), 1994.

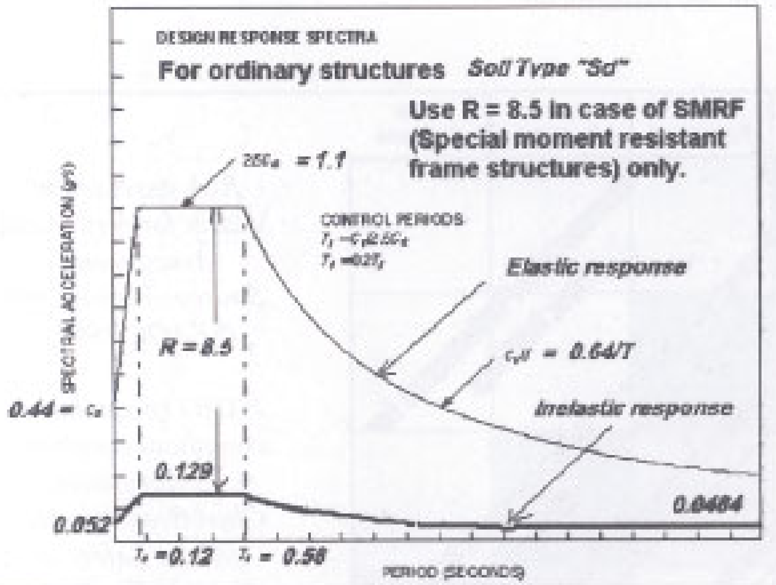


Source: Munich Re. Group, 2001.

DESIGN RESPONSE SPECTRA

According to the UBC-97 soil classification and soil profiles found in Kathmandu Valley, soil type S_D should be used in most of the areas of Kathmandu and Lalitpur municipalities, except for those where soil liquefaction potential is high.

Soil type S_E should be used in Bhaktapur Municipality, and soil type S_F in those areas within the valley where soil liquefaction potential is high.



Design Response Spectra for soil type S_D in Kathmandu Valley, based on UBC-97 specifications [10].

For each project, the Design Response Spectra should be developed according to the soil profile found at the site.

When there is a lack of information S_D type can be used, except for places where soil liquefaction potential is high..

Chapter 6

EVALUATION OF THE EARTHQUAKE PERFORMANCE OF HOSPITALS IN KATHMANDU VALLEY

PURPOSE AND SCOPE

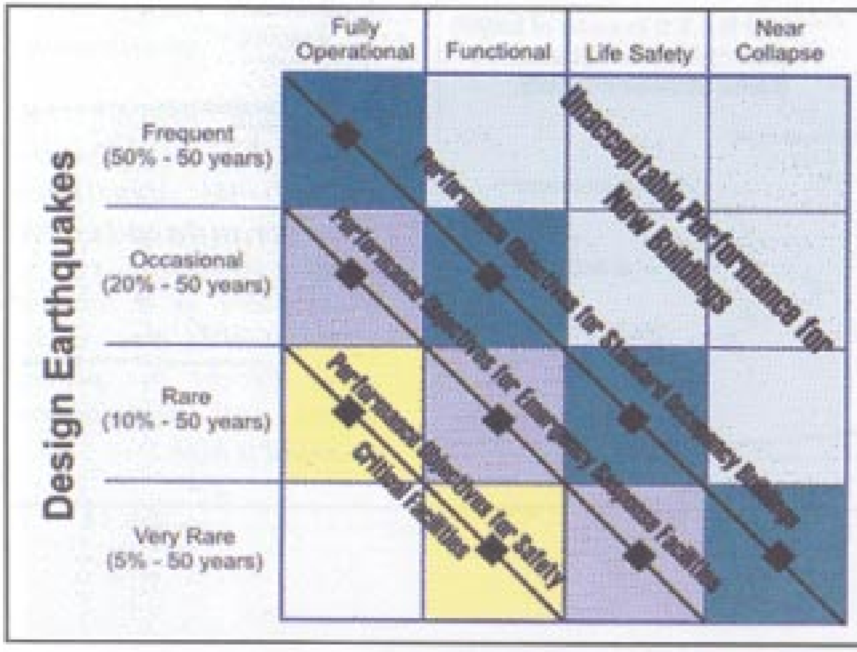
Using visual inspection a qualitative structural assessment was carried out to estimate the earthquake performance of hospitals in Kathmandu Valley.

There are approximately 50 hospitals in Kathmandu Valley, from which 14 hospitals were chosen for the purpose of this evaluation. The selected group is composed of hospitals of 50 or more beds with emergency facilities and operating theatres. Nine of the hospitals are governmental, and five are non-governmental or private.

The purpose of this evaluation is for emergency planning only. This assessment cannot be used as a seismic prediction, but it can be used to understand the general earthquake performance of hospitals in Kathmandu Valley. The assessment was based on expert criteria and follows the approach and methodology defined in Chapters 3 and 4.

Detailed structural assessments were conducted at the five major hospitals (Bir, Army, Teaching, Patan and Bhaktapur). For these facilities, the findings and recommendations for mitigation of earthquake risk are presented in Appendices 7 to 11.

The following risk acceptance matrix, proposed by the Structural Engineers Association of California (SEAOC)[22], was used for the assessments:



Risk Assessment Matrix for Structural Assessment. Source: Vision 2000 (SEAOC,1995).

PAHO recommends compliance with the Performance Objectives specified for the Safety of Critical Facilities.

Hospitals Assessed in Kathmandu Valley (50 or more Beds)

	Hospital Name	Site	Description of Buildings within the Hospital	Building's Material Type
1	Bir Hospital	Mahaboudha	Two 5-storey rectangular plan ("New" buildings)	RC
			4-storey "I" plan (Old building)	RC
			5-storey "L" plan (ICU building)	BC
			3-storey "V" plan (VIP-Burns unit building)	BC
2	Army Hospital	Chauni	3-storey irregular plan	RC
		Mohaboudha	2-storey rectangular plan	BM
3	Birendra Police Hospital	Maharajganj	3-storey rectangular plan	RC
4	Sukra Raj Tropical & Infectious Disease	Teku	2-storey irregular plan	BC
			3-storey rectangular plan	RC
5	Kanti Hospital	Maharajganj	2-storey irregular plan	BC
			2-storey irregular plan	RC
6	Maternity Hospital	Thapathali	3-storey irregular plan	BC
			2-storey irregular plan	BL
			5-storey irregular plan	RC
7	Patan Hospital	Lagankhel	4-storey irregular plan	RC
			1-storey irregular plan	RC
8	Bhaktapur Hospital	Dudh Pati	3-storey irregular plan	BC
			1-storey rectangular plan	RM
9	Teaching Hospital	Maharajganj	2 to 4-storey irregular plan	RC
10	Nepal Medical College	Aterkhel	2-storey rectangular plan	RC
			8-storey irregular plan	RC
			1-storey rectangular plan	BC
11	Kathmandu Medical College	Sinamangle	7-storey irregular plan	RC
12	Medicare National Hospital & Research Centre	Naxal	Two 4-storey irregular plan	RC
			1-storey regular plan	RC
13	B & B Hospital	Gwarko	6-storey irregular plan	RC
14	Model Hospitals	Baghbazar	3-storey irregular plan	BM
			5-storey regular plan	RC

RC = Reinforced concrete, BM = Brick in mud, BC = Brick in cement mortar, RM = Reinforced masonry, BL = Brick in lime mortar.

Earthquake Performance Assessment of Hospitals in Kathmandu Valley

Hospital		Expected Structural Damage	
		MMI = VIII	MMI = IX
Bir Hospital	Two 5-storey rect. plan	Substantial to Heavy	Very Heavy
	4-storey "I" plan	Very Heavy	Destruction
	5-storey "L" plan	Destruction	Destruction
	3-storey "V" plan	Substantial to Heavy	Very Heavy
Army Hospital	3-storey Chauni	Moderate	Substantial to Heavy
	2-storey Mohaboudha	Negligible to Slight	Moderate
Birendra Police Hospital	3-storey rectangular plan	Very Heavy	Destruction
Sukra Raj Tropical & Infectious Disease	2-storey irregular plan	Substantial to Heavy	Very Heavy
	3-storey rectangular plan	Moderate	Substantial to Heavy
Kanti Hospital	2-storey BC	Substantial to Heavy	Very Heavy
	2-storey RC	Negligible to Slight	Moderate
Maternity Hospital	3-storey BC	Very Heavy	Destruction
	2-storey BL	Substantial to Heavy	Very Heavy
	5-storey RC	Very Heavy	Destruction
Patan Hospital	4-storey irregular plan	Moderate	Substantial to Heavy
	1-storey irregular plan	Negligible to Slight	Moderate
Bhaktapur Hospital	3-storey irregular plan	Substantial to Heavy	Very Heavy
	1-storey rectangular plan	Negligible to Slight	Moderate
Teaching Hospital	2 to 4-storey irregular plan	Negligible to Slight	Moderate
Nepal Medical College	2-storey rectangular plan	Moderate	Substantial to Heavy
	8-storey irregular plan	Very Heavy	Destruction
	1-storey rectangular plan	Negligible to Slight	Moderate
Kathmandu Medical College	7-storey irregular plan	Substantial to Heavy	Very Heavy
Medicare National Hospital & Research Centre	Two 4-storey irregular plan	Substantial to Heavy	Very Heavy
	1-storey regular plan	Negligible to Slight	Moderate
B & B Hospital	6-storey irregular plan	Substantial to Heavy	Very Heavy
Model Hospitals	3-storey irregular plan	Substantial to Heavy	Very Heavy
	5-storey regular plan	Destruction	Destruction

***Major governmental general hospitals**: Bir, Army, Teaching and Patan.*
***Other governmental hospital:** Bhaktapur (District & General), Birendra Police (General), Maternity, Kanti (Children), Teku (Tropical & Infectious Diseases).*
***Non-governmental and private hospitals:** B&B, Nepal Medical College, Kathmandu Medical College, Medicare National Hospital & Research Centre and Model Hospitals.*

RESULTS AND CONCLUSIONS

The following matrix, proposed by the consultant, was used to estimate the functional status of hospitals under a given structural damage category.

Estimated Functional Status of Hospitals after an Earthquake

No.	Damage Category	Description of Functional Status of Lifeline Systems	Hospital Status
1	NEGLIGIBLE TO SLIGHT	Most of the lifeline systems may be fully functional. The few damaged systems may be recovered within hours.	Fully operational
2	MODERATE	Many of the lifeline systems may be fully functional. The damaged systems may be recovered within hours or days.	Partially functional
3	SUBSTANTIAL TO HEAVY	Few of the lifeline systems may be functional. Many of the damaged systems may be recovered within hours or days, others in weeks or months. Building will not be used for days, weeks or months due to moderate structural damage.	Out of service for weeks or months
4	VERY HEAVY	None of the lifeline systems are expected to function. The building will not be used for a long time, if ever, due to heavy or very heavy structural damage.	Out of service for years, or forever
5	DESTRUCTION		

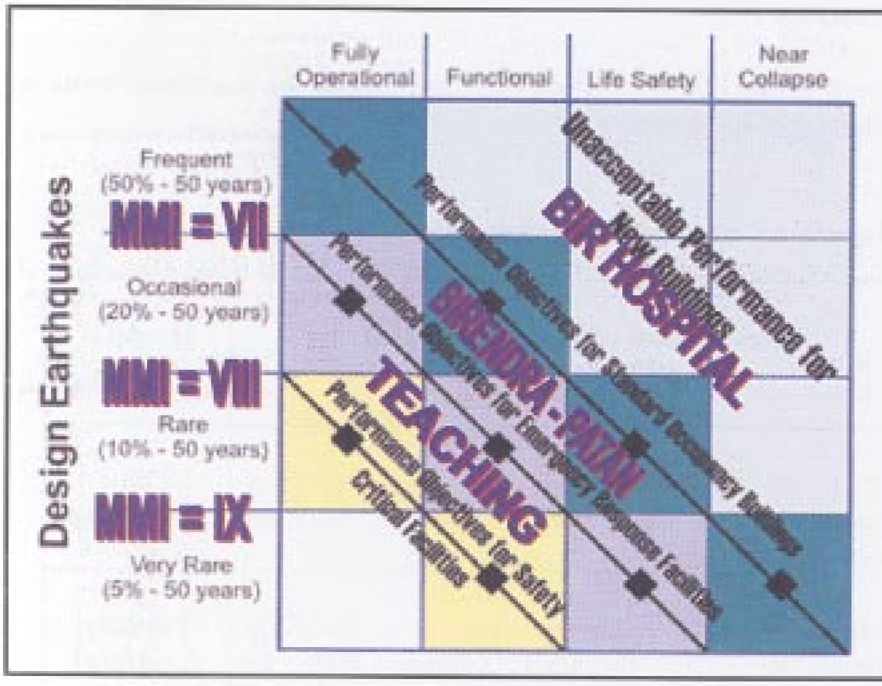
Finally, the following conclusions were drawn:

a) ***Frequent earthquakes of small intensity (MMI = VII):*** All or almost all of the hospitals may withstand the earthquake without collapse, 70% may be fully operational, and 30% partially functional.

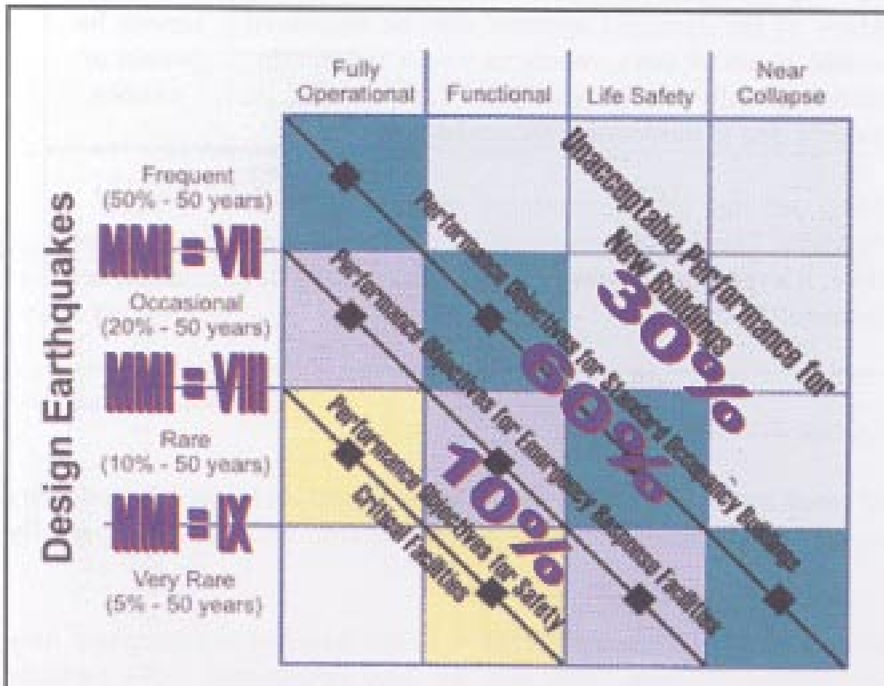
b) ***Occasional earthquakes of moderate intensity (MMI = VIII):*** Most of the hospitals may withstand the earthquake without collapse, 10% may be fully operational, 30% partially functional, and 60% out of service, a few of them (10%) may collapse.

c) ***Rare earthquakes of high intensity (MMI = IX):*** Many hospitals may withstand the earthquake without collapse, only 10% will be partially functional, 60% may be out-of-service in complying with a life-safety performance, and 30% of the structures may collapse.

Earthquake Performance of Governmental Hospitals in Kathmandu Valley



Building performance of major hospitals in Kathmandu Valley.



Building performance of governmental hospitals (Bir, Maternity and Police hospitals out of the acceptance level).

Chapter 7

RECOMMENDATIONS FOR IMPROVING THE STRUCTURAL DESIGN OF NEW HOSPITALS

1. In the case of reinforced concrete (RC) buildings, the seismic design forces need to be increased from 50% to 100%. Currently, hospitals in Nepal are designed for a seismic coefficient equal to or less than 0.12. A maximum coefficient equivalent to a horizontal acceleration of 12% of gravity's acceleration is considered insufficient according to the seismic hazard of Nepal. It is recommended that a maximum seismic coefficient of from 0.18 to 0.24, depending on the type of structural system that is to be chosen, is used.

2. It is necessary to improve the quality of building material. A minimum compressive strength of 21 MPa should be used when designing reinforced concrete structures. Currently, a design strength not greater than 18 MPa is generally specified. Moreover, because of poor quality control and lack of equipment for precise measurement and mixing of concrete aggregates, the real strength is usually less than 80% of the designed strength.

   In the case of masonry structures, bearing walls should be reinforced with steel bars, instead of being constructed without any reinforcement. Cement mortar should also be improved in quality. It is normal practice in Nepal to prepare mortar by mixing one part of cement with six parts of sand (1:6). A cement mortar in a ratio equal to or less than 1:3 is recommended.

3. Reinforced concrete (RC) structures with moment-resistant-frame systems were commonly found in hospitals constructed during and after the 1970's and such systems are likely to be used in future hospitals. Based on the seismic hazard in Nepal, it is strongly recommended that special-moment-resistant-frame (SMRF) systems are designed whenever an hospital building is to be constructed with RC frames. SMRF systems should comply with the specifications from UBC-97 and ACI-99 American Codes, including the seismic provisions indicated for the design of structures in Seismic Zone 4.

   The above codes allow the construction of SMRF without height restrictions. As codes are minimum requirements and hospitals essential structures, it is also recommended that hospital buildings more than 5 storeys high are built using dual systems instead of moment-resistant-frame-systems. Dual systems use shear walls, which are more effective than frames at controlling storey displacements, limiting non-structural damage and protecting a hospital's ability to function.

4. It is also recommended that low rise structures (4 storeys or less) of rectangular plan are built instead of high rise and complex structures. If complex buildings have to be constructed, the vertical and plan irregularities described in Appendix 6 should be avoided and seismic joints need to be used where necessary.

   The design and construction of seismic joints needs to be improved in Nepal. In most buildings seismic joints were not found where necessary, were found closed by tiles, walls or parapets, or the gaps were designed in short lengths. As a result, it can be expected that a buildings' earthquake performance will not be the same as that designed. In some cases structural and non-structural damage will be significantly increased by problems related to seismic joints.

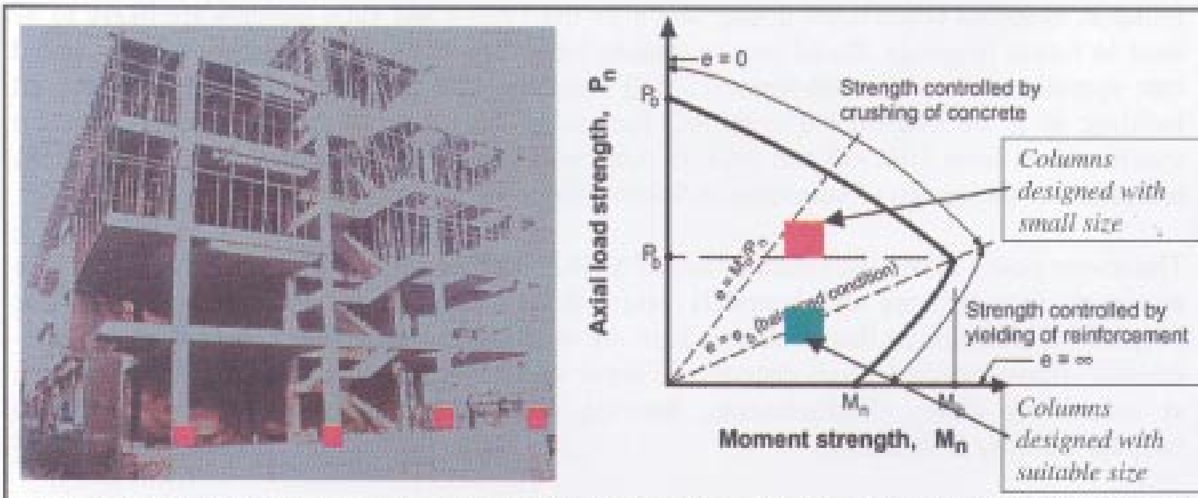
5. Column design should be improved in RC moment-resistant-frame-structures.

   It is normal practice in Nepal to build columns of the same size from the ground to the top floor, and to use columns of much smaller size than necessary on the ground floor level.

   Nowadays, a cost-effective earthquake design in countries located in Seismic Zone 4 such as Nepal, Ecuador, Japan and USA, can be achieved by gradually and smoothly decreasing the dimensions of columns and beams up the building. The size of the columns should also be large enough to provide a ductile strong-column / weak-beam mechanism, which allows the structure to experience the damage governed by flexure without collapsing, thus increasing life safety.

   In some hospital buildings and most of the ordinary buildings in Kathmandu Valley the size of columns was found to be insufficient at the lower levels. The use of small columns in moment-resistant-frame-structures reduces strength capacity and ductility to withstand moderate and high intensity earthquakes (MMI = VIII–IX) and was found to be one of the major potential causes of building collapse in RC structures.

   When column size is insufficient, the failure mechanism is fragile, without ductility, and is controlled by compression and shear. Buildings built with small columns will collapse in a "pancake" mode (slab on slab) and the life-safety target is not achieved.



Buildings in Kathmandu constructed in RC frame structures are usually designed with small columns controlled by shear and compression (crushing of concrete without ductility). This is critical on the ground floor level where a building's collapse is prone to be triggered. Columns to be controlled by bending (yielding of reinforcement with ductile behaviour) must be larger, with cross-sectional areas approximately double those that are normally used.

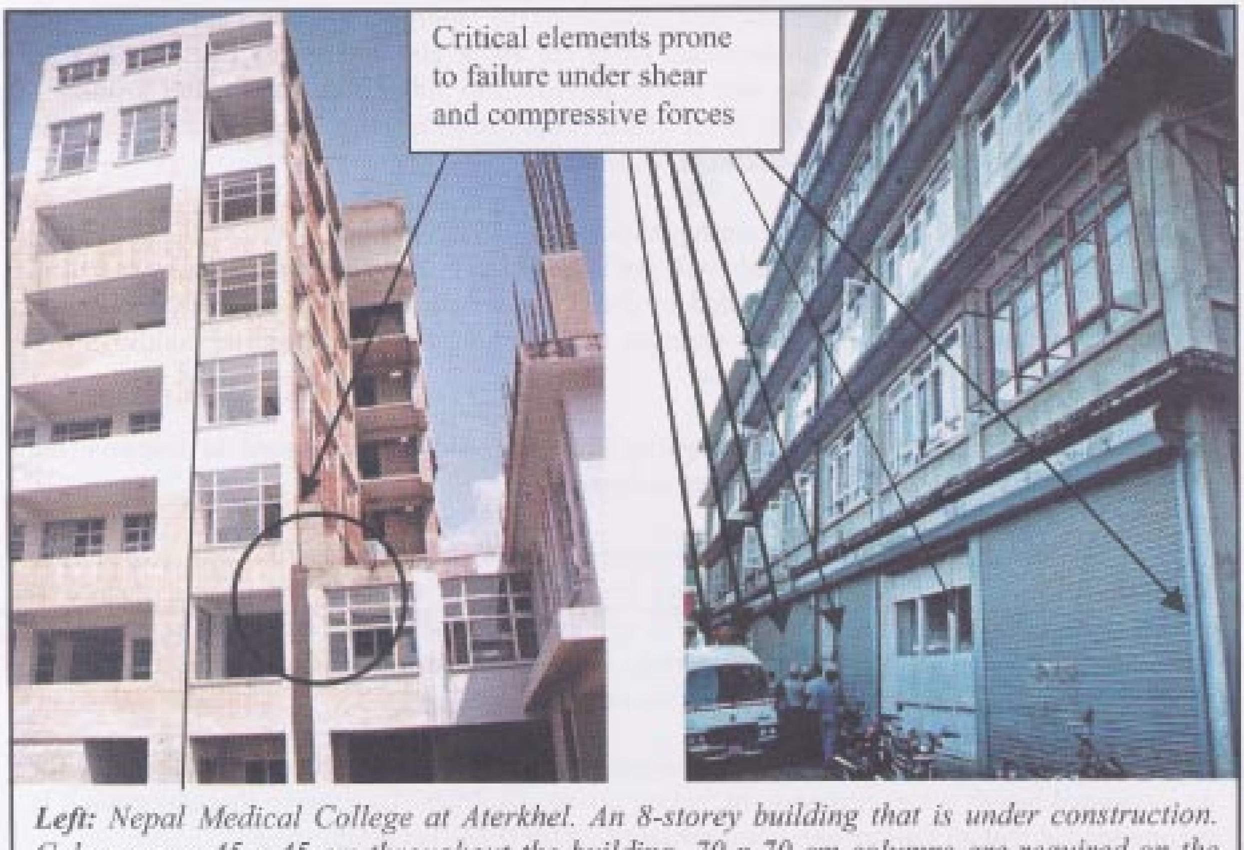
Larger columns than those normally used in Kathmandu need to be designed and constructed. The small size of columns is critical at the ground floor level, where a weak storey can usually be found and a building's collapse is expected to be triggered.

Structures in which a weak ground floor is combined with other structural vulnerability factors, such as low-quality concrete, can experience a catastrophic collapse even during less strong earthquakes (MMI = VII).

Birendra Police Hospital

Columns are 23 x 23 cm (9 x 9 inches) in size, from ground to top floor.

They should be 40 x 40 cm at the ground floor, 35 x 35 cm at the first floor, and 30 x 30 cm at the top (second) floor.



Left: *Nepal Medical College at Aterkhel. An 8-storey building that is under construction. Columns are 45 x 45 cm throughout the building. 70 x 70 cm columns are required on the ground floor.* ***Right:*** *Model Hospital's surgery block at Baghbazar. A 5-storey building with 23 x 23 cm columns. On the ground floor 50 x 50 cm columns are required. Private hospitals are usually designed like ordinary buildings using RC structures.*

Chapter 8

RECOMMENDATIONS FOR IMPROVING EARTHQUAKE RESPONSE IN THE HEALTH SECTOR

Using the earthquake performance evaluation of hospitals, the earthquake performance evaluation of ordinary buildings and the mass casualty simulation in Kathmandu Valley presented in Appendices 2 and 3, the following conclusions were made:

a) The health sector in Kathmandu Valley is not prepared to cope with the inflow of the large number of causalities that can be expected during an earthquake of intensity MMI = VII or more. The emergency departments in the four major hospitals (Bir, Army, Teaching and Patan) are well-trained for successfully coping with emergency patients from an intensity MMI = VI^+ earthquake, an event which is considered similar to a road accident with 30 to 50 emergency cases in each major hospital.

b) Most of the hospitals will be fully operational or at least partially functional after an intensity MMI = VII earthquake, but the combined capacity of the emergency departments in hospitals will not be enough to cope with demand. There are about 200 emergency beds installed in governmental hospitals (a number that can be increased to 500 without any major problem), and less than 3,500 in-patient beds in all of the hospitals within the valley. During intensity MMI = VII^+, up to 4,500 casualties can be expected.

c) During MMI = $VIII^+$-IX^- intensity earthquakes between 100,000 and 200,000 casualties can be expected and most of the hospitals will not be functional. In such an earthquake scenario, emergency services should be provided at green areas such as Tundikhel Parade Ground. Except for a few health facilities, for example the Teaching Hospital, hospital buildings will not be usable in the emergency response.

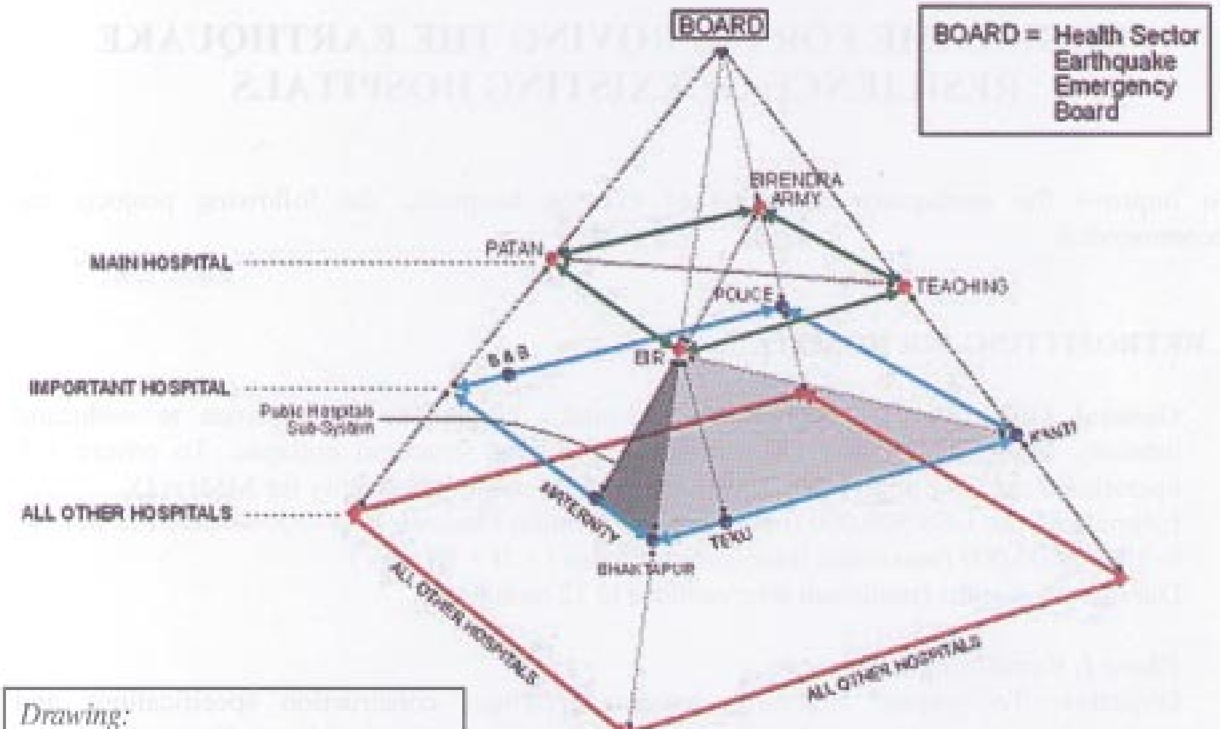
Based on the above conclusions, the following recommendations are issued to improve the emergency response in an earthquake disaster scenario:

1. It is of the utmost priority to work on emergency planning for an earthquake scenario of intensity MMI = VII. Such earthquakes are frequent events based on the seismic hazard in Kathmandu Valley. Planning for MMI = VII will also increase preparedness for larger events and can be done with the assumption that, apart from very few exceptions, the health infrastructure will be able to function after the earthquake.

2. Emergency planning should be conducted using a systemic approach, considering the need for an integrated health sector response, including private facilities. To achieve that objective it is recommended that an Earthquake Management System (EMS) is established.

   As shown in the following figure, the EMS is a pyramidal structure that links hospitals and requires a leading board.

Earthquake Management System (EMS)



Drawing:
Mr. Chandan Ranamagar - NSET

An EMS is needed to co-ordinate actions within the health sector, aiming to mitigate structural and non-structural vulnerabilities in the preparedness phase, improve response and increase resilience during and after earthquakes, improve communication and experience sharing, conduct training and to develop contingency plans in the health sector.

3. It is recommended that preventive-maintenance policies and actions toward earthquake safety are adopted in every hospital. Minor maintenance works can significantly improve earthquake response and resilience. Those works include introducing emergency signals, re-opening seismic joints closed by architectural elements such as tiles, walls and parapets, and a thorough evaluation of the stability of slender equipment. This should be done especially in the medically critical and essential areas, and main lifeline systems rooms for control and storage. All slender equipment and furniture needs to be anchored using belts or bolts, whichever is applicable.

4. It is necessary to increase the number of ambulances available in hospitals. Most of the hospitals, including major facilities, have no ambulance, or only one ambulance which is not appropriately equipped. There are less than 20 ambulances in the whole health sector in Kathmandu Valley and six of them belong to the Royal Nepal Army.

5. An earthquake contingency plan needs to be developed for Kathmandu Valley, integrating the health sector's response with others. Transportation and radio-communication links between hospitals need to be improved. Traffic jams in the valley's road network and lack of communication will be major problems. Appropriate countermeasures need to be planned.

Chapter 9

PROGRAMME FOR IMPROVING THE EARTHQUAKE RESILIENCE OF EXISTING HOSPITALS

To improve the earthquake resilience of existing hospitals, the following projects are recommended:

1. RETROFITTING BIR HOSPITAL

General Objective: To upgrade the hospital's earthquake performance to withstand intensity MMI = VIII and IX earthquakes without structural collapse. To ensure full operational capacity up to MMI = VIII and partial functional capacity for MMI = IX..
Estimated Cost: US$ 500,000 (minimum intervention Phases I + II)
to US$ 3,000,000 (maximum intervention Phases I + II + III + IV)
Duration: 6 months (minimum intervention) to 12 months

Phase I: Retrofitting design
Objective: To prepare structural designs, drawings, construction specifications and methodology, timetable and detailed budget to retrofit existing buildings. Designs of minor architectural and lifeline-systems modifications need to be made, as well as structural designs if necessary.
Estimated Cost: US$ 20,000 – US$ 50,000
Duration: 2 to 3 months

Phase II: Retrofitting construction of "L" and "wedge" buildings
(intensive care unit block and corridor connecting "L" to surgery block)
Objective: To upgrade seismic performance from MMI = VII to MMI = IX.
Estimated Cost: US$ 500,000 – US$ 1,000,000
Duration: 3 to 6 months

Phase III: Retrofitting construction of "I" and "V" buildings
(surgery and burns unit blocks)
Objective: To upgrade seismic performance from MMI = VIII to MMI = IX.
Estimated Cost: US$ 1,000,000 – US$ 1,500,000
Duration: 4 to 8 months

Phase IV: Retrofitting construction of "new" buildings
(administrative, out-patients and emergency department blocks)
Objective: To improve seismic performance from MMI = VIII to MMI = IX
Estimated Cost: US$ 1,000,000 – US$ 1,500,000
Duration: 4 to 8 months

2. IMPROVING SEISMIC PERFORMANCE OF ARMY AND PATAN HOSPITAL

General Objective: To increase seismic performance to withstand intensity MMI = IX earthquakes without structural collapse. To ensure full operational capacity for MMI = VIII, and partial functional capacity for MMI = IX.
Estimated Cost: US$ 110,000 - US$ 300,000
Duration: 3 to 6 months

Phase I: Quantitative structural and non-structural assessment of buildings
Objective: To conduct a detailed structural analysis to assess seismic performance, providing numerical data for the design of minor structural retrofitting, if necessary, and non-structural interventions in architectural components (such as facade walls, staircases). Complementary works: soil and material testing, cost analysis, and building survey and drawing.
Estimated Cost: US$ 5,000 – US$ 10,000 (per hospital)
Duration: 4 to 6 weeks (per hospital)

Phase II: Implementation of recommendations from quantitative assessment
Objective: To conduct structural retrofitting and non-structural interventions in architectural components. If necessary, minor lifeline-systems modifications need to be made, along with structural and architectural interventions.
Estimated Cost: US$ 100,000 – US$ 300,000 (per hospital)
Duration: 2 to 4 months

3. ENSURING FULL OPERATIONAL CAPACITY AND ENLARGING THE EMERGENCY DEPARTMENT IN TEACHING HOSPITAL

General Objective: To ensure full operational capacity for intensity MMI = VIII-IX.
Estimated Cost: US$ 15,000 - US$ 25,000
Duration: 3 months

Phase I: Non-structural assessment of buildings
Objective: To conduct an assessment to design non-structural interventions in architectural and lifeline systems. Numerical analysis of water tank structures, and any other important equipment fixed to the building, is required.
Estimated Cost: US$ 2,000 – US$ 3,000
Duration: 3 to 4 weeks

Phase II: Project design to enlarge emergency department from 16 to 35 - 50 beds.
Objective: To design architectural modifications around the existing emergency department rooms, with or without minor structural changes.
Estimated Cost: US$ 2,000 – US$ 3,000
Duration: 3 to 4 weeks

Phase III: Implementation of recommendations from Phases I and II
Objective: To construct non-structural interventions and build architectural modifications to enlarge emergency department rooms.
Estimated Cost: US$ 10,000 – US$ 20,000
Duration: 6 to 9 weeks

4. DEVELOPMENT OF AN EARTHQUAKE MANAGEMENT SYSTEM (EMS) AND EMERGENCY PLANS

General Objective: To increase preparedness, improve response and enforce emergency planning in hospitals. To conduct periodical workshops to exchange experiences, and to support working groups committed to organising trainee programmes and drills, as well as to develop emergency plans for an integrated health sector response.
Estimated Cost: US$ 10,000 - US$ 20,000 (per year)

5. RETROFITTING BIRENDRA POLICE HOSPITAL

General Objective: To upgrade seismic performance to withstand intensity MMI = VIII-IX earthquakes without structural collapse. To ensure full operational capacity up to MMI = VIII and partial functional capacity for MMI = IX.
Estimated Cost: US$ 500,000 to US$ 3,000,000
Duration: 6 months (minimum intervention) to 12 months

Phase I: Retrofitting design
Objective: To prepare structural designs, drawings, construction specifications and methodology, timetable and detailed budget to retrofit existing buildings. If necessary, designs of minor architectural and lifeline-systems modifications may need to be created, along with structural designs.
Estimated Cost: US$ 20,000 – US$ 30,000
Duration: 6 to 9 weeks

Phase II: Retrofitting construction
Objective: To upgrade seismic performance from MMI = VIII to MMI = IX.
Estimated Cost: US$ 250,000 – US$ 500,000
Duration: 3 to 6 months

6. CONSTRUCTING A NEW HOSPITAL IN BHAKTAPUR AND SETTING UP NEW EMERGENCY FACILITIES

Phase I: Set up new emergency facilities in the existing Bhaktapur Hospital
Objective: To equip a 7 observation bed emergency block constructed in Bhaktapur Hospital during year 2002 and to set up operations.
Estimated Cost: US$ 50,000 – US$ 100,000
Duration: 2 to 4 weeks

Phase II: Build a new 120 bed hospital in Bhaktapur equipped with large emergency department rooms for 35 to 50 observation beds.
Objective: To enable medical services to cope with the emergency demand from Bhaktapur in the event of earthquakes from intensity MMI = VII to MMI = VIII.
Estimated Cost: US$ 8,000,000 – US$ 12,000,000
Duration: 2 years

7. QUANTITATIVE STRUCTURAL ASSESSMENT OF MATERNITY, KANTI, TEKU AND B&B HOSPITALS

General Objective: To get a better understanding of each buildings' capacity to withstand earthquakes. Soil liquefaction risk at Maternity and Teku hospitals may be a difficult problem to manage. A quantitative assessment will provide numerical data which may indicate the need for structural retrofitting, if it is cost-effective. Complementary works: soil and material testing, soil liquefaction potential evaluation, cost analysis, and building survey and drawing may be required.
Estimated Cost: US$ 5,000 – US$ 10,000 (per hospital)
Duration: 4 to 6 weeks (per hospital)

Priorities are defined in the following table:

Programme for Improving Earthquake Resilience of Hospitals in Kathmandu Valley

Project	Priority		
	Very High	High	Medium
1. Retrofitting of Bir Hospital			
Phase I: Retrofitting design	X		
Phase II: Retrofitting construction of "L" and "wedge"	X		
Phase III: Retrofitting construction of "I" and "V" buildings		X	
Phase IV: Retrofitting construction of "New" buildings			X
2. Improving seismic performance of Army and Patan hospitals			
Phase I: Quantitative structural and non-structural assessment	X		
Phase II: Implementation of recommendations	X		
3. Ensuring full operational capacity and enlarging the emergency department in Teaching Hospital			
Phase I: Non-structural assessment of buildings		X	
Phase II: Project design to enlarge the emergency department		X	
Phase III: Implementation of Phases I and II		X	
4. Development of an Earthquake Management System (EMS) and emergency plans	X		
5. Retrofitting of Birendra Police Hospital			
Phase I: Retrofitting design			X
Phase II: Retrofitting construction			X
6. Construction of a new hospital in Bhaktapur and creation of new emergency facilities			
Phase I: Set up new emergency facilities	X		
Phase II: Build a new 120 bed hospital		X	
7. Quantitative structural assessment of Maternity, Kanti, Teku and B&B hospitals			X

Chapter 10

ADDITIONAL CONTRIBUTIONS AND COMMENTS MADE BY NSET

GENERAL

This report presents the methodology adopted and the main conclusions of conducting the structural assessment of hospital buildings in Kathmandu Valley. The work was commissioned by the World Health Organisation in Nepal (WHO Nepal) and conducted by the National Society for Earthquake Technology – Nepal (NSET) in association with the Disaster Health Working Group and the Epidemiology and Diseases Control Division of the Department of Health Services (EDCD), Ministry of Health.

At the request of NSET, WHO Nepal engaged an expatriate consultant for a period of approximately two months to assist in the structural vulnerability assessment. This was regarded as a necessity mainly because it was the first time that a seismic structural vulnerability assessment of complex hospital buildings had been contemplated in Nepal. Engaging an experienced expatriate consultant was expected to augment the theoretical knowledge of Nepalese professionals and help them to understand the practical aspects of conducting an assessment for a complex system such as a hospital.

PROJECT OBJECTIVES

The main objectives of the project were:

A. Development of a systematic approach towards the assessment of the structural vulnerability of hospital buildings and health institutions in Nepal by implementing such an assessment for hospitals in Kathmandu Valley.
B. Identification of appropriate measures for improving the earthquake resilience of the existing health infrastructure.
C. Transfer of technology and development of local capacity for such work in the country.
D. Dissemination of the findings for facilitating the implementation of the identified earthquake risk reduction measures.

PROJECT SCOPE

The scope of the project encompassed:

Assessment

A structural vulnerability assessment of five hospitals was carried out in detail; however, fourteen major hospitals (with more than 50 beds) were evaluated by qualitative visual inspection. The purpose of the visual assessment was emergency planning, whereas the detailed assessment was made to provide some recommendations to mitigate earthquake risk, on the basis of the findings from the assessment.

Reporting

The technical report was written by the expatriate consultant based upon the work done jointly by him and a team of NSET engineers. It provides the technical approach, methodology, findings, and recommendations for improving the earthquake performance of hospitals and health institutions in Kathmandu Valley. It also includes the detailed structural vulnerability assessment of five hospitals (Appendices 7 to 11).

Dissemination of Findings

The findings and recommendations of the study were disseminated by organising a series of seminars attended by representatives of the Ministry of Health, hospital directors, the heads of UN agencies and the UN Disaster Management Team, members of the Disaster Health Working Group, representatives of the health sector (e.g. emergency chiefs and maintenance engineers from 14 major hospitals) and the technical sector represented by structural designers, university professors, and representatives from professional societies of engineers and architects.

APPROACH

The approach for undertaking the project was characterised by the following:

- Provision of all necessary assistance to the WHO expatriate consultant in terms of existing knowledge and experience in Nepal in the field of earthquake risk management, prevalent building typologies and the inherent vulnerabilities of Nepalese structures based on local experiences.
- Creation of suitable conditions for the transfer of technology to Nepal in terms of the vulnerability assessment of hospital buildings and health facilities. NSET engineers were active recipients of the technology transfer process and now they are able to take up similar tasks independently.
- Provision of professional services to WHO in co-operation with the expatriate consultant in the assessment of seismic structural vulnerability of five hospitals, and the development of a comprehensive methodology for such assessments in Nepalese conditions.
- An understanding that the findings of the assessment should form the basis for identifying the appropriate measures (methods and systems) for improving the earthquake resilience of the existing health infrastructure in Nepal.
- Dissemination of the project findings and experiences in order to facilitate the process of implementing initiatives to reduce earthquake risks in the health infrastructure in Nepal.

METHODOLOGY

The following methodology was adopted:

Collection and Review of Pertinent Secondary Data and Information

All available data, information and maps, including seismological reports and building codes, were collected, reviewed and compiled.

NSET provided the expatriate consultant with all pertinent published and unpublished documents and briefed him on the current status of knowledge.

The outcomes were: 1) Familiarisation with the current situation of the health facilities, 2) Identification of the requirements of the assessment methodology, 3) Identification of the target hospitals and their buildings for the assessment, and 4) Detailing of the work plan.

NSET engineers and technicians surveyed the different buildings of Bir Hospital and prepared AutoCAD drawings for the assessment.

Development of Methodology and Formats for the Assessment

In this task NSET engineers worked with the expatriate consultant in detailing the survey formats. They jointly ran through the whole process, identified the gaps in information and prepared the final survey checklist. The checklist for visiting hospitals is explained on page 30-31.

Structural Survey of the Hospitals

A joint team consisting of the expatriate consultant, NSET engineers and a NSET technician visited the target hospitals several times. First, a reconnaissance visit was made before screening the hospitals for assessment. After the reconnaissance visit, 14 hospitals were selected for assessment and visited with a checklist. After inspecting this large number of hospitals (14 hospitals with more than 30 buildings), the five most critical facilities (most important facilities from a disaster management perspective) were selected for detailed structural assessment.

These five hospitals (Bir, Army, Patan, Teaching and Bhaktapur) were visited several times by the team to verify the data collected and to collect new and necessary information from each hospital. The table of hospitals surveyed with type, location, structure type, number of storeys, date of completion, number of beds, number of doctors and number of nurses working is given in the following table:

List of Hospitals Assessed for Earthquake Vulnerability

Code	Name of Hospital	Type	Location				Structure Type	Number of Storeys	Date of Completion	No of Beds	Total Doctor	Total Nurses	Remarks
			District	Municipality	Ward No.	Place							
Government Hospitals													
GH-1	Bir Hospital	General	Kathmandu	Kathmandu	30	Mahaboudha	RC BM BM	5 4 3	1985 1968 -	392	180	210	
GH-2	Birendra Army Hospital	General	Kathmandu	Kathmandu	14	Chauni	RC	3	-	380	80	85	
GH-3	Birendra Police Hospital	General	Kathmandu	Kathmandu	3	Maharajganj	RC RC	2 3	1985 1983	150	40	42	
GH-5	Sukra Raj Tropical and Infectious Disease	Infectious	Kathmandu	Kathmandu	12	Teku	BC BC	2 1	1982 1999	103	13	50	
GH-6	Kanti Hospital	Children		Kathmandu	3	Maharajganj	RC RC	2 2	1993 1993	250	75	107	
GH-7	Maternity Hospital	Maternity	Kathmandu	Kathmandu	2	Thapathali	BC BL RC	3 2 5,4,3	1965 1959 1975	310	60	110	
GH-9	Patan Hospital	General	Lalitpur	Lalitpur	5	Lagankhel	RC	4	1982	200	60	250	
GH-11	Bhaktapur Hospital	General	Bhaktapur	Bhaktapur	17	Dudh Pati	BC HC	3 1	1978 2001	50	11	25	
GH-14	Military Hospital	-	-	-	-	Mohaboudha	-	-	-	-	-	-	
TH-1	Teaching Hospital	General	Kathmandu	-	3	Maharajganj	RC	2,4	1984	401	200	350	
TH-2	Nepal Medical College	General	Kathmandu	-	7	Aterkhel	RC RC BC	1 6 1	1997 1997 -	394	140	87	
TH-3	Kathmandu Medical College	General	Kathmandu	Kathmandu	7	Sinamangle	RC	7	2000	-	62	54	
PH-8	Medicare National Hospital & Research Centre	General	Kathmandu	Kathmandu	1	Naxal	RC RC RC	4 1 4	- - -	60	70	39	
PH-20	B & B Hospital	Orthopedic	Lalitpur	Lalitpur	7	Gwarko	RC	5	1997	100	50	110	
NH-1	Model Hospitals	General	Kathmandu	Kathmandu	31	Baghbazar	BM RC	3 5	- -	50	8	34	

Notes:

Code	Description	Code	Description
GH	Government Hospital	RC	Reinforced Concrete Frame
TH	Teaching Hospital	BM	Brick in Mud
PH	Private Hospital	BC	Brick in Cement
NH	Non-governmental Hospital	BL	Brick in Lime

Survey Data Analysis

The survey data of hospital buildings were analysed on the basis of the following points:

- Definition of seismic hazard
- Evaluation of soil and site effects
- Identification of structural vulnerability factors
- Identification of building design criteria
- Evaluation of earthquake performance
- Identification of main features of lifeline systems
- Assessment of reliability of hospital infrastructure

The analysis resulted in a statement on the structural stability of various components and the building as a whole. Identification of possible intervention options (retrofitting options) for improving the buildings' strength was also made for five hospitals.

The economics of the various intervention options was estimated on the basis of NSET's past experiences of retrofitting school buildings.

The outcomes of this task are: 1) A statement of the structural vulnerability of the target hospital buildings and their components, 2) A statement on the most feasible of the structural intervention options for each of the buildings assessed, 3) A statement on the methodology for implementing the structural intervention, and 4) A preliminary cost estimate.

WORK SCHEDULE

NSET started preparations for the work in August 2002. In the preparatory phase (August-October 2001) NSET carried out the following activities:

- Development of project concepts
- Creation of an inventory of the hospitals and hospital buildings
- Reconnaissance and establishment of initial contacts with the hospital authorities
- Collection and collation of all secondary information including soil profiles, soil characteristics and geological conditions pertinent to the identified hospital sites, assessment of earthquake hazard and earthquake risks

Intensive field survey work started on 8 October 2001 and the whole study was completed on 7 December 2001. The detailed schedule of the activities carried out is shown in the following table:

Schedule of Work for Structural Vulnerability Assessment of Hospitals in the Kathmandu Valley

S. No.	Activity	August				September				October				November				December			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	Collection of available data and drawings of hospitals in Kathmandu Valley by NSET	■	■	■	■	■	■	■	■												
2	Analysis of preliminary data gathered and setting up priority for the study by NSET								■	■											
3	Briefing the expatriate consultant on past works on structural assessment done by NSET										■										
4	Collection and review of literature										■	■									
5	Reconnaissance of hospital buildings and meetings with hospital administrators										■	■									
6	Meeting with engineering professionals and technicians at hospitals												■	■	■						
7	Develop methodology (survey format, identify survey targets, update schedule)										■		■		■						
8	Conduct survey													■	■	■					
9	Data analysis										■	■	■	■	■	■	■				
10	Field verification												■	■	■	■	■				
11	Report preparation												■	■	■	■	■	■	■	■	■
12	Preparation for summary workshop																■				
13	Summary workshop (public meeting to discuss the outcome and endorse the follow up actions)																	■			
14	Report submission																				

CHECKLIST FOR VISITING HOSPITALS

For the survey of hospital buildings, a checklist was developed as follows:

Step 1: Explain the Scope of Work and Methodology

- The assessment will recommend actions to reduce earthquake vulnerability.
- In the case of Bir Hospital and the others to be studied using a quantitative approach, the assessment will propose structural solutions to make the buildings safe during earthquakes.
- The hospital may be visited several times. Ask for suitable contact persons for future contact. Usually the people in charge of emergency management and lifeline systems maintenance and operation. Ask for phone numbers and working hours.
- A short questionnaire will be submitted to the hospital.
- A draft report will be submitted to the hospital containing the findings from the hospital.
- The final report will be submitted to the hospital.

Step 2: Collect Information

- Architectural, structural and lifeline systems drawings.
- Geotechnical information including boring logs.
- Material testing reports during construction.
- Ask about damage during previous earthquakes.
- Ask about any foundation settlements which have occurred.
- Ask someone who was present during hospital construction about foundation type, water table level, and structural construction system.
- Ask about building age and how the different facilities were constructed over time. It is meaningful to get information regarding any new construction development carried out informally, without engineering design, such as adding a new floor.
- Ask the person in charge of lifelines maintenance / operation about the problems that usually, often and sometimes happen during normal and peak operation hours. Also ask about needs and his thoughts about how to reduce non-structural vulnerability.
- Ask the person in charge of lifelines maintenance / operation about how maintenance demand is increasing with time, how water and energy supply is improving or getting worse with time, as well as waste water disposal, toxic releases such as gasses, chemicals and so on. Ask for maintenance routine.
- Ask the person in charge of emergency services about the problems that usually, often and sometimes occur during normal and peak operation hours. Also ask about needs and his thoughts about how to reduce problems.
- Ask the person in charge of emergency services about how the emergency demand is increasing with time and what the most common cases under treatment are.
- Ask about the feasibility for conducting new geotechnical studies such as boring holes or open mining for inspecting foundations and destructive material testing in beams and walls.
- Ask the hospital director to confirm the number of beds, doctors and nurses that are already collected and the bed occupancy rate, number of daily surgeries, number of

patients in emergency services, number of patients in consultancy and any other statistics that should be considered relevant to understanding the hospital's capacity and what percentage of its capacity is being used during normal operation.

Step 3: Visiting Essential and Critical Facilities (after collecting information)

- Operating theatres, intensive care unit, cardio care unit, burns unit, central sterile services department, neuro-surgical unit, emergency department, labs, radiology, nuclear medicine, blood bank, and any other essential and critical facilities need to be inspected.
- Inspect any facility that uses hazardous materials which can explode or cause problems such as collateral risk triggered by an earthquake.
- Inspect any facility that operates sub-structures such as tanks for haemodialysis etc.

Step 4: Visiting Lifeline Facilities (after collecting information)

- Inspect the energy feeders and distribution through the building (capacity, redundancy and dependency) as well as the emergency generators for backup energy (time, redundancy, % of demand to cover, served areas etc.). Ask about the demand during peak hours.
- Inspect or ask about the water supply system (capacity, redundancy, and dependency). Ask about the demand during peak hours. Ask about any water treatment plant or storage tank placed on a roof that may cause eccentric masses and torsion to a building.
- Inspect the sewerage system. Ask about areas affected by wastewater, toxic and / or hazardous material and garbage disposal. Ask about and search for leakages of any fluid that can cause damage to RC or structural materials, such as deterioration of concrete strength, steel bar corrosion, and so on.
- Inspect the steam system if it provides energy to autoclaves and sterilization units associated with critical facilities. Inspect the central boiler house especially if it is inside the main building as there may be soft storey there, or problems with lifelines going through seismic joints.
- Gas systems such as oxygen, air-suction, and nitrous oxide should be inspected. Ask for the pipeline layout, since these kinds of facilities are usually fragile pipes and it is necessary to assess whether or not they are crossing through seismic joints in a proper way.
- Check storage and usage of liquefied petroleum gas cylinders as well as any other means of fuel used in the hospital to provide energy to kitchen, laundry, etc.
- Inspect communication systems, such as telephones, radio calls, alarms, pagers, local intercoms and others. Assess their reliability in the event of an emergency.
- Inspect transportation facilities, such as lifts, corridors, gates, stairs, etc. Assess their reliability and means of egress in the event of an emergency.

Step 5: Correlation among Structural Systems, Medical Facilities and Lifeline Systems

- Inspect all seismic joints to observe if they are working properly or not. As well as this, try to identify any lifeline going through a seismic joint, the use of flexible connectors etc.
- Inspect all areas of possible structural intervention in future, such as facades, corners, seismic joints, columns etc.

- Be aware of, and search for, lifelines attached to structural elements.
- Identify the usage of any possible area of future intervention. Try to avoid areas where essential and critical facilities are located. If it is not possible to avoid an intervention in a place where these facilities are placed, try to find a solution to keep medical services working.

COMMENTS ON THE REPORT

A. This is a technical report, written by the expatriate consultant Mr. Jaime F. Argudo, based upon the works carried out jointly with NSET engineers Mr. Ramesh Guragain, Mr. Ram Chandra Kanel, and Mr. Surya Narayan Shrestha.

B. The report is well written and reflects the works carried out. However, there are diverging opinions regarding the following four points:

1) Chapter 6, Evaluation of Earthquake Performance of Hospitals in Kathmandu Valley, page 12, table column 3, row 4:
'Substantial to Heavy' could be 'Very Heavy'

2) Chapter 6, Evaluation of Earthquake Performance of Hospitals in Kathmandu Valley, page 12, table column 4, row 4:
'Very Heavy' could be 'Destruction'

3) Appendix 7, Structural Vulnerability Assessment of Bir Hospital, page 59, paragraph 3, line 3:
'MMI = IX' could be 'MMI = VIII'

4) Appendix 7, Structural Vulnerability Assessment of Bir Hospital, page 59, paragraph 3, line 4:
'above 0.35 g' could be 'of 0.2 g to 0.35 g'

C. Comments on the estimated costs in Chapter 9, Programme for Improving Earthquake Resilience of Existing Hospitals, page 20:

The cost for retrofitting and reconstruction has been estimated to be very high as compared to the actual conditions in Nepal. Based on NSET's experiences, the cost of retrofitting should as a maximum be about 50% of the cost of new construction of a reinforced concrete building.

With this consideration, we propose the following changes:

1) 1. Retrofitting of Bir Hospital, paragraph 1, line 4, estimated cost:
Replace US$ 500,000 with US$ 200,000

2) 1. Retrofitting of Bir Hospital, paragraph 3, line 4, estimated cost:
Replace US$ 500,000 - US$ 1,000,000 with the following:
Retrofitting of "L" building: US$175,000 - US$220,000
Reconstruction of the "wedge" with a lift and staircase: US$80,000 - US$100,000

3) <u>1. Retrofitting of Bir Hospital, paragraph 4, line 4, estimated cost</u>:
Replace US$ 1,000,000 - US$ 1,500,000 with US$ 500,000 - US$ 1,000,000

4) <u>1. Retrofitting of Bir Hospital, paragraph 5, line 4, estimated cost</u>:
Replace US$ 1,000,000 - US$ 1,500,000 with US$ 850,000 - US$ 1,500,000

CONCLUSION

A detailed performance evaluation of the hospitals is described elsewhere in this publication. A summary of the results of the study is given here. For different levels of earthquakes the performance of hospitals in Kathmandu Valley was found as follows:

- ***Frequent earthquakes of small intensity (MMI = VII):*** All or almost all hospitals may withstand the earthquake without collapse, 70% may be fully operational, and 30% partially functional.

- ***Occasional earthquakes of moderate intensity (MMI = VIII):*** Most of the hospitals may withstand the earthquake without collapse, 10% may be fully operational, 30% partially functional, and 60% out of service of which a few (10%) may collapse.

- ***Rare earthquakes of high intensity (MMI = IX):*** Many hospitals may withstand the earthquake without collapse, only 10% will be partially functional, 60% out of service in complying with a life-safety performance, and 30% of the structures might collapse.

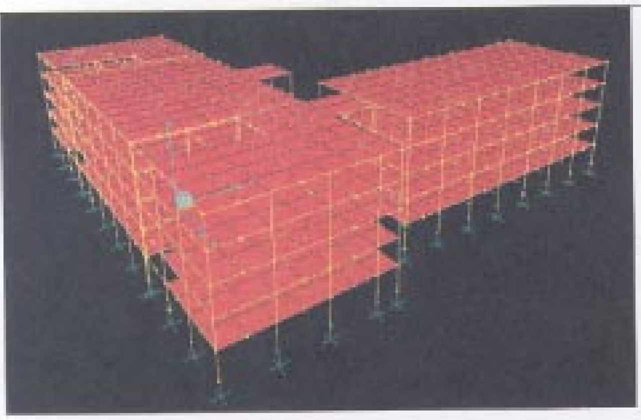
Appendix 1

BUILDING LOCAL CAPACITIES IN NEPAL

In order to transfer technology and build local capacities in Nepal, engineers from NSET were trained. The training focused on the methodology of conducting quantitative structural assessment in hospitals. Among other activities, the following were performed:

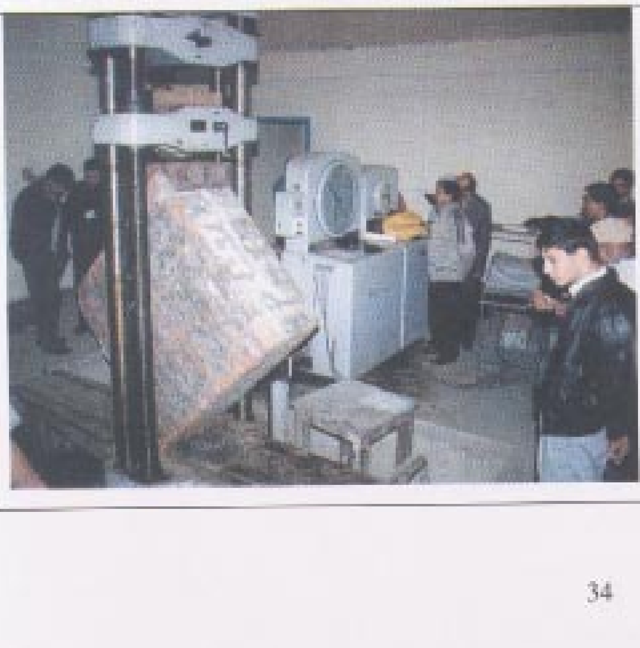
a) ***Structural analysis of Bir Hospital:*** Mathematical models were applied to five buildings in the hospital. Based on the numerical results provided by these models, a quantitative assessment was carried out by NSET, under the consultant's guidance. The results from the analysis provide suitable data for designing the structural retrofitting of Bir Hospital.

b) ***Testing of materials:*** A masonry block (1.2 x 1.2 x 0.46 m) was built by NSET and tested in Tribhuvan University Laboratory under American Standards for Testing Materials (ASTM). This prototype was the first in Nepal to be tested to obtain the shear strength of masonry wall assemblies. It was prepared in a 1:1 cement-mortar relationship and failed in shear at an ultimate strength of 7.2MPa. In the future, masonry samples from Bir Hospital and the other critical health facilities to be quantitatively assessed can be tested to obtain reliable data regarding the strength of the material.



Mathematical model of out-patients and emergency department blocks ("new" buildings) of Bir Hospital.

Structural analysis: Mr. Ramesh Guragain – NSET



Testing of a 1.2 x 1.2 x 0.46 m non-reinforced-masonry-block prototype in Tribhuvan University Laboratory to obtain the diagonal tensional strength (shear strength) in masonry assemblies according to ASTM.

Appendix 2

EVALUATION OF THE EARTHQUAKE PERFORMANCE OF ORDINARY BUILDINGS IN KATHMANDU VALLEY

BUILDING PERFORMANCE TYPE

Ordinary buildings in Kathmandu Valley were classified into five types, based on earthquake performance. Type 1 is the worst and Type 5 the best:

Type 1: Adobe, stone, brick in mud, adobe & stone, stone & brick in mud
Type 2: Non-reinforced masonry made of brick in mud, brick in lime, brick in cement, brick in mud & brick in cement
Type 3: Reinforced concrete ordinary-moment-resistant-frames (OMRF)
Type 4: Reinforced concrete intermediate-moment-resistant-frames (IMRF)
Type 5: Reinforced concrete special-moment-resistant-frames (SMRF)

Using data from The Study on Earthquake Disaster Mitigation in The Kathmandu Valley, Kingdom of Nepal (NSET, 2001), the building stock in Kathmandu Valley was classified as shown in the following table:

Building Types in Kathmandu Valley According to Structural Performance

Building Type	Structural System		Percentage of Buildings	
	Type	Definition		
1	AD	Adobe (earth blocks in mud).	19%	34%
	ST	Stone in mud.	7%	
	AD-ST	Adobe combined with stone.	8%	
	ST-BM	Combination of stone and brick in mud.		
2	BM	Non-reinforced masonry with brick in mud.	18%	43%
	BL	Non-reinforced masonry, brick in cement mortar.	21%	
	BC	Non-reinforced masonry, brick in lime mortar.		
	BM-BC	Non-reinforced masonry combination of BM-BC.	4%	
3	RC-OMRF	Reinforced concrete structure and infill masonry walls, without earthquake-resistant design. Most of the 3- or more-storey buildings.	15%	23%
4	RC-IMRF	Reinforced concrete structure and infill masonry walls, with moderate level of earthquake-resistant design. Mainly 1 or 2-storey buildings.	8%	
5	RC-SMRF	Reinforced concrete structure and infill masonry walls, with special design for earthquake resistance. A few hospitals and other buildings.	<1%	<1%

DEFINITION OF STRUCTURAL SYSTEMS

Non-reinforced-masonry bearing-walls system:
A load-bearing system in a building without seismic design in which its bearing-walls do not meet the special detailing requirements for ductile behaviour. This system is only suitable for Seismic Zone 1. In Nepal, most of the hospitals of this kind were constructed by combining clay bricks with mortar cement.

Ordinary moment-resisting-frame-system (OMRF):
A load-bearing system in a building without seismic design in which its moment-resisting-frame does not meet the special detailing requirements for ductile behaviour. This system is only suitable for Seismic Zone 1.

Intermediate moment-resisting-frame-system (IMRF):
A load-bearing system in a building with a seismic design, in which its moment-resisting-frame has moderate ductile behaviour and complies with the requirements of Seismic Zone 2.

Special moment-resisting-frame-system (SMRF):
A load-bearing system in a building with high-performance seismic design, in which its moment-resisting-frame is specially designed to create ductile behaviour and comply with the requirements of Seismic Zones 3 and 4. Although this system should be adopted for RC frame structures in Nepal, its use is currently an exception.

DAMAGE ESTIMATION IN KATHMANDU VALLEY BUILDINGS

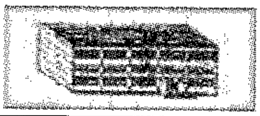
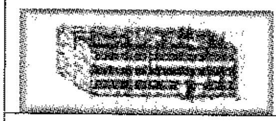
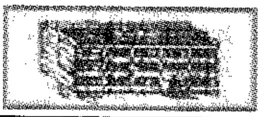
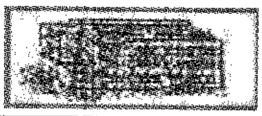
By combining the size and classification of building damage, as defined by the European Micro-seismic Scale for different earthquake intensities, with expected losses and building stock distribution, a gross damage estimation was made for 250,000 buildings in Kathmandu Valley. The results are shown in the following tables:

Estimated Number of Buildings Damaged in Kathmandu Valley

<table>
<tr><th rowspan="2">Earthquake Intensity</th><th rowspan="2">No Damage</th><th colspan="5">Damage Category</th></tr>
<tr><th>Negligible to Slight</th><th>Moderate</th><th>Substantial to Heavy</th><th>Very Heavy</th><th>Destruction</th></tr>
<tr><td>VI</td><td>201,688 (80.68%)</td><td>37,725 (15.09%)</td><td colspan="2">10,088 (4.04%)</td><td colspan="2"><500 (< 0.2%)</td></tr>
<tr><td>VII</td><td colspan="2">140,225 (56.09%)</td><td>69,438 (27.78%)</td><td>35,663 (14.27%)</td><td colspan="2">4,675 (1.87%)</td></tr>
<tr><td>VIII</td><td>-</td><td colspan="2">140,226 (56.1%)</td><td>69,438 (27.78%)</td><td>35,663 (14.27%)</td><td>4,675 (1.87%)</td></tr>
<tr><td>IX</td><td>-</td><td colspan="3">144,901 (58%)</td><td>69,438 (27.75%)</td><td>35,663 (14.25%)</td></tr>
</table>

Although building performance varies in Kathmandu Valley, building classification was made as simple as possible and according to the criteria used in the European Micro-seismic Scale.

Damage Classification According to European Micro-seismic Scale

RC Frame Structures	Masonry Structures	Damage Category	Damage Description
		NEGLIGIBLE TO SLIGHT	No structural Slight non-structural
		MODERATE	Slight structural Moderate non-structural
		SUBSTANTIAL TO HEAVY	Moderate structural Heavy non-structural
		VERY HEAVY	Heavy structural Very heavy non-structural
		DESTRUCTION	Very heavy structural

Expected Loss of Buildings According to Damage Categories

Damage Category	Negligible to Slight	Moderate	Substantial to Heavy	Very Heavy	Destruction
Expected Losses	0 – 5%	5 – 15%	15 – 40%	40 – 80%	80 – 100%

Expected loss of buildings is estimated as a percentage of costs, as follows:

Expected loss of buildings = damage direct-cost / building cost.

Percentage of Buildings Damaged

MMI = VI Damage Categories	Building Type 1	2	3	4
Negligible to Slight	Many (10-60%)	Few (1-10%)	Few (1- 10%)	
Moderate	Few (1–10%)	Few (1–10%)		

MMI = VII Damage Categories	Building Type 1	2	3	4
Negligible to Slight		Some (5- 30%)	Some (5- 30%)	Few (1- 10%)
Moderate	Many (10- 60%)	Many (10-60%)	Few (1- 10%)	
Substantial to Heavy	Many (10-60%)	Few (1–10%)		
Very Heavy	Few (1–10%)			

MMI = VIII Damage Categories	Building Type 1	2	3	4
Negligible to Slight			Some (5-30%)	Many (10-60%)
Moderate		Some (5-30%)	Many (10-60%)	Few (1- 10%)
Substantial to Heavy	Many (10-60%)	Many (10-60%)	Few (1–10%)	
Very Heavy	Many (10-60%)	Few (1–10%)		
Destruction	Few (1–10%)			

MMI = IX Damage Categories	Building Type 1	2	3	4
Negligible to Slight				Some (5 – 30%)
Moderate			Some (5 – 30%)	Many (10-60%)
Substantial to Heavy		Some (5 – 30%)	Many (10-60%)	Few (1- 10%)
Very Heavy	Many (10-60%)	Many (10-60%)	Few (1- 10%)	
Destruction	Many (10-60%)	Few (1–10%)		

Appendix 3

EARTHQUAKE MASS CASUALTY SIMULATION

To reach an understanding of how many people will demand hospital services, an earthquake mass casualty simulation was carried out for Kathmandu Valley. This simulation is based on the expected damage from the MMI scale to the various building types and its stock[9]. In Kathmandu Valley there are approximately 250,000 buildings. The simulation was conducted for earthquakes of different MMI intensities. The results are shown as follows:

Estimated Number of Buildings with very Heavy Damage to Destruction

MMI	With Very Heavy Damage to Destruction	
	Number	Percentage
VI	0 – 500	0 – 0.2%
VII	500 – 5,000	0.2 – 2%
VIII	5,000 – 50,000	2 – 20%
IX	50,000 – 125,000	20% - 50%

Using the estimated number of buildings with either very heavy damage or which are destroyed and the mean values from the empirical data compiled by Coburn & Spence, 1992, the number of people killed was calculated. The gross number of people severely injured was estimated as being five times the number of people killed. The population in Kathmandu Valley was assumed to be 1.5 million. The results are shown in the following table:

Expected Number of People Killed and Injured in Kathmandu Valley

MMI	People Killed		People Severely Injured	
	Number	Percentage	Number	Percentage
VI	0 – 20	0 – 0.001%	0 – 100	0 – 0.005%
VII	20 – 750	0.001 – 0.5%	100 – 3,750	0.005 – 2.5%
VIII	750 – 22,500	0.5 – 1.5%	3,750 – 112,500	2.5 – 7.5%
IX	22,500 – 75,000	1.5 – 5%	112,500 – 375,000	7.5 – 25%

Appendix 4

SOIL LIQUEFACTION EVALUATION

BACKGROUND

Liquefaction is a phenomenon in which the strength and stiffness of a soil is reduced by earthquake shaking or other dynamic loading. It occurs in saturated soils, in which the space between individual particles is completely filled with water. Earthquake shaking causes the water pressure to increase, exerting pressure on the soil particles which can easily move against each other. This phenomenon is highly likely to occur in soils of low to medium consistency, in which the earthquake energy exerted during MMI = VII–VIII intensities can be enough to liquefy shallow layers.

During liquefaction, the strength of the soil decreases and the ability of a soil deposit to support foundations for buildings and bridges is reduced, as seen in this photo of the overturned apartment complex buildings in Niigata in 1964 [25].

Liquefaction mostly occurs in sandy soil layers classified as SP (SUCS US Standards), which have low fine (silts – clays) content and are uniformly graded. However, liquefaction has also been observed in silty-sand soil layers classified as SM, although much greater earthquake energy is required to liquefy SM soils than that needed to liquefy SP soils.

THE HYDROSTATIC WATER-TABLE LEVEL IN KATHMANDU VALLEY

Determining the location of the hydrostatic water-table level within a soil profile is a key issue in an assessment of whether a potential SP or SM layer in Kathmandu Valley will liquefy or not.

In Kathmandu Valley there is a very shallow aquifer, usually found at a depth of 1 to 2 metres. In the northern area from Maharajganj to Naxal and in the southern Lalitpur municipality from Satdobato to Pulchowk, as well as in other high-flat areas like Baneshwar and Tribuvan International Airport, it is believed that the "unconfined aquifer" does not experience hydrostatic pressure and its water-table level should not be considered as the hydrostatic level.

In those places located at the foot of mountains, such as Chauni, Chabahil, Gwarko-Lalitpur, and low, flat areas such as Teku, Tripureshwar, Thapathali and others, the shallow aquifer level should be assumed to be confined and therefore experiencing hydrostatic pressure that can produce liquefaction.

The Ground Water Management Project in Kathmandu Valley, conducted by JICA in 1989-1990, indicates that between 1972 and 2001 the pumping of water for consumption caused the piezometric head of the confined aquifers to drop 6 to 8 metres in downtown Kathmandu (Asan, Thamel, Naxal) and 8 to 12 metres in northern Kathmandu (Maharjganj). This has significantly reduced the liquefaction potential in those areas where shallow sandy layers prone to liquefaction can frequently be found.

GEOLOGY AND SOILS IN KATHMANDU VALLEY

Kathmandu Valley is a synclinal tectonic basin consisting of fluvio-lacustrine deposits from the Pleistocene age resting on top of Precambrian metamorphic bedrock. In Kathmandu Municipality Gokarna and Kalimati formations are predominant, Gokarna to the northeast and Kalimati to the southwest. Bhaktapur city is located on a hill that is part of the Kalimati formation. In Latitpur Municipality Kalimati and Chapagau formations are predominant.

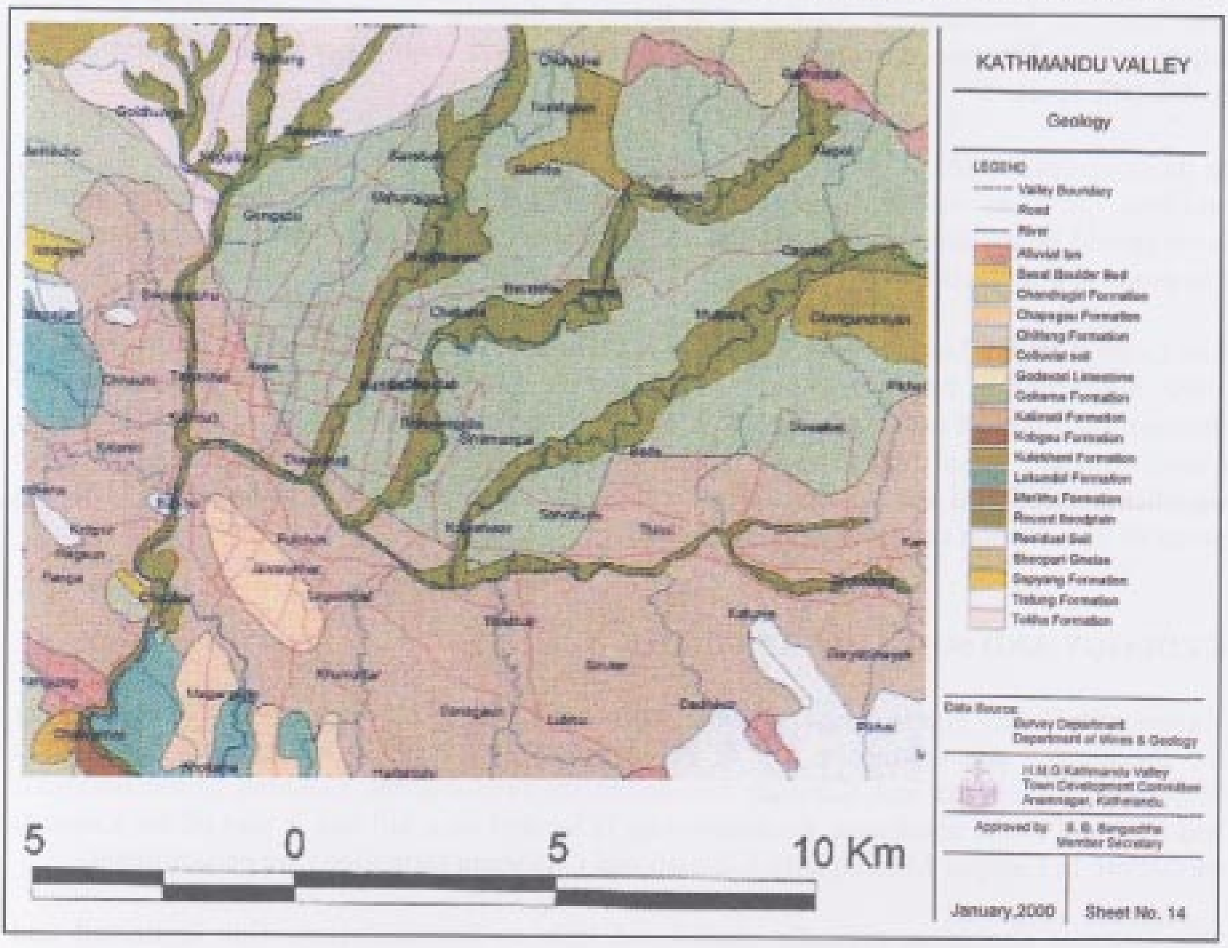
The Gokarna formation typically consists of light to brownish-grey, fine laminated and poorly graded silty sand with intercalation of clay of variable thickness. Shallow SP sandy soils, which are highly prone to liquefaction even under small to moderate intensity earthquakes (MMI = VII-VIII), are often found within the Gokarna formation.

The Kalimati formation is grey-to-dark silty clay and clayey silt. Organic clay, fine sand beds and peat layers are commonly found. SM silty-sand soil layers intercalated with silt or clay layers are often found from 5 to 15 metres down. Such layers are prone to liquefaction under moderate to high intensity earthquakes (MMI = VIII-IX).

The Kalimati formation surrounds Jawalakhel and Lagankhel hills which are located on Chapagau formation. At Jawalakhel Chowk, a soil investigation conducted by JICA under The Study on Earthquake Disaster Mitigation in Kathmandu Valley, 2000-2001 found a non-liquefiable soil profile of good strength capacity.

Most of the soils with moderate to high liquefaction potential are to be found along riverbanks, in the so-called recent flood plains.

Generally, apart from soils located at the foot of mountains, those soils in Kathmandu Valley located above 1,300 metres are expected to be either non-liquefiable or to have a low liquefaction potential.



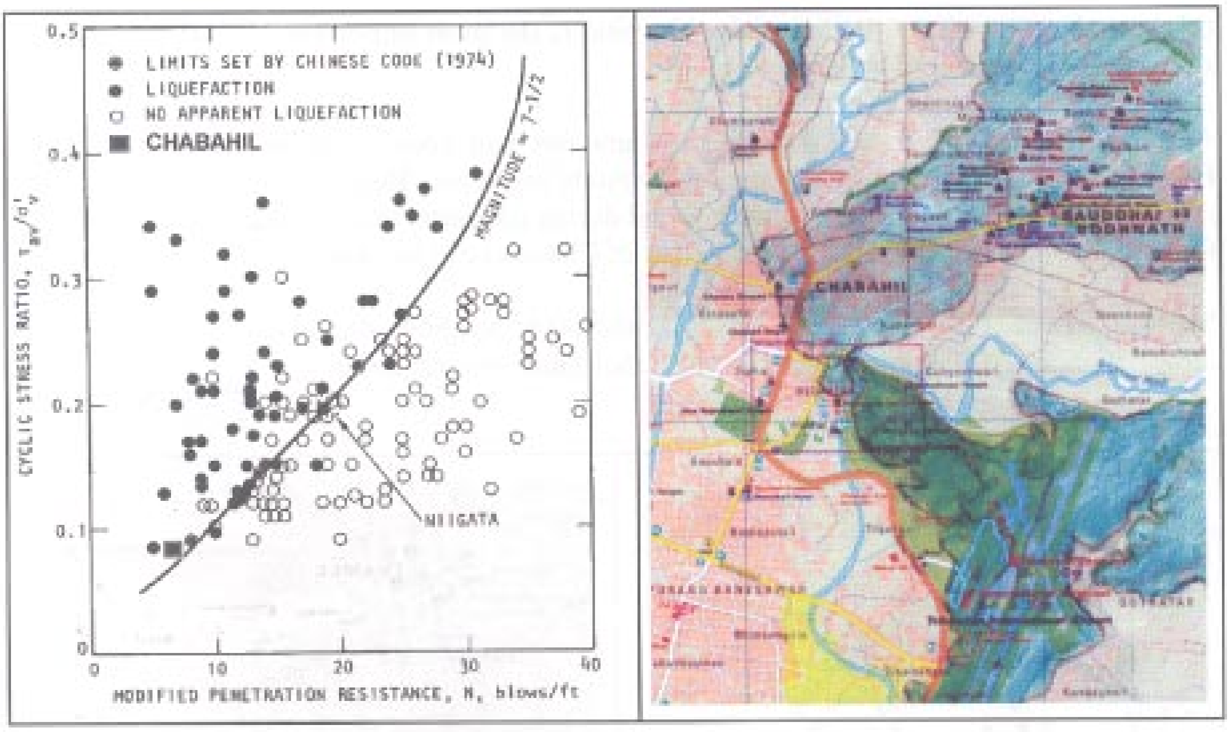
The geology of Kathmandu metropolitan area. Recent flood plains, where soil liquefaction potential is high, are shown in green.

SOIL LIQUEFACTION EVALUATION AT CHABAHIL, WARD NO. 7

A soil liquefaction evaluation was carried out at the site where the new nursing home building of the Medicare National Hospital & Research Centre was constructed during 2001. The site is adjacent to the left side of the Chabahil-Maharajganj section of the ring road and is situated approximately 50 metres before Chabhil Road Junction towards Maharajgunj. Chabahil is located at a the foot of a mountain, where natural springs can be found, and the piezometric head of a confined aquifer can be presumed to be very shallow.

At the site, a sandy layer (SP) was found from the ground surface to a depth of 5-6 metres, having a modified penetration resistance $N_1 = 7$. The liquefaction analysis was carried out assuming that liquefaction will occur at a depth of 3 metres, where soil can be presumed to be saturated. The liquefaction potential was found to be very high - the sandy layer may liquefy in an earthquake of intensity MMI = VII or above.

However, a detailed evaluation of the hydrostatic water-table level using piezometers is recommended. If the piezometric head is found to be below 6 metres in depth, the liquefaction potential will be significantly reduced.



Soil liquefaction analysis at Chabahil.
For peak ground acceleration = 0.1 g (MMI = VII).

SOIL LIQUEFACTION EVALUATION OF BIR HOSPITAL AT MOHABUDHA

A soil liquefaction evaluation was carried out next to Bir Hospital's existing facilities, at the site where the new trauma centre complex is to be constructed. The site is located in Mohabouda, Ward 30, at an elevation of 1,298 metres.

At the site, a silty-sand layer (SM) was found between 6 and 10 metres below the surface, having a modified penetration resistance $N_1 = 10$. The liquefaction analysis was carried out assuming that liquefaction might occur at a depth of 8 metres, where the soil can be presumed to be saturated. The liquefaction potential was found to be low - the silty-sand layer may liquefy during intensity MMI = IX. However, a detailed evaluation of the hydrostatic water-table level using piezometers is recommended.

PUBLIC HOSPITALS LOCATED ON SOILS WITH MODERATE TO HIGH LIQUEFACTION POTENTIAL

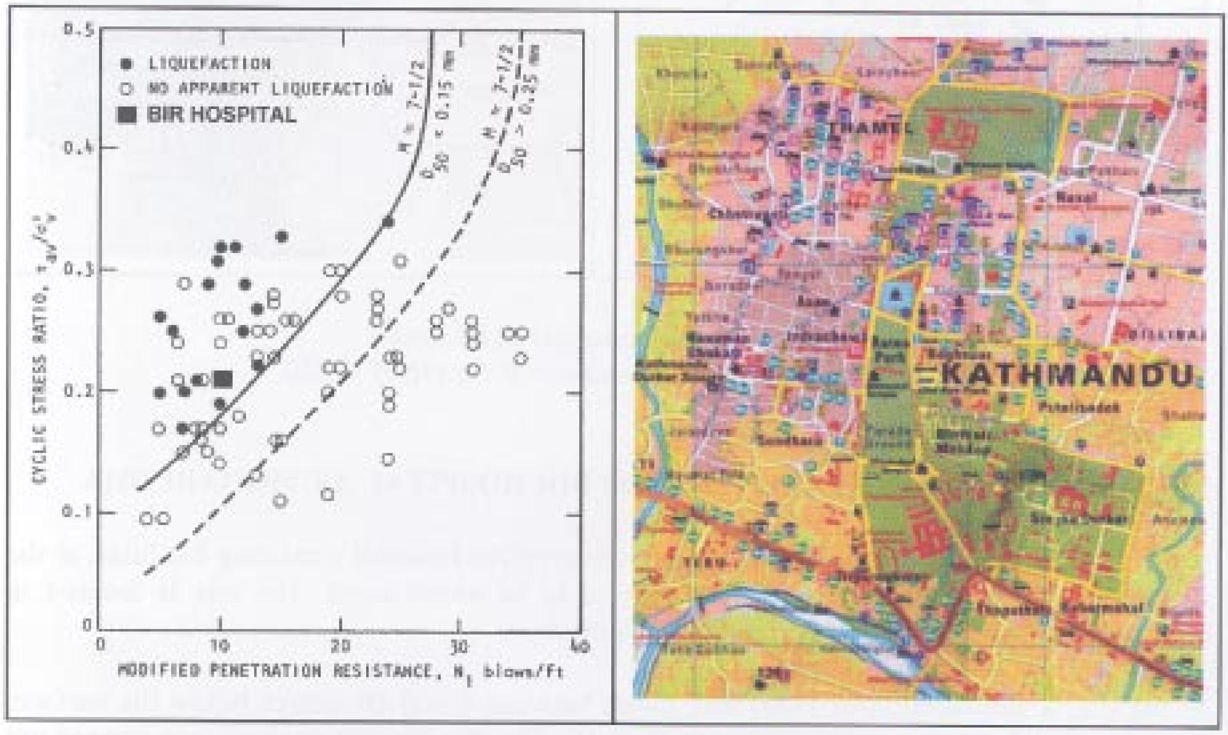
As mentioned above, soils with high liquefaction potential are generally found along riverbanks, especially if the ground elevation is very low.

The following public hospitals are located in such places: Sukra Raj Tropical and Infectious Disease Hospital at Teku (1,281 m), Nepal Eye Hospital at Tripureswar (1,283 m), and Maternity Hospital at Thapathali (1,282). The Bagmati River water level lies at about 1,280 metres.

Of these three hospitals, the Maternity Hospital is the most important one, where a new 5-storey building is near to being completed.

Another hospital where soil liquefaction analysis had been recommended is the Army Hospital at Chhauni, one of the major hospitals in Nepal. Beneath the Army Hospital a shallow aquifer and sand deposits were found during its construction. Since it is located at the foot of a mountain, a situation similar to that of Chabahil can be expected at Chhauni.

No liquefaction analysis was conducted at the other hospitals due to lack of geotechnical information, but it is strongly recommended that future studies do so.



Soil liquefaction analysis of Bir Hospital at Mohaboudha.
For peak ground acceleration = 0.35 g (MMI = IX).

DRAINAGE PROBLEMS AT GWARKO – LALITPUR

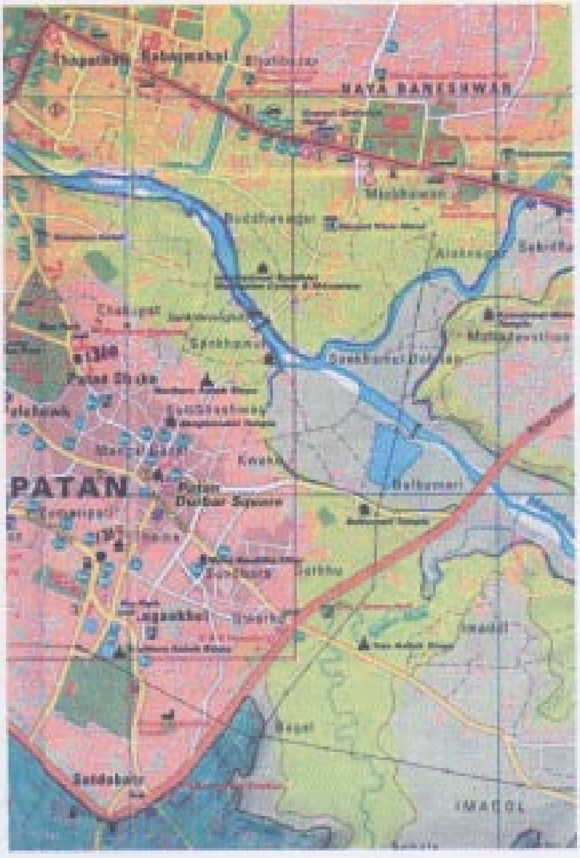
B&B Hospital is the most important private facility in Kathmandu Valley. It is located at Gwarko – Lalitpur, at an elevation of 1,297 metres.

Nearly half of the underground water from the Jawalakhel and Lagankhel hills flows to Gwarko, and is dammed at a piece of land located beside B&B Hospital.

This is due to a trap formed by Patan's hills, the ring road, and Mangal Bazar road.

Because of this drainage problem the hydrostatic water-table level is very shallow at this site, and soil liquefaction may occur if a sandy layer prone to liquefaction exists within the soil profile. No liquefaction analysis was done due to lack of geotechnical information.

To solve the drainage problem it is recommended that two culverts are placed in the roads referred to above. In this way, the water-table level will be decreased, and the liquefaction potential – if it exists – will be reduced. For the time being, the drainage problem at B&B Hospital is not only a potential source of liquefaction, but also a source of major environmental and sanitary problems.



Drainage problems at Gwarko – Lalitpur. A pond had formed next to B&B Hospital as a result of water damming.

The water-table level had risen, increasing the possibility of liquefaction if there is any shallow sandy layer prone to it.

Appendix 5

SITE EFFECT EVALUATION

DEFINITION

When seismic motion coming from bedrock passes through the soft sediments overlying that bedrock, the ground motion intensity can be amplified. This phenomenon is called "site effect".

In soft silty-clay quaternary deposits, the ground motion amplification rate can be as large as 400% during small ground-shaking intensities (MMI < VII), from 150% to 200% during moderate intensity (MMI = VIII), and cannot be produced if the seismic intensity is high (MMI = IX).

In stiffer soils, the ground motion amplification rate is often less than 150% the intensity of the bedrock motion, whatever the size of the earthquake.

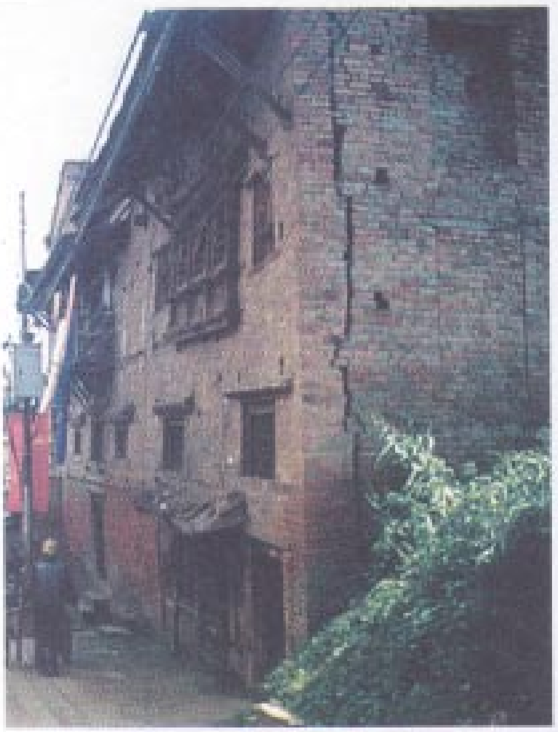
GROUND MOTION AMPLIFICATION IN KATHMANDU VALLEY

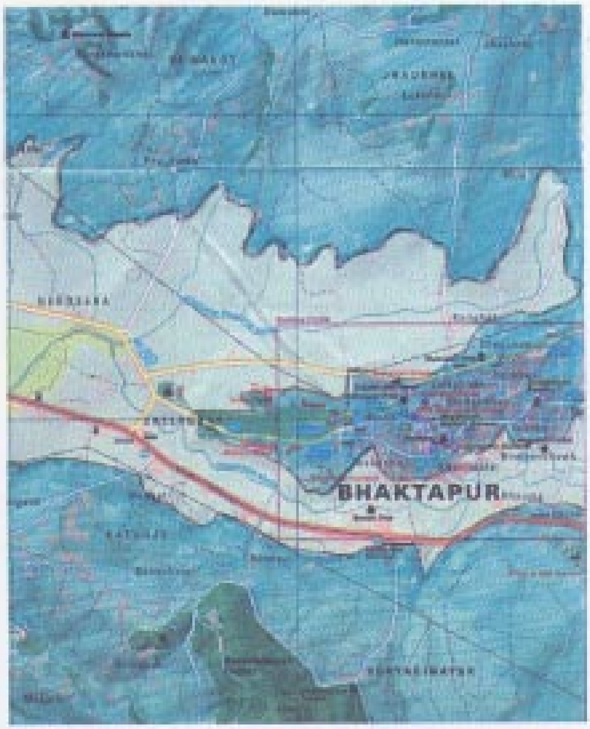
Except for in Bhaktapur, where a homogeneous soft soil deposit was found, the soils in Kathmandu Valley are a combination of soft and slightly compacted stiff layers, which are not soft enough to produce large amplification rates.

The Study on Earthquake Disaster Mitigation in Kathmandu Valley, 2000-2001 conducted by JICA found amplification rates ranging from 100% to 200% for an intensity MMI = VIII earthquake. The lower amplification rates correspond to the stiffer deposits commonly found within the Gokarna formation in the northern areas, and the higher amplification rates to the much softer deposits commonly found within the Kalimati formation, of which the Bhaktapur hills are the softest.

The Bhaktapur hills are about 40 metres high and are an continuation of other hills - a topographical effect which adds even more amplification to the soil. The soil dynamic characteristics and geomorphology will cause soil amplification that is large enough to increase the intensity of small and moderate earthquakes by one degree. For example, if Kathmandu Municipality experiences an earthquake of intensity MMI = VI, Bhaktapur will experience MMI = VII.

The situation in Bhaktapur city becomes critical, not only due to an increase of the ground shaking intensity, but also because the building stock is of lower quality than in other areas of Kathmandu Valley. The density of casualties in Bhaktapur will therefore be much larger than in any other place within the valley.





Left: *Damage to a building in Bhaktapur city due to previous ground shakings of intensity MMI = VI.*
Right: *Bhaktapur hills, as shown on the map, are a continuation of mountains. Soil amplification will occur because of the soil characteristics and the topographical situation.*

Appendix 6

DEFINITION OF TERMS

FOUNDATION TYPES

Shallow Foundation

A shallow foundation is one in which its width is greater than its depth. All of the hospitals in Kathmandu Valley are constructed with a shallow foundation, despite the fact that in many cases, buildings of six or more storeys need a deep foundation when they are located in areas prone to liquefaction.

Spread or Isolated Footing

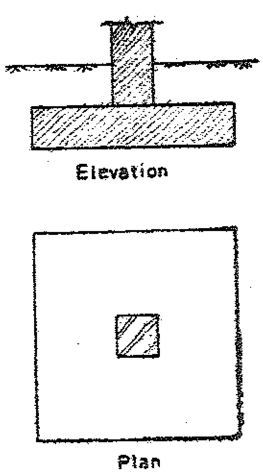
A shallow foundation provided to support columns individually.

Strip Footing

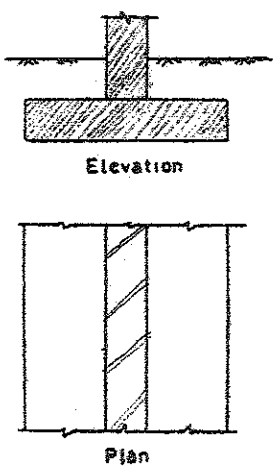
A shallow foundation provided to support bearing walls or column rows along a building's axis.

Mat or Raft Foundation

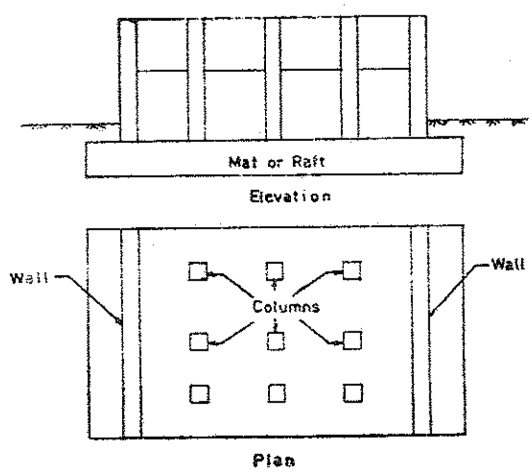
A shallow foundation provided to support a number of columns and walls under the entire structure.



Spread footing



Strip footing



Mat foundation

STRUCTURAL VULNERABILITY FACTORS

First-storey Weakness

This is a vulnerability factor local to Kathmandu Valley. A "weak-storey effect" induced by a lack of seismic capacity in the first storey. In Nepal a rule of thumb is that most of the RC moment-resistant-frames and non-reinforced-masonry bearing-walls systems are constructed with columns or walls of the same size from the bottom to the top of the building.

This usually results in too much strength in the top storeys and too little strength in the first storey. This effect is exacerbated by the common practice of adding one or more storeys to the building based upon its capacity to withstand additional vertical loads. As a consequence, the strength capacity in buildings with four or more storeys is frequently insufficient to withstand moderate or high intensity earthquakes (MMI = VIII–IX).

Lack of Quality Materials

During building construction, the use of concrete or cement mortar of a poor design will lead to a significant reduction in both strength capacity and ductility behaviour. In Nepal, it is common practice to prepare cement mortar by mixing 1 part cement to 6 parts sand. This results in masonry in which the mortar is weaker than the brick, and is of poor strength. During the occupancy of the building deterioration in building material quality is caused by different factors, such as dampness from leaking pipes, environmental factors, etc.

Short Column Effect

This effect happens when infill wall parapets are attached to RC or masonry columns, and only a portion of the column's length is able to deform under lateral seismic loads. These columns are much stiffer than others, so can receive much larger earthquake forces. Short columns are usually not designed to withstand large lateral forces, so will fail in a shear mechanism with diagonal cracks.

Lack of Redundancy of Columns or Bearing Walls

This is the existence of an insufficient number of columns or bearing walls to withstand earthquake loads. Redundancy can be evaluated by using UBC-97 specifications, section 1630[10]

Pounding Effect among Structures

The effect of crushing between neighbouring structures of independent dynamic behaviour, which are either separated by a seismic joint of insufficient dimension or attached without seismic joints.

Vertical Structural Irregularities

Stiffness irregularity or soft storey: A storey in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of the average stiffness of the three storeys above.

Mass (weight) irregularity: Mass irregularity is considered to exist when the effective mass of any storey is more than 150 percent of the effective mass of an adjacent storey. A roof that is lighter than the floor below need not be considered.

Geometric irregularity: Geometric irregularity is considered to exist where the horizontal dimension of the lateral-force-resisting system in any storey is more than 130 percent of that in an adjacent storey. One-storey penthouses need not be considered.

In-plane discontinuity in vertical lateral-force-resisting element: An in-plane discontinuity is an in-plane offset of the lateral-load-resisting elements greater than the length of those elements.

Discontinuity in capacity or weak storey: A storey in which the storey strength is less than 80 percent of that in the storey above. The storey strength is the total strength of all seismic-resisting elements sharing the storey shear for the direction under consideration.

PLAN STRUCTURAL IRREGULARITIES

Torsion irregularity: Torsion irregularity is considered to exist when the maximum storey drift, computed including accidental torsion, at one end of the structure transverse to an axis is more than 1.2 times the average of the storey drifts of the two ends of the structure.

Re-entrant corners: Plan configurations of a structure and its lateral-force-resisting system contain re-entrant corners, where both projections of the structure beyond a re-entrant corner are greater than 15 percent of the plan dimension of the structure in the given direction.

Diaphragm discontinuity: Diaphragms with abrupt discontinuities or variations in stiffness, including those having cut-out or open areas greater than 50 percent of the gross enclosed area of the diaphragm, or changes in effective diaphragm stiffness of more than 50 percent from one storey to the next.

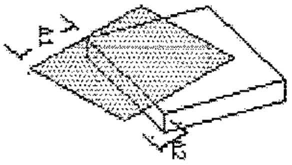
Out-of-plane offsets: These are discontinuities in a lateral force path, such as out-of-plane offsets of the vertical elements.

Nonparallel systems: The vertical lateral-load-resisting elements are not parallel to or symmetric about the major orthogonal axes of the lateral-force-resisting system.

PLAN IRREGULARITIES

Torsional irregularity

Architectural Plan



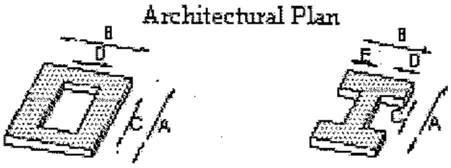
Re-entrant corners

$A > 0.15B$ **or** $C > 0.15D$

Architectural Plan

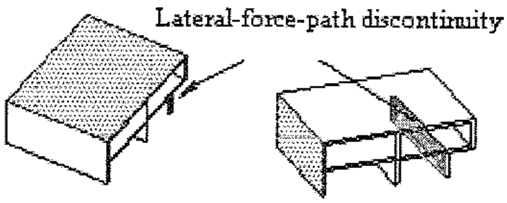
Diaphragm discontinuity

Architectural Plan

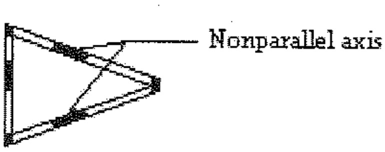


$C \times D > 0.5A \times B$ **or**
$(C \times D + C \times E) > 0.5\, A \times B$

Out-of-plane offsets



Nonparallel Systems



Architectural Plan

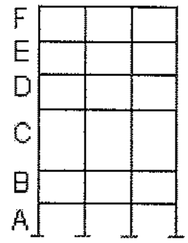
VERTICAL IRREGULARITIES

Soft story

$K_c < 0.70\, K_D$

or

$$K_c < \frac{(K_D + K_E + K_F)}{3}$$

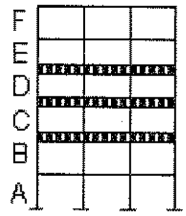


Mass irregularity

$m_D > 1.50\, m_E$

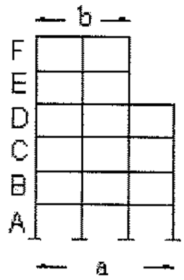
or

$m_D > 1.50\, m_C$



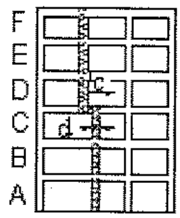
Geometric irregularity

$a > 1.30\, b$



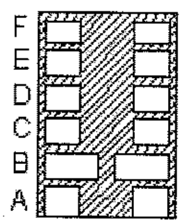
In-plane discontinuity

$c > d$



Weak story

$B < 0.80\, C$



Appendix 7

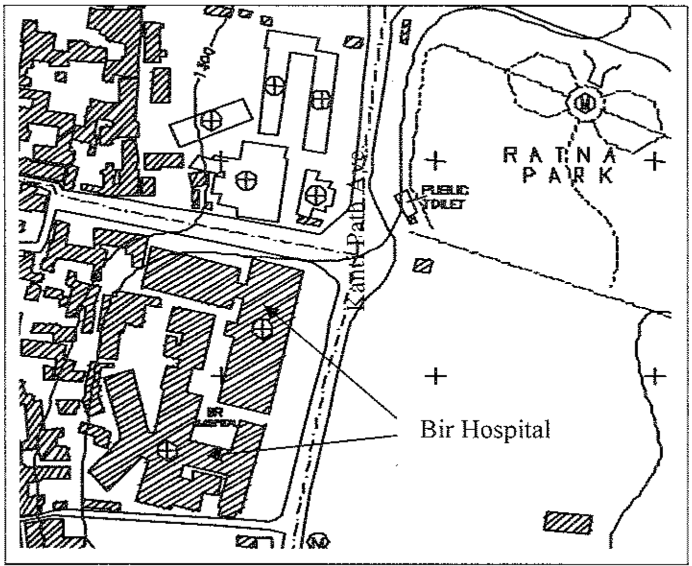
STRUCTURAL VULNERABILITY ASSESSMENT OF BIR HOSPITAL

LOCATION AND PROFILE

Bir Hospital is located in the core area of Kathmandu Municipality, Ward 30 (Mahaboudha). It is the largest public hospital in Nepal. 25% of its admissions come from outside Kathmandu Valley.

Medical Profile:

Classification: General Public Hospital.
Staff: 180 doctors and 210 nurses.
Critical and essential facilities: ED, OT, ICU, CCU, radiology, burns unit, nuclear medicine unit.
Total number of beds: 392.
Bed occupancy rate: 90 to 100%.
OT rooms: 8.
Observation beds in ED: 20.
Beds in ICU: -
Ambulances: 1.
Annual ED patients: 65,000.
Current occupancy-rate of 100%.



SEISMIC PERFORMANCE OF THE BUILDINGS

General Composition of the Buildings

The hospital is composed of five main buildings and a number of minor structures attached to the main buildings such as a corridor, a wedge and lateral annexes.

The "I" building (old building or surgical block)

The "I" building is best known as "the old building" or "the surgical block". This structure has an irregular plan with two rectangular wings of different lengths and a rectangular web in the middle defining an "I". It will be referred, in this study, as the "I" building. The main services in this building are the operating theatres and the neuro-surgical unit.

The "I" building was constructed in 1968 by USAID as a 3-storey reinforced concrete structure with thick infill masonry walls. Later, one floor was added on its two wings, and two on the middle area of its web, making it a 5-storey building.

The "L" building (intensive care unit building)

This building can easily be identified by its brick facades and "L" plan. It was constructed in 1973 as a 3-storey masonry building. Later, two floors were added. Now it is a 5-storey building where the intensive care unit, neo-natal and other critical care units are located from the first to the third floor, and a new cardio-surgical unit is currently being placed on the forth floor (2001).

The "V" building (burn unit building)

This building was constructed after the completion of the "L" and "I" buildings. It was initially constructed as a 2-storey masonry building to house in-patient beds for VIP patients. Later, one floor was added for the burn unit, making it a 3-storey building.

The "new" buildings

There are two "new" buildings. They are 5-storey buildings constructed in 1985 in co-operation with the Indian Government. Both buildings have rectangular plans. In these buildings most of the out-patient services are placed. One building, holding the emergency department, is located next to a secondary street. The second building faces Kanti Path. This is a composition of three structures separated by small seismic joints. A corridor forming a 90-degree angle rigidly connects the two "new" buildings. Five water tanks are placed on the roofs of the "new" buildings.

The "wedge"

This is a small, rectangular, 4-storey masonry structure that can easily be thought to be a part of the "I" building, especially when seen from the inside of the building. The wedge serves as a corridor and toilets are placed there.

This structure is attached like a wedge between the longest wing of the "I" building and the "L" building. It was built in 1973 as a non-engineering construction to connect the surgical units with the critical care units located in the "I" and "L" buildings respectively.

The "weak corridor"

This is a very small structure that serves as a corridor and rigidly connects the vertex of the "V" building to the centre of the longest wing of the "I" building.

Lateral annexes

There are two lateral annexes, one a 3-storey and the other a 1-storey masonry structure, attached to the "I" building at one of its re-entrant corners and to the "L" building at the other.

***Left building:** "L" (intensive care block). **Central building:** The "wedge". **Right building:** One of the "I" building wings (surgical block) connected to a yellow "V" building (VIP block) by a "weak corridor".*

Soil Condition, Foundation Type and Structural Systems in the Buildings

Bir Hospital is located on a site regarded as having low soil liquefaction potential. This was assessed in Appendix 4 based upon the recent geo-technical studies conducted at a neighbouring site where a new trauma building will be constructed.

The "new" buildings are constructed on mat foundations, the "I" building has spread footings with depth girders connecting its columns, and the "L" and "V" buildings have strip footing foundations.

The "new" buildings have reinforced concrete (RC) structural systems, which are assumed to behave as intermediate-moment-resistant-frames (IMRF) with moderate ductility behaviour. The infill walls are masonry-in-cement. Most of them are thin (10 cm) and weak, probably made of small bricks or hollow blocks.

The "I" building has a RC structure, which is assumed to be an ordinary-moment-resistant-frame (OMRF) with low ductility behaviour. Some of its infill brick in cement masonry walls are very thick (38 cm), and the lift walls are also very thick and probably made of RC.

The "L" and "V" buildings, wedge, corridor and annexes are all bearing-wall structural systems made of brick in cement non-reinforced masonry. The shear walls bear RC slabs. In the "L" building the wall is 39 cm thick, and in the "V" building from 10 to 45 cm thick.

The masonry strength is unknown, but for the purpose of this assessment it is assumed to have a compressive strength of 7 kg/cm^2 and a shear strength of 2 kg/cm^2, because it is normal practice in Kathmandu to prepare the mortar mix in the relation 1 part cement to 6 parts sand. Such a cement mortar is considered to be weak.

The above information was obtained through visual observations of Bir Hospital and interviews with relevant employees. There are no structural drawings available, so if a detailed and quantitative structural vulnerability analysis needs to be conducted, further investigation is necessary to validate this data and to evaluate the building materials' seismic strength and behaviour.

Structural Vulnerability Factors in the Main Buildings

In the following tables, the vulnerability factors that can influence the seismic performance of the main buildings are summarised:

The "I" building:

<table>
<tr><th colspan="2" rowspan="2">Vulnerability Factors</th><th colspan="5">Influence on the Building's Seismic Performance</th></tr>
<tr><th>High</th><th>Medium</th><th>Low</th><th>None</th><th>Not Known</th></tr>
<tr><td rowspan="2">Poor quality of materials</td><td>From construction stage</td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>Due to deterioration effect</td><td></td><td colspan="2">X</td><td></td><td></td></tr>
<tr><td rowspan="5">Plan Irregularities</td><td>Torsion irregularity</td><td>X</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Re-entrant corners</td><td>X</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Diaphragm discontinuity</td><td>X</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Out-of-plane offsets</td><td></td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>Nonparallel systems</td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td rowspan="5">Vertical Irregularities</td><td>Soft storey</td><td></td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>Mass irregularity</td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>Geometric irregularity</td><td></td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>In-plane discontinuity</td><td></td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>Weak storey</td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td colspan="2">First-storey weakness</td><td></td><td>X</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Short column effect</td><td></td><td>X</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Lack of redundancy of columns or bearing walls</td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td colspan="2">Pounding effect among structures</td><td>X</td><td></td><td></td><td></td><td></td></tr>
</table>

The "L" building:

<table>
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<tr><td rowspan="2">Poor quality of materials</td><td>From construction stage</td><td>X</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Due to deterioration effect</td><td></td><td></td><td>X</td><td></td><td></td></tr>
<tr><td rowspan="5">Plan Irregularities</td><td>Torsion irregularity</td><td>X</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Re-entrant corners</td><td>X</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Diaphragm discontinuity</td><td></td><td colspan="2">X</td><td></td><td></td></tr>
<tr><td>Out-of-plane offsets</td><td></td><td colspan="2">X</td><td></td><td></td></tr>
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<tr><td colspan="2">Lack of redundancy of columns or bearing walls</td><td></td><td colspan="2">X</td><td></td><td></td></tr>
<tr><td colspan="2">Pounding effect among structures</td><td>X</td><td></td><td></td><td></td><td></td></tr>
</table>

The "V" building:

<table>
<tr><th colspan="2" rowspan="2">Vulnerability Factors</th><th colspan="5">Influence on the Building's Seismic Performance</th></tr>
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<tr><td>Due to deterioration effect</td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td rowspan="5">Plan Irregularities</td><td>Torsion irregularity</td><td>X</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Re-entrant corners</td><td>X</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Diaphragm discontinuity</td><td>X</td><td></td><td></td><td></td><td></td></tr>
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<tr><td colspan="2">Pounding effect among structures</td><td>X</td><td></td><td></td><td></td><td></td></tr>
</table>

The "New" buildings:

<table>
<tr><th colspan="2" rowspan="2">Vulnerability Factors</th><th colspan="5">Influence on the Building's Seismic Performance</th></tr>
<tr><th>High</th><th>Medium</th><th>Low</th><th>None</th><th>Not Known</th></tr>
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<tr><td>Mass irregularity</td><td></td><td></td><td colspan="2">X</td><td></td></tr>
<tr><td>Geometric irregularity</td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>In-plane discontinuity</td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>Weak storey</td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td colspan="2">First-storey weakness</td><td></td><td>X</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Short column effect</td><td></td><td></td><td>X</td><td></td><td></td></tr>
<tr><td colspan="2">Lack of redundancy of columns or bearing walls</td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td colspan="2">Pounding effect among structures</td><td>X</td><td></td><td></td><td></td><td></td></tr>
</table>

Structural Vulnerability Assessment

The "I" building

The "I" building has masonry walls that are much more rigid than the RC structure but less strong. The infill masonry walls will carry most of the seismic loads during small intensity earthquakes MMI = VI–VII. Above intensity VII, the infill masonry walls will be extensively damaged, leaving only the RC frame structure to resist the loads from the seismic forces.

The columns are small in size (38 x 38 cm at the ground floor level) and have low steel-reinforcement ratios, providing poor ductility. In addition, the columns were designed for a 3-storey building, but they are bearing-loads from four or five storeys; thus much of their compressive strength has been used to support vertical loads and thereby not enough strength is available to resist lateral seismic loads. Under such conditions the columns will be controlled by compression instead of bending and the collapsing mechanism in the RC-OMRF is expected to be fragile at the ground level.

Also, considering the other vulnerability factors described in the previous section, such a fragile mechanism of collapse can occur soon after the RC-OMRF reaches its ultimate strength capacity. This may happen during moderate intensity earthquakes MMI = VIII with a peak ground acceleration of from 0.2 g to 0.35 g.

The "L" building

The "L" building has non-reinforced masonry walls without ductility. It was built as a 3-storey building without seismic design. It is now a 5-storey building, and a major portion of the walls' strength is being used to support permanent gravity loads. Little strength is available to resist earthquake loads.

This structure is highly vulnerable. It is much weaker than the "I" building and the "wedge" to which it is connected. Earthquake vibrations will cause the "I" building to hit the "wedge" like a hammer, consequently the "L" building will react as a junk. The "L" building will absorb the exerted energy from this pounding effect, and will prematurely collapse in a pancake failure soon after the bearing walls reach their ultimate strength capacity.

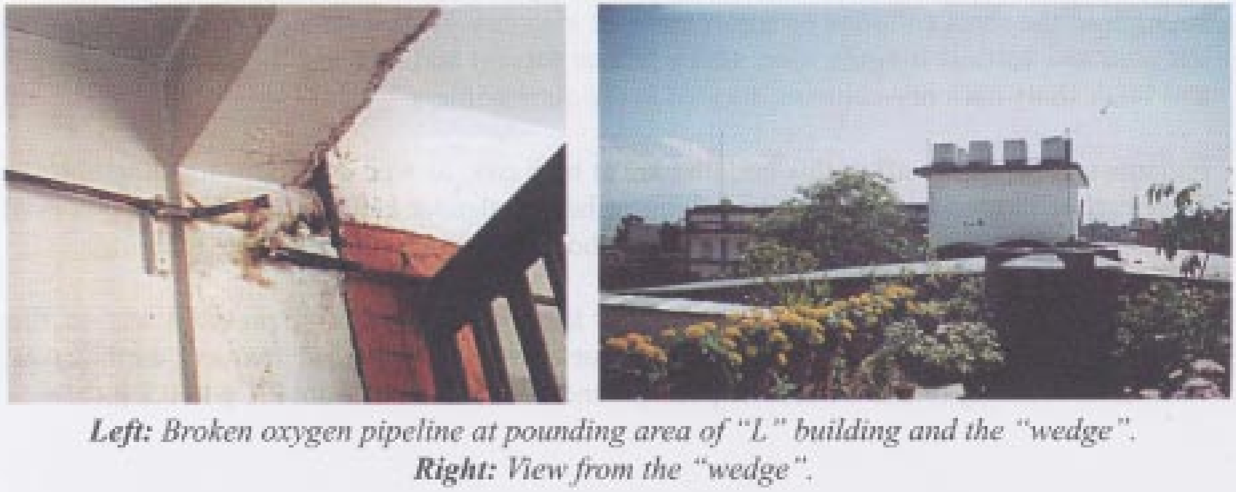
Such a premature collapse mechanism will be triggered by two factors; first, is the lack of strength in the short columns of non-reinforced masonry in the first-storey. And second, are the plan and vertical irregularities, which induce torsion and increase the stress in the walls and weak short-masonry-columns, located at the outer corners.

Patients and medical staff in this building are at high risk, as well as people standing outside. They can be injured or killed by the falling of heavy, slender and badly connected pieces of RC blocks that are decorating facades, even without the collapse of the whole building.

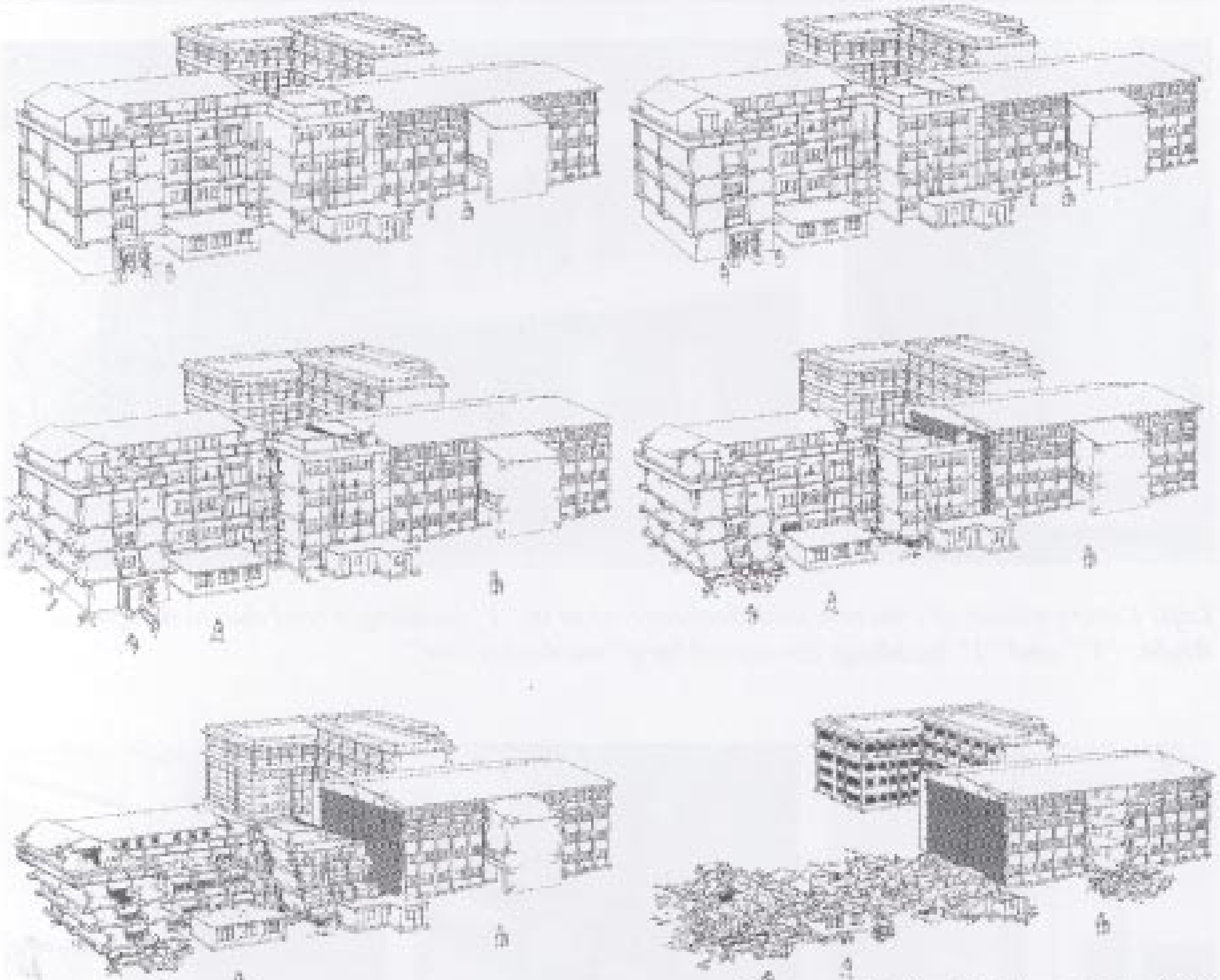
Also, taking into account the other vulnerability factors described in the previous section, this fragile mechanism of collapse is likely to occur during the so-called frequent earthquakes, with small intensity (MMI = VII) and peak ground acceleration of from 0.1 g to 0.2 g.

*"L" building: **Left:** Masonry or RC blocks can fall down and injure people during a MMI = VI-VII earthquake. **Middle and Right:** Short columns will be able to trigger the building and lead to fragile-collapsing-mechanism (pancake failure) during a MMI = VII earthquake.*

Cracks in pounding area between the "wedge" and the "L" building.
***Left:** Top storey. **Right:** First storey.*



***Left:** Broken oxygen pipeline at pounding area of "L" building and the "wedge".*
***Right:** View from the "wedge".*



Drawings: Mr. Chandan Ranamagar - NSET

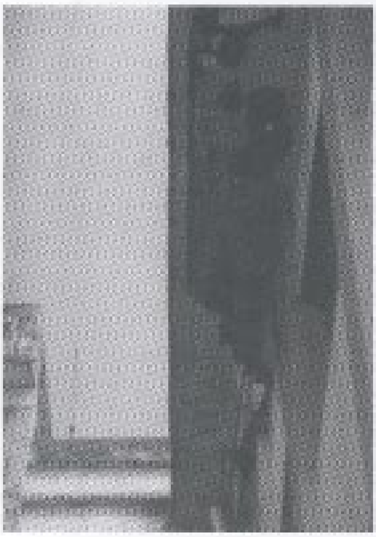
Probable pattern of collapse to "L" building, or intensive care unit, during a MMI = VII' earthquake.

The "V" building

The "V" building has non-reinforced masonry walls without ductility. It was built as a 2-storey building without seismic design, but with a large number of thick walls. Now it is a 3-storey building, with a soft top storey and poorly connected outer walls.

The "weak corridor" that connects the "V" building to the "I" building is expected to crack or collapse during earthquakes of small intensities (MMI = VI–VII). In this building the collapse will be triggered by the weakness of the first-storey outer walls, where short masonry columns are located, and the softness of the top floor. The "V" building has plan and vertical irregularities that induce torsion and increase the stress in the external walls.

Also, considering the other vulnerability factors described in the previous section, very heavy damage can occur soon after the bearing walls reach their ultimate strength capacity. This may happen during moderate earthquakes of intensity MMI = IX, with peak ground acceleration above 0.35 g.



Left: *Deterioration of concrete and steel corrosion in "I" building's roof due to dampness.*
Right: *"V" and "I" buildings connected by a "weak corridor"*

"New" buildings. ***Left:*** *Seismic joint of small size in the main building facing Kanti Path.* ***Middle:*** *Diaphragm discontinuity in one of the three structures composing the main new building.* ***Right:*** *Masonry parapets rigidly connect the new buildings where a seismic joint was designed.*

The "new" buildings

The "new" buildings were designed to behave as four independent structures with rectangular plans. Three seismic joints were introduced in the structural design. It is evident that the main seismic joint between the two buildings is not working.

This can be concluded from visual inspection, and from the fact that damage occurred in the infill masonry during very low intensity shakes (MMI = V). Masonry parapets rigidly connect these buildings.

In the building located next to Kanti Path, mortar debris was observed inside two seismic joints, slightly connecting its three structures. These joints can easily be opened by an earthquake of intensity MMI = VII or above. A pounding effect is then likely to occur due to torsion induced by diaphragm discontinuities in the two edge structures in this building.

Because the seismic joints are not working properly, the buildings will vibrate together predominantly in torsion. Shear stresses and damage will be concentrated at the corners. Thus, the IMRF structures, originally designed to develop a ductile mechanism of collapse for life safety, may fail to do so during high intensity earthquakes (MMI = IX). The IMRF structures are flexible and the infill masonry walls are thin, therefore heavy structural and very heavy non-structural damage is expected to occur during moderate intensity earthquakes (MMI=VIII).

SEISMIC PERFORMANCE OF LIFELINE SYSTEMS

Main Features of the Lifeline Systems

The lifeline systems' main features were obtained from suitable references[1] - [2], visual observations and interviews with relevant hospital employees. The results are as follows:

Electricity

There are two independent 11kV feeder lines connected to the public power supply. The automatic backup line is connected to Sundhara substation. The peak demand is estimated to be 750kVA. There are two transformers of 250kVA, often overloaded during peak demand. There is one manually operated emergency diesel generator that can provide 160kVA - 25% of the average hospital consumption - mainly to essential facilities such as operating theatres and emergency department, but not to the central sterilisation supply department.

Water

A treatment plant was recently installed to exploit water from a bore hole. The hospital's water consumption is estimated to be 100 to 250 m^3/day. There is one storage tank of 100 m^3 at ground floor level, and five 12m^3 tanks on the roofs of the "new" buildings. The dynamic effects induced by water tanks located on the roofs of the "new" buildings, as well as the resistance of the supporting elements, need to be evaluated in great detail. There is a large number of leaking pipes and dampness on walls, beams and columns.

Sewerage

Hospital sewerage is connected to the city network. The main sewage problems are related to items left in lavatory pans.

Steam

Electric generators supply steam to autoclaves at the central sterilisation supply department and the emergency department. No central boiler unit exists. During energy shortages, kerosene stoves will be used for sterilisation.

Medical gases

Oxygen is provided from a central room to operating theatres, the intensive care unit, the critical care unit and the cardio-thoracic unit. This means of supply is not reliable because of fragile pipelines. The cylinders used to supply oxygen are not restrained in either the central room or at the delivering sites. Two main units provide air and suction to operating theatres, intensive care units and critical care units.

Telephones

There is a 16-line PABX system connected to an UPS that can supply energy for less than 30 minutes. If the PABX runs out of service, the 13 lines which are directly connected to specific departments will be out of service.

It is expected that the external major telephone stations and the main microwave transmission network will be either overcrowded or out-of-service during an earthquake of intensity VII or above. In this case, mobile phones can be used as backup.

Paging, intercom and alarms

The paging system can support 200 pagers, but only 10 are working. The intercom is not functional. The emergency department has an alert system to call the staff in a mass casualty event. If the PABX goes out of service, the internal communication will be greatly affected.

Roads

Kanti Path is the only main road for access to the hospital. A traffic jam on this road is likely to occur in an earthquake of intensity VII or above.

Internal transportation

There are five lifts, two of them connected to the backup power system. The backup power may be enough to operate one lift, which should be the one near the operating theatres in "I" building.

There are six staircases; some of them are usually closed. The single staircase in the "L" building is very narrow and in the event of a mass evacuation, crowding can be expected with the possibility of people getting injured.

Waste disposal

Waste disposal methods were not available to this study. There is no information about an incineration unit, which may not be allowed at the hospital due to its proximity to densely populated areas. Collateral risks need to be evaluated.

Hazardous materials

LPG is used for cooking and water heating. There are two banks of four cylinders. There are 17 cylinders at the site, most of which are filled. None of the LPG cylinders are restrained. There is a nuclear medicine unit, with nuclear equipment to be installed soon. The nuclear equipment will be installed on the ground floor of the "new" building. Security measures in this room need to be evaluated.

Non-structural Vulnerability Assessment

Based upon the main lifeline systems' features and the structural vulnerability assessment described in previous sections, a non-structural vulnerability assessment has been made for earthquakes of various intensities. The estimated results are shown in the following table:

Non-structural Vulnerability Assessment of Bir Hospital

Buildings	Modified Mercalli Intensity Scale		
	MMI = VI	MMI = VII	MMI =VIII
"I"	Slight Damage	From Moderate to Heavy Damage	From Heavy to Very Heavy Damage
"L"	Moderate Damage	From Heavy to Very Heavy Damage	From Heavy to Very Heavy Damage
"V"	Slight Damage	From Moderate to Heavy Damage	From Heavy to Very Heavy Damage
"New"	Slight Damage	Moderate Damage	Heavy Damage

HOSPITAL RELIABILITY ASSESSMENT

Based upon the structural and non-structural vulnerability assessments described in previous sections and combining the results from the different buildings, a hospital reliability assessment is made for earthquakes of various intensities. The results are shown in the following table:

Bir Hospital Reliability Assessment

Modified Mercalli Intensity Scale		
MMI = VI	MMI = VII	MMI = VIII
Fully operational	Partially operational (intensive care unit building either collapsed or very heavily damaged)	Out of service for months or years

EMERGENCY PREPAREDNESS AND RESPONSE

Bir Hospital is one of the four main hospitals in Kathmandu Valley and is of utmost importance from a disaster management perspective due to its strategic location in front of a huge open area (Ratna Park) and near the city centre. The city centre is the most seismically vulnerable area in Kathmandu city and is expected to account for a large number of causalities during moderate to high intensity earthquakes (MMI = VIII-IX).

The lack of strength, pounding effects among structures and significant torsion movements due to a large number of irregularities in plan and elevation in the buildings' design, make the buildings prone to moderate to very heavy structural damages if an earthquake strikes. This is specially critical in the "L" building.

There is a mass casualty plan that will help the emergency department to successfully attend to the incoming casualties from a very small earthquake of MMI = VI. But neither the emergency department nor any other department in the hospital is prepared to successfully cope with the inflow of the large number of casualties from earthquakes of MMI = VII or above.

Emergency planning for an earthquake scenario of MMI = VII is both feasible and necessary for Bir Hospital. For an earthquake of MMI = VIII it becomes difficult and perhaps impractical, since the hospital is expected to be out of service, and the in-patients and medical staff should be considered as victims due to the probable collapse of some buildings. Besides, due to the size of such an earthquake, the incoming mass casualties will be better treated in tents in the open areas located nearby than in the ruins of the hospital.

For emergency planning, the following facts should be considered:

a) The emergency department is expanding; within months it will have doubled in size and will be able to attend to approximately 100 causalities. However, the expanded area is located in a separate structure. The emergency department will be divided into two structures separated by the corridor that rigidly connects the two "new" buildings. Damage in this area is expected to be larger than in other areas within the "new" buildings.

b) In a few years, the emergency department will be moved to the trauma building, a new structure which is to be constructed.

MAIN CONCLUSIONS AND RECOMMENDATIONS

Non-structural Aspects

Lack of reliable internal and external communication will be a serious problem. Most of the medical staff's private mobile phone numbers are not known to emergency department management staff. It would be suitable to create a private mobile phone database for emergency situations. In addition, pagers and the intercom system need to be updated and repaired.

The electricity supply seems reliable from two independent feeders. However, during earthquakes of intensity MMI = VII and above, the electricity supply from the city network becomes unstable. Bir Hospital should have the capacity to be self-sufficient for at least three days without external assistance. It is strongly recommended that Bir Hospital is equipped with a second emergency generator as it is stated in A Report on Emergency Preparedness and Seismic Vulnerability of Bir Hospital (NSET, R. Patton & B. Thomas, 2000).

The water distribution system needs to be examined and repaired to eliminate the problem of leaking pipes. The leaks are producing dampness in reinforced beams and columns, and are a source of corrosion in steel bars and deterioration of strength in the concrete.

A thorough evaluation of the stability of slender equipment all over the hospital is also recommended, especially within the medically critical and essential facilities as well as in the rooms for controlling and storing the main lifeline systems. Slender equipment and furniture need to be secured using belts or bolts, whichever is applicable.

Structural Aspects

A detailed structural analysis needs to be conducted to quantitatively assess the stability and behaviour of the buildings during earthquakes of different intensities.

However, from a qualitative approach, it is clear that most of the existing buildings were not seismically designed and so need to be retrofitted to be able to withstand an earthquake of intensity MMI = VIII with full or at least partial operational capabilities remaining.

It is strongly recommended the "L" and "I" buildings are retrofitted to improve their seismic performance. Based on visual inspection, it seems necessary to demolish the "wedge" in order to build a new structure where a staircase, wider than the existing one, and a lift should be placed. This new structure should be separated from the retrofitted buildings by two seismic joints. The new lift should have a backup electricity supply.

It is also recommended that the dynamic effects induced by the water tanks located at the top of the "new" buildings are evaluated.

In the "new" buildings, the masonry parapets should be remodelled to avoid the rigid connection of buildings. Tiles, masonry debris and any other type of links should be removed to clean the seismic joint between the two "new" buildings allowing them to behave independently during earthquake motions.

The new trauma building needs to be structurally designed for an earthquake intensity of MMI = IX with a peak ground acceleration of 0.4 g and a seismic coefficient of at least 0.24. The designed seismic performance of this building needs to provide full or at least partial operational capabilities during such an earthquake.

Appendix 8

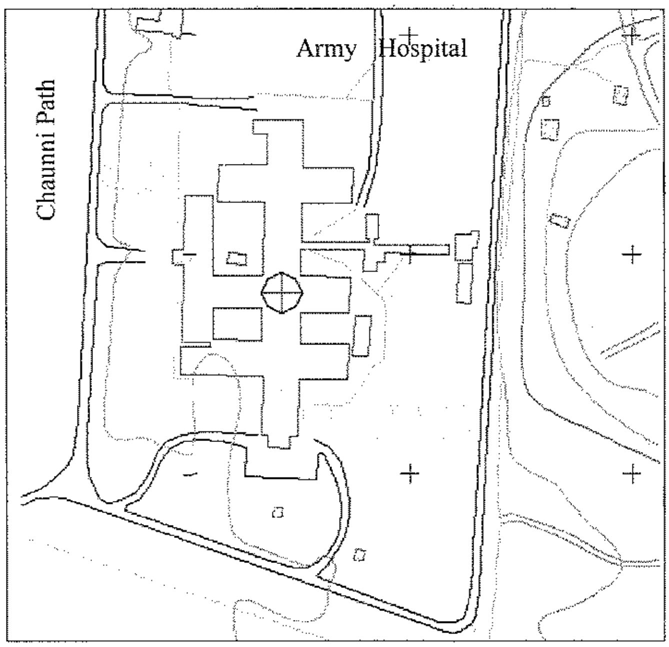
STRUCTURAL VULNERABILITY ASSESSMENT OF ARMY HOSPITAL

LOCATION AND PROFILE

Army Hospital is located in the western area of Kathmandu Municipality, Ward 14 (Chauni). It is the second largest hospital in Nepal. Approximately 100% of the admissions are army personnel and their families.

Medical Profile:

Classification: General Military Hospital.
Staff: 80 doctors and 85 nurses.
Critical and essential facilities: ED, OT, ICU, intensive trauma care unit, triage hall, radiology, blood bank (10 pints for each group are available).
Total number of beds: 380 (100 can be added).
Bed occupancy rate: 80 to 90%.
OT rooms: 4.
Observation beds in ED: 10 (40 can be added).
Beds in ICU: -
Ambulances: 5-6.
Annual ED patients: -



SEISMIC PERFORMANCE OF THE BUILDING

General Composition of the Building

The hospital is an assemblage of many blocks that are rigidly linked in such a way that they create a single building with a very irregular plan. It is a 3-storey reinforced concrete structure constructed more than 20 years ago. Later, new blocks were built and connected, enlarging the building in plan but not in elevation.

Soil Condition, Foundation Type and the Structural System in the Building

It is assumed that spread footings with depth girders connecting its columns were constructed beneath the building. It was reported that while the building's foundation was constructed, an aquifer was found flowing 1.2 metres below ground level. Because of this it became necessary to drain a large amount of water. It was also reported that sandy soils were found at site. Based upon the geo-technical studies conducted at the site during the hospital's construction, soil liquefaction potential is something that needs further investigation.

Settlements were also reported but from this study's visual inspection soil consolidation is not an issue that can affect the building's stability in the event of earthquakes.

The building has a reinforced concrete (RC) structural system, which is assumed to behave as an intermediate-moment-resistant-frame (IMRF) with moderate ductility. The infill masonry walls are brick in cement type. Most of them are about 15 cm thick. Decorative bricks cover the facade walls.

The above information was obtained from visual observations and interviews with hospital staff. There are no structural drawings available, so for a detailed and quantitative structural vulnerability assessment further investigation is necessary to validate this data and to evaluate the materials' strength and building's seismic behaviour during an earthquake.

Structural Vulnerability Factors in the Building

The different vulnerability factors that can influence the building's seismic performance are summarised in the following table:

Vulnerability Factors		Influence on the Building's Seismic Performance				
		High	**Medium**	**Low**	**None**	**Not known**
Poor quality of materials	From construction stage					X
	Due to deterioration effect				X	
Plan Irregularities	Torsion irregularity	X				
	Re-entrant corners	X				
	Diaphragm discontinuity	X				
	Out-of-plane offsets				X	
	Nonparallel systems				X	
Vertical Irregularities	Soft storey				X	
	Mass irregularity				X	
	Geometric irregularity			X		
	In-plane discontinuity				X	
	Weak storey				X	
First-storey weakness				X		
Short column effect			X			
Lack of redundancy of columns or bearing walls					X	
Pounding effect among structures					X	
Lack of seismic joints where necessary		X				

Structural Vulnerability Assessment

In some places, the building has seismic joints, which are closed by mortar, tiles and masonry walls. In other places, there is a lack of seismic joints. When an earthquake strikes, the lack of seismic joints and the plan irregularities will produce large torsion movements, as well as concentrate the stress and damage on the outer and re-entrant corners.

The size of the central columns (40 x 50 cm and 50 x 50 cm) is considered to provide sufficient strength to such elements, although the strength capacity of the outer columns (35 x 35 cm and 35 x 45 cm) needs to be evaluated in more detail. Particularly, the outer columns in the out-patients, physiotherapy and medical training centre block (35 x 35 cm) are less strong than the connecting beams.

When columns are weaker than beams, damage can be triggered first in the columns instead of the beams. In such a block, columns located at re-entrant and outer corners are likely to experience structural damage during high intensity earthquakes (MMI = IX).

The small size of the outer columns also creates a lack of torsion rigidity, and since torsion movements will be a predominant vibration pattern in this building, the non-structural damage to the facades will be much more extensive than the damage inside the building.

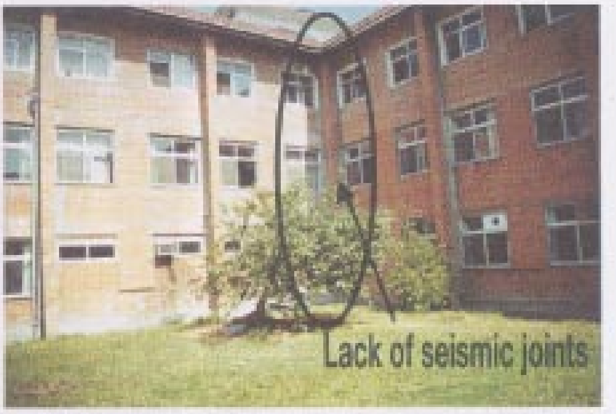
Few central columns were found to be insecure in the event of earthquakes. Only the columns that are supporting the ramp need to be evaluated in detail. The inclined ramp structure is much more rigid than others, and is introducing short-column effects in its bearing columns. Seismic joints designed to separate this structure from others were closed, so damage can be expected to concentrate in the area of the ramp.

Taking into account the building's structural configuration and the vulnerability factors described in the previous section, a fragile mechanism of structural damage may occur in the outer frames during high intensity earthquakes (MMI = IX) with a peak ground acceleration above 0.35 g. The structural damages will be characterised by the failure of a number of columns located at the outer and re-entrant corners. The extent of such damage is not expected to compromise the building's overall stability.

Slight to moderate structural damage is expected during intensity MMI = VIII events, and negligible to slight structural damage during intensity MMI = VII events. The structural vulnerability assessment is summarised in the following table:

Structural Vulnerability Assessment

Modified Mercalli Intensity Scale			
MMI = VI	**MMI = VII**	**MMI = VIII**	**MMI = IX**
No Damage	Negligible to Slight Damage	Slight to Moderate Damage	Moderate to Heavy Damage (failure of outer and re-entrant columns is possible).



Left: *Army Hospital main entrance.* ***Right:*** *One of the many re-entrant corners in the hospital. Decorative bricks cover the columns in the outer frames.*

Left: *Two blocks are rigidly connected with a weak corridor, which is likely to be crushed by strong ground shaking. The block on the right side is the out-patients, physiotherapy, and medical trainee centre block that has outer columns of 35 x 35 cm in size.*
Centre and Right: *A new one-storey block is under construction without seismic joints. The lack of joints and the plan irregularities can produce moderate to heavy structural damages in columns at outer and re-entrant corners during intensity MMI = IX.*

Indoors, there is a rigid inclined ramp defining short columns. Other central columns not bearing the ramp are considered to have enough seismic capacity according to their size.



Left: *Short column in the ramp area.* ***Centre:*** *Seismic joints closed by tiles, cement mortar, and a seal to avoid water leaks.* ***Right:*** *Seismic joint closed by masonry, and a repaired crack – probably caused by a previous small ground shaking - can be seen. In areas where seismic joints are closed, earthquakes usually produce the most severe damage.*

SEISMIC PERFORMANCE OF LIFELINE SYSTEMS

Main Features of the Lifeline Systems

Information about the main features of the lifeline systems was obtained from visual observations and interviews with relevant hospital staff. The findings are presented below:

Electricity

There is only one 11kV feeder line connected to the public power supply. There are two manually operated emergency diesel generators that can provide most of the energy required by the hospital. Supply to operating theatres, the emergency department, and other critical facilities can therefore be ensured.

Water

There is a water treatment plant, some small storage tanks, and a deep bore hole for the supply of water. The storage tanks rarely meet the hospital's water demand.

Sewerage

Hospital sewerage is not connected to the city network. The main sewage problem is disposal into the river.

Steam

Electric generators supply steam to autoclaves in the central sterilisation supply department and emergency department. No central boiler unit exists at Army Hospital.

Medical gases

There is a central oxygen room. Pipelines provide oxygen, air and suction to essential facilities such as operating theatres, the critical care unit and the intensive care unit. Oxygen is supplied to other units in cylinders. Air and suction are provided using electrical units.

Telephone, paging, intercom and alarms

The hospital has a sufficient number of telephone lines, so it seems likely that the hospital will be able to maintain communication in the event of an earthquake.

There is a central announcement system, intercom system and pagers. Furthermore, mobile phones and pagers have been provided to high-ranking staff.

Roads

From the east there are three access roads from the city-centre to Army Hospital. From the west, there are two main access roads that connect the hospital with the Ring Road. The accessibility is good for local standards and will be ensured by the Royal Nepal Army in the event of an earthquake.

Internal transportation

There are two lifts which can both be operated by backup power. The lifts are well maintained, as is most of the equipment within the hospital.

In general, there are no indications of lack of maintenance. There are 3 staircases designed to enable a quick and secure evacuation of the hospital's staff, visitors, patients etc., without over-crowding.

Internal transportation is not a problem. Due to the building plan configuration, evacuation can be done in very little time for those able to move on their own. The ramp and the capacity of its bearing columns to withstand major earthquakes should be checked.

Waste disposal

It is not known how waste disposal is carried out. The hospital has an incineration unit.

Hazardous materials

Hazardous materials are only used in the laboratories. Kerosene is used for cooking.

Non-structural Vulnerability Assessment

In Army Hospital two main features of non-structural vulnerability were found:

a) In the in-patient wards a large number of partition walls were constructed with big glass-windows to allow doctors a panoramic view of the patients. During an earthquake there is a risk that these windows will break and people will be injured by glass splinters.

b) The ramp was constructed as a part of an independent structure separated from neighbouring blocks by seismic joints. It seems to have been built initially without facades.

Now, the seismic joints have been closed and masonry facades have been attached to the ramp structure in such a way that these facades might be considered as fragile, and prone to large non-structural damage.

Based upon the main features of the lifeline systems and the structural vulnerability assessment described in previous sections, a non-structural vulnerability assessment was conducted for earthquakes of various intensities. The results are shown in the following table:

Non-structural Vulnerability Assessment

Modified Mercalli Intensity Scale			
MMI = VI	**MMI = VII**	**MMI = VIII**	**MMI = IX**
None to Negligible Damage	Slight to Moderate Damage	Moderate to Heavy Damage	Heavy to Very Heavy Damage

HOSPITAL RELIABILITY ASSESSMENT

As the hospital belongs to the Royal Nepal Army, it is expected to have a very good resilience capacity, much better than other hospitals in the Kathmandu Valley.

Based upon the structural and non-structural vulnerability assessments described in previous sections, a hospital reliability assessment was made for earthquakes of various intensities. The results are shown in the following table:

Army Hospital Reliability Assessment

Modified Mercalli Intensity Scale			
MMI = VI	**MMI = VII**	**MMI = VIII**	**MMI = IX**
Fully operational	Fully operational (depending upon the reliability of city network utilities)	Partially operational (due to a good resilience, and despite the extent of non-structural damage)	Partially operational (due to good resilience, and despite the extent of non-structural and structural damage)

EMERGENCY PREPAREDNESS AND RESPONSE

Army Hospital is one of the four major hospitals in Kathmandu Valley, and after Bir Hospital, is the second in importance from a disaster management perspective.

As it belongs to the Royal Nepal Army, the hospital will be required to play a leading roll in an earthquake scenario. This leading capacity is not only expressed by law, but is also due to the availability of equipment, logistics and personnel within the army.

Most of the hospitals in Kathmandu Valley have an insufficient number of ambulances and other means of transportation. In contrast, Army Hospital operates 5 or 6 ambulances during normal operation time, and is able to call on a large number of vehicles to cope with the needs of transportation during an earthquake.

The internal and external communication which this study estimates to be a serious problem for most of the hospitals may not be a problem for the Army Hospital, since radio communication facilities are usually available within the army forces. However, this is an issue that needs to be carefully planned in the context of a disaster contingency plan as radio communication systems from the army will also be called upon to support other major hospitals.

In the context of an earthquake contingency plan the following issues should be considered:

a) The hospital's capacity to place an extra 100 beds indoors. The hospital at Chauni can be supported by the Mohaboudha facilities, which are located where the Army Hospital used to stand, near the Bir Hospital, and in front of Tundikhel Parade Ground. Another 200 indoor beds can be placed in the Mohaboudha building.

b) The main structure in the Mahaboudha facilities is a 3-storey-building constructed with very thick brick in cement masonry walls (70 to 80 cm), which is considered to be able to withstand an earthquake of approximately MMI = IX intensity. As well as 200 in-patient beds, emergency management headquarters can be placed in this building because of its strategic location in front of a huge open area (Tundikhel Parade Ground).

c) At Army Hospital in Chauni, there is a 24-hour emergency team. It consists of 5 members trained and equipped to provide first aid. This team plays an important role in traffic accidents and can also play an essential role during small earthquakes of intensity MMI = VI.

d) A large number of tents can be put up outdoors in the open areas surrounding the hospital, as well as at Tundikhel Parade Ground. It is not known to this study whether the Army Hospital is able to provide the large number of tents which is needed to cope with the demands following a moderate or high intensity earthquake (MMI = VIII–IX).

e) Neither the emergency team nor the emergency department is prepared to successfully attend to an incoming flow of mass casualties from earthquakes of intensity MMI = VII or above.

For earthquake scenarios of MMI = VII, VIII and IX, emergency planning is necessary in Army Hospital.

The Old Military Hospital building, which is considered to be able to withstand up to intensity MMI = IX earthquakes.

It is of low structural vulnerability because of its thick walls (70 - 80 cm).

MAIN CONCLUSIONS AND RECOMMENDATIONS

Non-structural Aspects

Lack of preparedness against earthquakes will be a serious problem for Army Hospital. Most of the medical staff is unaware of how to proceed in the event of an earthquake, and there is no contingency plan that will enable an efficient response to a seismic scenario. Experience of, and capacity in, mass casualty management is considered very good at the hospital due to the large number of traffic accidents, but traffic accidents are only comparable with intensity MMI = VI earthquakes. This is why a contingency plan that can ensure an efficient response to earthquakes above intensity MMI = VI is essential.

The lack of planning for, training in, and awareness of earthquakes of intensities MMI = VII and above becomes very critical when considering the fact that Royal Nepal Army is likely to play the leading role in managing such emergency situations. Beside this, the Army Hospital will be called upon to lead the emergency response of the major hospitals in the valley. This fact should be considered in the contingency plan. Regular drills should be implemented to train the staff in emergency procedures.

It is also recommended that the hospital to be provided with a second independent electricity feeder, to increase the reliability of the electricity supply from the public network.

In the in-patient wards, the big glass-windows should be modified or removed. Laminated glass can be used instead of the ordinary glass, or transparent plastic sheets can be placed on panes to control the glass splinters if the glass panes break.

To mitigate the non-structural vulnerability of other architectural elements and equipment it will be necessary to reduce the plan irregularities by following the structural recommendations given below.

Structural Aspects

A detailed structural analysis needs to be conducted to mathematically and quantitatively assess the building's stability and behaviour during high intensity earthquakes (MMI = IX), to ensure that the outer frames will withstand such a ground shaking, and to reduce non-structural architectural damage to the facades.

It is clear from a qualitative approach that the building will significantly improve its seismic behaviour if the following recommendations are addressed:

a) Seismic joints should be introduced or re-opened where possible, to reduce plan irregularities: torsion, re-entrant corners and diaphragm (slab) discontinuities.

b) Reinforced masonry parapets should be introduced on both sides of the ramp's bearing-columns, to avoid short column effects.

c) The fragile facade located next to the ramp should be evaluated in detail. It seems that this facade is not properly connected to the ramp's structure and if it is made of masonry, it will experience very heavy damage during an earthquake.

d) On basis of the information provided by the hospital staff about soil condition at the site, it is recommended that the soil liquefaction potential is evaluated based upon the mechanical characteristics of soil's layers and the hydrostatic water-table level in the underground aquifer. The hydrostatic water-table level must be measured using piezometers.

Appendix 9

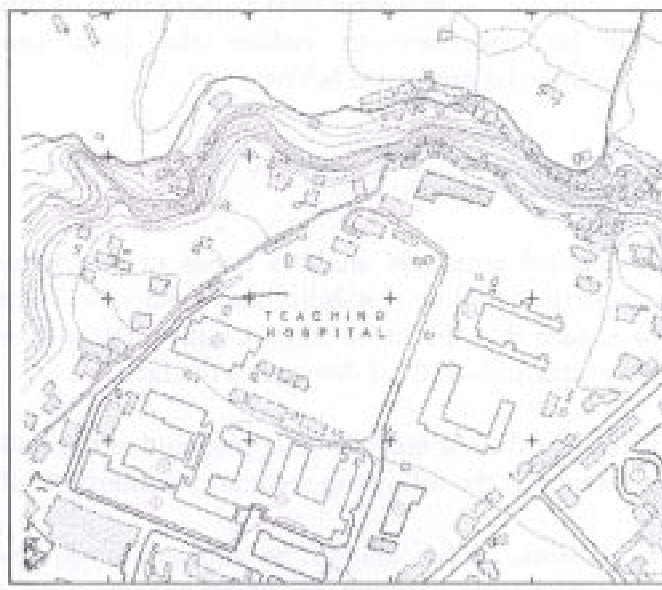
STRUCTURAL VULNERABILITY ASSESSMENT OF TEACHING HOSPITAL

LOCATION AND PROFILE

Teaching Hospital is located in Kathmandu Municipality, Maharajganj, Ward 3. Tribhuvan University runs the facilities under a Nepal - Japan collaboration framework.

<u>Medical Profile</u>

Classification: University Teaching and General Public Hospital.
Staff: 200 doctors and 350 nurses.
Critical and essential facilities: ED, OT, ICU, radiology, pathology, etc.
Total number of beds: 401.
Bed occupancy rate: 85 – 90%.
OT rooms: -
Observation beds in ED: 16, most of the time occupied by emergencies.
Beds in ICU: -
Ambulances: 1.
Annual ED patients: 35,000.



SEISMIC PERFORMANCE OF THE BUILDINGS

General Composition of the Buildings

The hospital has many blocks. Block D and B are four and three storey buildings respectively. Blocks A and C are 2-storey buildings. Blocks E, F, G, H, I, J, and K are 1-storey buildings. All of the blocks were constructed in 1984.

Since 1984, a few other buildings have been constructed. The two most important ones are the nursing and orthopaedic blocks, which are located in the northern area of Teaching Hospital's campus.

B, C and D blocks are connected by weak corridors, but are separated by seismic joints covered by mortar plastering which has already cracked due to previous ground shakings of seismic intensity MMI = VI.

A corridor connects A and B blocks. B block is a 2-storey independent structure with a setback in its first floor. Two seismic joints, seeming to be well-constructed, separate this corridor from the blocks, but pounding cracks were found on outer infill masonry walls. From this it can be concluded that the gap used might not be wide enough and that the buildings are dynamically interacting to some extent.

A, B and D blocks have plan irregularities such as re-entrant corners, diaphragm discontinuities, torsion, and vertical irregularities due to setback storeys. Seismic joints to divide the blocks into structures of rectangular plan, and a stiff foundation and rigid superstructure were used in a good way, given the buildings' architectural layout and the high earthquake risk in Kathmandu Valley.

Soil Condition, Foundation Type and Structural Systems in the Buildings

The hospital is located on a site where topographical maps show an altitude of 1,331 metres above sea level. A river-stream is flowing some 400 metres to the West, and its bed is below the topographic contour line of 1,310 metres.

Despite the fact that there were not geotechnical or soil investigation reports available, from previous geological studies and site geomorphologic conditions, it can be concluded that the soil profile is predominantly composed of gravels and sands of fair to good compaction and relative density over 60%.

Due to a good drainage condition, the piezometer water table level is expected to be more than 20 metres or more below the ground surface level, so soil liquefaction potential can be assumed to be very low or nil.

In every building, strip footings were used to support the columns and very deep girders were used as well. The foundation is 2 metres deep, so it is very rigid and soil-structure interaction and the pounding effect among neighbouring structures is expected to be significantly reduced.

All of the buildings have structural systems classified as special-moment-resistant-frame (SMRF) of high ductility behaviour.

The infill masonry walls are hollow-block-in-cement. Most of them are 15 to 20 cm thick. A strong-column and weak-beam ductile mechanism of failure had been designed, and the structure is strong enough to withstand major earthquakes with low ductility demands.

This information was obtained from visual observations, interviews to hospital staff, and structural drawings:

Structural Vulnerability Factors in the Buildings

The extent to which different vulnerability factors can influence the buildings' seismic performance are summarised in the following table.

Vulnerability Factors		Influence on Building's Seismic Performance				
		High	Medium	Low	None	Not Known
Poor quality of materials	From construction stage					X
	Due to deterioration effect				X	
Plan Irregularities	Torsion irregularity		X			
	Re-entrant corners			X		
	Diaphragm discontinuity			X		
	Out-of-plane offsets				X	
	Nonparallel systems				X	
Vertical Irregularities	Soft storey				X	
	Mass irregularity				X	
	Geometric irregularity		X			
	In-plane discontinuity				X	
	Weak storey				X	
First-storey weakness					X	
Short column effect					X	
Lack of redundancy of columns or bearing walls					X	
Pounding effect among structures			X			
Lack of seismic joints where necessary					X	

Structural Vulnerability Assessment

The moment-resistant-frame-structures were designed with large cross-section columns. For example, sections of 50 x 50 cm or 45 x 45 cm were used on the ground floor in block B.

The frames are considered strong enough to remain elastic up to intensity MMI = VIII earthquakes, and to have enough ductility to dissipate energy with only slight to moderate structural damage in the beams during high intensity earthquakes (MMI = IX).

The SMRF systems used are also stiff enough to limit storey drift deformations, keeping non-structural damage from slight to moderate during intensity MMI = VIII earthquakes.

Taking into account the buildings' structural configuration and the vulnerability factors described in the previous section, the structural vulnerability assessment is summarised as follows:

Structural Vulnerability Assessment

Modified Mercalli Intensity Scale			
MMI = VI	MMI = VII	MMI = VIII	MMI = IX
No Damage	No Damage	Negligible to Slight Damage	Slight to Moderate Damage

SEISMIC PERFORMANCE OF LIFELINE SYSTEMS

Main Features of the Lifeline Systems

The lifeline systems' main features were obtained from visual observations and interviews with relevant hospital staff. The results are as follows:

Electricity

There is one special 11kV feeder line with an independent connection to a power station. This is usually reliable. There is a backup feeder connected to operating theatres, the emergency department and the intensive care unit.

There are three automatic emergency diesel generators. Backup generators can provide most of the energy required by the hospital, with each one having a capacity of 208kVA. There is a diesel storage tank with a capacity of 1,500 litres. The three generators serve most of the hospital, including critical and essential facilities.

Water

A treatment plant, a deep bore hole, and a well supply water. There are five water tanks located on the roofs of the buildings. Each tank has a capacity of 12,000 litres and is fixed at four points, elevated 2 metres from the slab, and held by a truss constructed with small but thick steel angles. The stability of these water tanks during earthquakes should be checked.

Sewage

Hospital sewerage is not connected to the city network. Normally there are no problems with sewage, although the hospital can have up to 30 cm of water on the low areas for short periods during the monsoon season. No critical services have been affected. Because of the good drainage condition of the site, this is not considered to be a problem.

Steam

Steam is supplied to the autoclaves at the central sterilisation unit and the emergency department by electric generators. The central sterilisation supply department has electric boiling units.

Medical gases

There is a central room for the production and distribution of medical gases. Oxygen, suction and nitrous oxide are provided through pipelines from the central room to essential and critical facilities. Oxygen is provided to other facilities in cylinders. Air and suction are provided from electrical units.

Oxygen, suction and nitrous oxide pipelines are painted yellow, red and blue respectively. Flexible connections were found in those pipelines going through seismic joints.

Telephone, paging, intercom and alarms

There are some pagers but not enough. The intercom and announcement systems are very good. Most of the hospital areas are served. There is a fire alarm, but it has not been tested. Periodic drills are not conducted.

Telephones are a big problem as they usually run out of service. Mobile phones belonging to personnel are not available for calling. It is suggested that a mobile-phone database is created and used to call staff in emergencies. Mobile phones provided by the hospital are only available to the Director and Dean.

Roads

Maharajgunj Road is the only main road that accesses the hospital. This road is connected to the Ring Road 800 metres to the North. The accessibility of the site is considered good for local standards, but there is a lack of alternative routes.

Internal transportation

In A, B, E, F, G, H, I, and K blocks there are no lifts. There is a ramp for the vertical transport of patients, and enough staircases.

Internal transportation is good enough, but there is a lack of emergency evacuation and walkway signs.

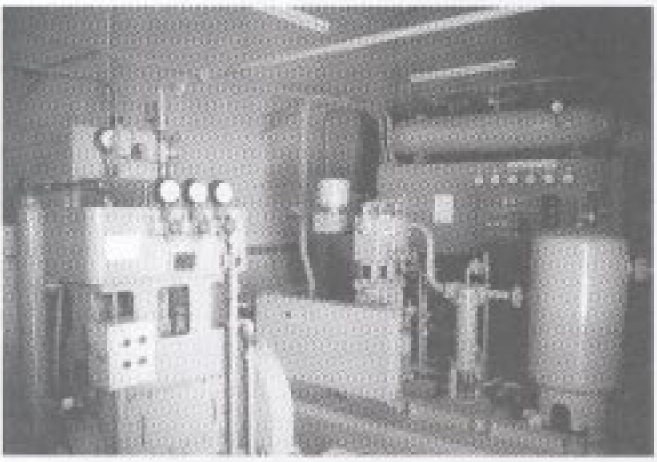
Waste disposal

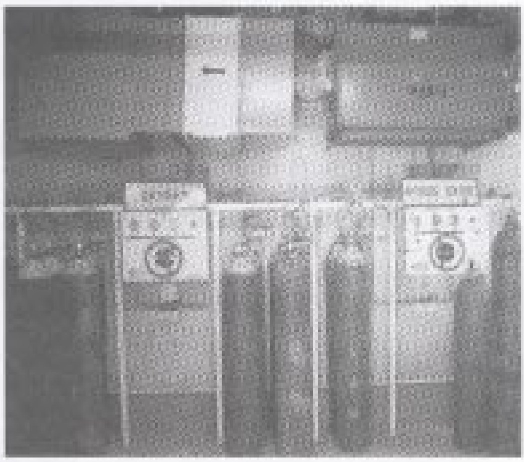
There is an incineration unit, located in a suitable place and with no reported problems.

Hazardous materials

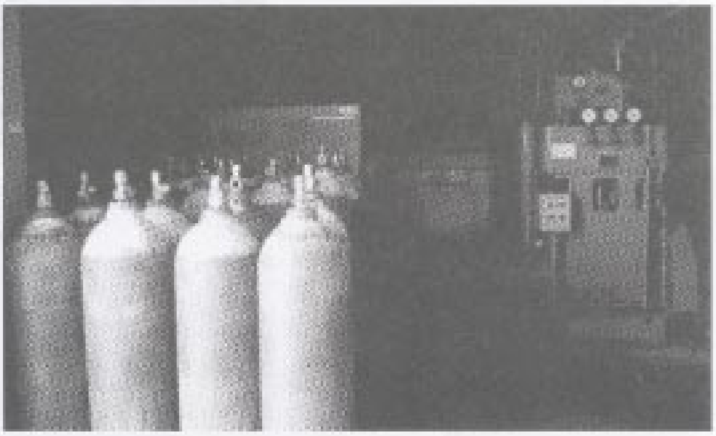
Large numbers of LPG cylinders are used for cooking and heating. There is a risk derived from handling and using LPG cylinders, and also a dependency on their supply from India. If there is a problem with either roads or imports, the hospital will experience a shortage. LPG storage is safe enough, strategically located next to the water treatment plant.

Other than LPG and substances commonly used in laboratories, there are no hazardous materials in use. Nuclear medicine is not available.





Central oxygen room. ***Left:*** *Oxygen plant. Maintenance is very good for local standards.* ***Right:*** *Oxygen cylinders being refilled. The lateral stability of such cylinders should be improved by using devices designed to fit the cylinders to the ground while they are refilled.*



Left: *Oxygen cylinders in a storage area.* ***Right:*** *Oxygen cylinders in the central oxygen room. To reduce non-structural vulnerability it is necessary to keep slender equipment, harmful to people, well-fitted and restrained against overturning.*

Non-structural Vulnerability Assessment

In Teaching Hospital the following features of non-structural vulnerability were found:

a) Vertical and plan irregularities and small seismic gaps would produce moderate to heavy non-structural damage in lifeline facilities and architectural components only during high intensity earthquakes (MMI = IX). The building structure is stiff so large lateral drifts, which are the main cause of damage in non-structural elements, are not expected to occur during small to moderate earthquakes.

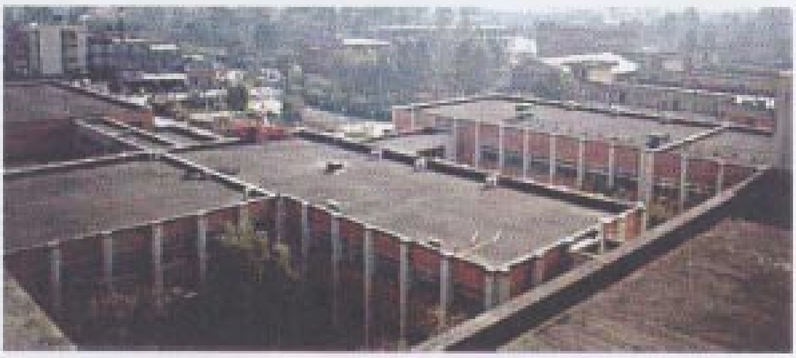
b) Lifeline systems in the hospital are complex for local standards, but international design standards seem to have been complied with and the quality of maintenance is very good.

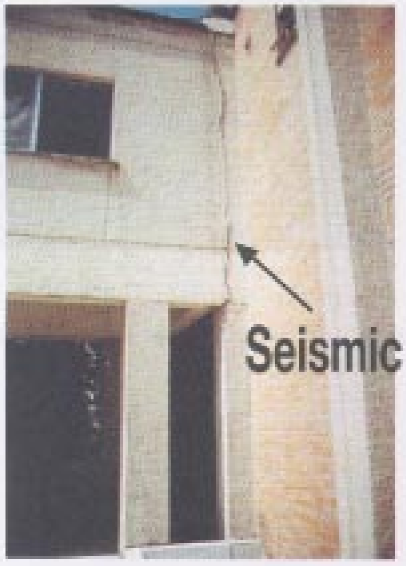
Based upon the main lifeline systems' features and the structural vulnerability assessment described in previous sections, a non-structural vulnerability assessment was conducted for earthquakes of various intensities. The results are shown in the following table:

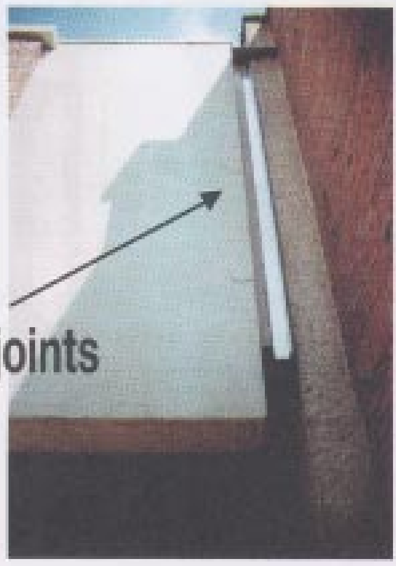
Non-structural Vulnerability Assessment

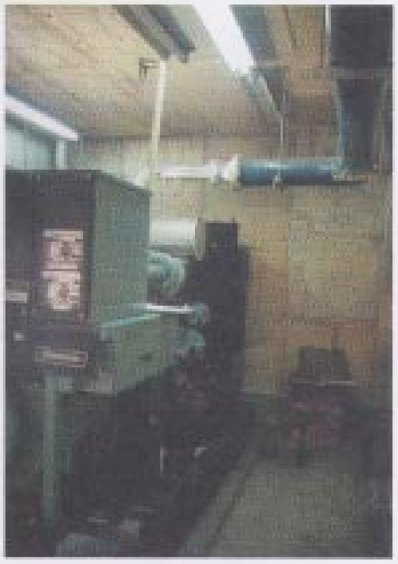
Modified Mercalli Intensity Scale			
MMI = VI	**MMI = VII**	**MMI = VIII**	**MMI = IX**
No Damage	Negligible to Slight Damage	Slight to Moderate Damage	Moderate to Heavy Damage

Seismic joints are not totally open. The buildings can dynamically interact and pound during earthquakes. This may cause slight to moderate damage to non-structural components during high intensity earthquakes (MMI = IX).

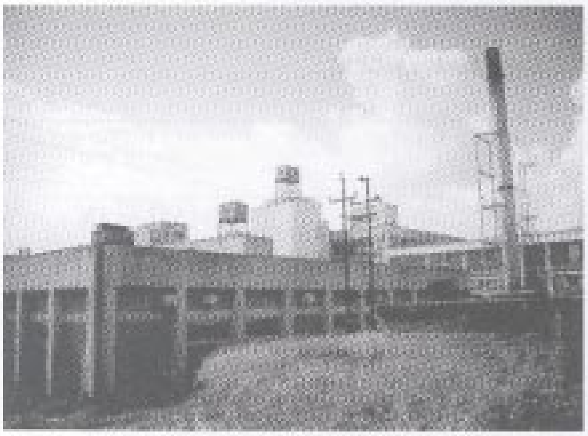


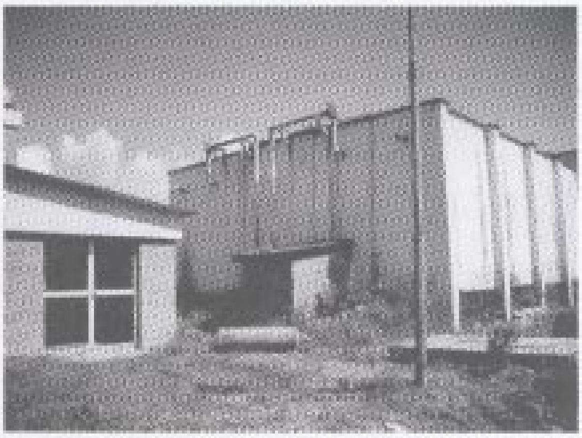




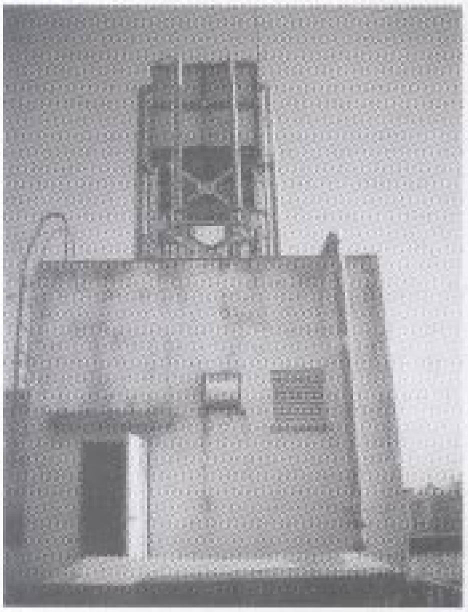


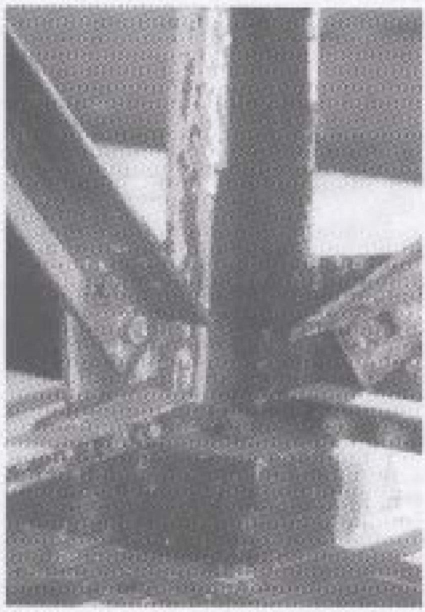
Left: *A seismic joint between block B and a weak corridor connecting it with block C. Mortar plastering has already cracked due to previous ground shakings.*
Middle: *Small cracks can be found in masonry walls due to pounding between structures. The buildings are interacting to some extent. This may cause slight to moderate damage to non-structural components during high intensity earthquakes (MMI = IX).*
Right: *Three automatic diesel generators of 208kVA provide electricity backup to the hospital. Most of the hospital can be powered, including essential and critical facilities.*





Left: *Water tanks (12 cubic-metres in capacity) on the roofs of buildings. The stability of such structures under intensity MMI = VIII-IX earthquakes need to be assessed.*
Right: *The main tank of the water treatment plant which is large enough to cope with water demand for at least a week.*





Left: *A 12 cubic-metre water tank on the roof of a 4-storey block.*

Right: *The strength capacity of water tank restraints should be checked.*

HOSPITAL RELIABILITY ASSESSMENT

The resilience capacity of Teaching Hospital is considered uncertain. Teaching Hospital has qualified staff; the Emergency Department Chief was trained in emergency management in Canada, but as in other hospitals in Nepal, there is not enough experience to deal with earthquakes.

The following may prevent the hospital from being fully functional: the extent of damage expected in city networks during intensity VIII and IX earthquakes, the dependency on LPG supply from India, and the lack of alternative ways to access to the site in order to transport goods and fuel.

Based upon the structural and non-structural vulnerability assessments described in previous sections, a hospital reliability assessment was conducted for earthquakes of various intensities. The results are shown in the following table:

Teaching Hospital Reliability Assessment

Modified Mercalli Intensity Scale			
MMI = VI	**MMI = VII**	**MMI = VIII**	**MMI = IX**
Fully operational	Fully operational	Fully operational or partially operational (depending upon the reliability of the city utilities networks, earthquake resilience, and stocks of diesel, water and LPG)	Partially operational (due to extent of non-structural damage)

EMERGENCY PREPAREDNESS AND RESPONSE

Teaching Hospital is one the four major hospitals in Kathmandu Valley, and after Bir and Army hospitals is the third in importance from a disaster management perspective.

It is asked to play a very important roll in managing complex emergency cases because of its specialised staff and facilities. This fact has to be taken into account in any emergency planning and preparedness process. In the context of an earthquake contingency plan the following issues should be considered:

a) It is necessary to enlarge the emergency department room. The Government should support this project. The emergency room is very small; sometimes 2 patients have to share one bed. Teaching Hospital had requested JICA to build a new emergency room, and the International Committee of the Red Cross (ICRC) had suggested enlarging it towards the neighbouring entrance hall. At least 30 observation beds are needed to cope with small mass casualty demand.

b) The cases coming into the emergency room tend to be surgical problems, hearth attacks, respiratory problems, and others. 90% of cases are very real emergencies. Few cases are from road accidents as these are treated by Army, Bir and Patan hospitals. The hospital attends nearly 100 emergencies per day, which is a large amount for its emergency room capacity. Up to 50 emergency cases can be managed simultaneously without major problem.

c) Police and Army hospitals deliver patients to Teaching Hospital, mainly those cases which are very difficult. Army Hospital has asked for help in special emergencies such as that of the Royal Family. In this situation the Teaching Hospital sent doctors to perform surgery. In 1987 the hospital also managed the stadium emergency, when a group of casualties were brought to its facilities. At that time, 60 cases were managed. Initially, most of the casualties went to Bir Hospital, but when it became overcrowded, the Teaching Hospital had to provide support.

d) Because of the limited space in the emergency department, tents are very necessary. The hospital has none. There is a parking area where a few tents, housing up to 200 people, can be located. In such a situation, it will be fine to bring the very real emergencies to Teaching Hospital.

e) Teaching Hospital does not have a trauma unit, but they have established a co-ordinated action between the surgical and orthopaedic departments, so as to be able to attend trauma cases as well. Handicap trauma facilities are not available.

f) The transportation of patients is a big problem. There is only one ambulance available and it is not well equipped.

g) Teaching Hospital has a disaster plan, and a team in charge of disaster management composed of the chiefs of the emergency, surgical, orthopaedic, and anaesthetic departments. There is good understanding of the fact that the lack of space, ambulances, radio communications and reliable telephones, tents and other emergency supplies will limit the hospital's response to an earthquake emergency.

h) The management system depends on Tribhuvan University and JICA, and is under a special international-co-operation framework.

i) There are no official links between the Army and Teaching hospitals. There are some unofficial links with the Bir Hospital because of the sharing of medical staff.

Teaching Hospital is used to working alone under its own protocols, and its services are primarily responding to academic demands. These facts are considered to reduce involvement and resilience against earthquakes.

There is a need for an integrated response from the health sector in Kathmandu Valley. In the event of earthquakes, Teaching Hospital medical expertise should be fully available and integrated into a joint emergency response system.

The constitution of an Earthquake Management System (EMS) for the integrated response of major hospitals is considered to be a priority issue for society.

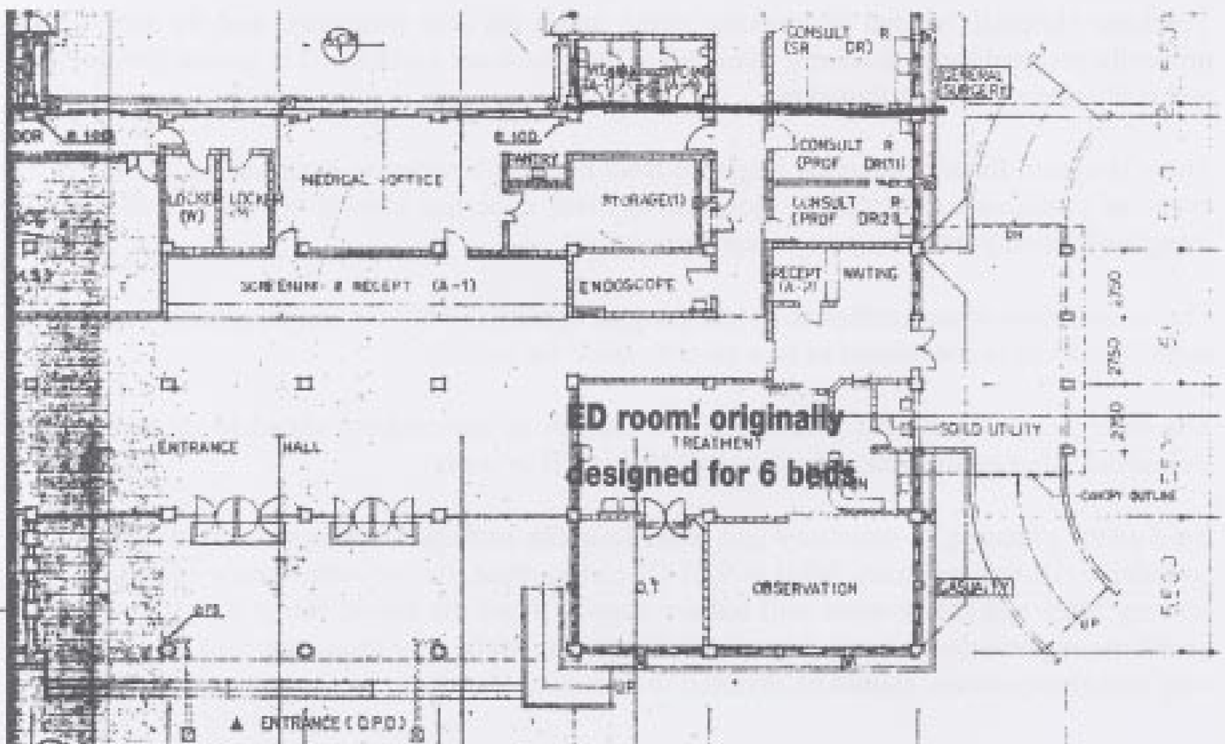
The emergency department is not prepared enough to successfully attend to incoming mass causalities from earthquakes of intensity MMI = VII or more.

Emergency planning is necessary and feasible under earthquake scenarios from MMI = VII and above. During intensity MMI = VIII-IX earthquakes, the incoming mass causalities will be very large and the hospital will require support from the Royal Nepal Army to divert an overflow of patients. A limited number of patients, preferably those that can be considered very real emergencies, should be diverted to Teaching Hospital.

Entrance Hall of block A, next to the emergency department room.

This is a potential area into which the emergency department area can be extended.

It is also recommend that the stability of the glass wall located in this area is increased.



Originally designed to accommodate 6 beds, the emergency department room now has 16. Its current capacity is permanently exceeded. It is necessary to enlarge this room to a capacity of at least 35 observation beds.

MAIN CONCLUSIONS AND RECOMMENDATIONS

Non-structural Aspects

A detailed non-structural assessment is recommended with specific emphasis on lifeline systems and equipment. This assessment does not need to be accomplished by a detailed quantitative structural analysis, but it must be detailed enough to provide an output to be used to reduce non-structural vulnerability and to increase the resilience and reliability of services.

It is necessary to assess the detailed non-structural mitigation measures that, once adopted, will permit the hospital to remain fully functional after intensity MMI = IX earthquakes.

In such a non-structural assessment the following issues need to be considered:

a) The stability of the water tanks located on the roofs of the buildings.

b) The stability of glass facades and a wall located in the nursing building and entrance hall area (block A). It is not known whether these glass areas are laminated or not.

c) The extension of the emergency department area.

d) The need to increase preparedness against earthquakes. Most of the medical staff is not aware of how to proceed in emergencies of more than 60 patients. Training in mass casualty events of less than 60 cases is considered very good, but these emergency situations are only comparable with intensity MMI = VI earthquakes.

e) The importance of co-ordination with the army to ensure accessibility to the hospital in the event of moderate or high intensity earthquakes.

f) The strength of communication between Bir, Army, and Patan hospitals. Teaching Hospital should not be excluded from high-level health sector policies and resolutions.

Structural Aspects

A detailed structural analysis to quantitatively assess building behaviour during high intensity earthquakes (MMI = IX) is not required.

Any future development, for example the architectural redesign of the emergency department area, should follow the structural design criteria of the original design. It is necessary to ensure good performance in earthquakes of up to intensity MMI = IX.

Appendix 10

STRUCTURAL VULNERABILITY ASSESSMENT OF PATAN HOSPITAL

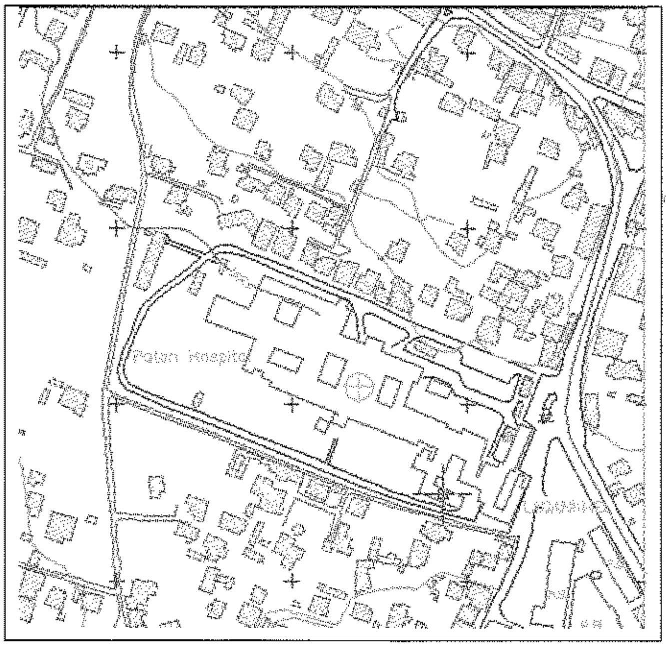
LOCATION AND PROFILE

Patan Hospital is located in Lalitpur Municipality, Lagankhel, Ward 5. Latitpur is located in the southern area of Kathmandu Valley.

The hospital is one of the largest in Kathmandu. United Mission to Nepal (A Christian organisation) runs the facility in co-operation with the Ministry of Health.

Medical Profile

Classification: General Public Hospital.
Annually 250,000 patients are treated.
Staff: 60 doctors and 250 nurses.
Critical and essential facilities: ED, OT, ICU, maternity & gynaecological units, radiology, and pathology.
Total number of beds: 300.
Bed occupancy rate: 90 – 100%.
OT rooms: 4, with 30 surgeries per day.
Observation beds in ED: 17, plus 7 for examination. Can be extended to 34.
Beds in ICU: 5, 100% occupied. Costly and difficult to finance for poor patients.
Ambulances: None.
Annual ED patients: 33,000.



SEISMIC PERFORMANCE OF THE BUILDINGS

General Composition of the Buildings

The hospital consists of a number of connected structures. The main building is a 4-storey structure, which is almost rectangular in plan, having outer and re-entrant corners. Three staircases are attached to this building, two at each end of the longest part of the building, and the third in the middle of the building. This building mainly holds the in-patient rooms and other non-critical facilities.

A 2-storey block is attached to the middle of the main building, opposite the main staircase. Operating theatres, radiology, intensive care units and other essential and critical facilities are located in this block. The main staircase is a 5-storey structure rigidly linked to the main building, connecting this building to a new 1-storey block where gynaecological units, including out-patient and in-patient maternity rooms, operating theatres etc. are located.

Several 1-storey structures are attached to three sides of the main building (none are attached to the side where the main staircase is placed). Most of the out-patient rooms and related services, as well as the emergency department, are located in these buildings.

Most of these facilities were constructed in 1982. Originally, the main building was designed as a 3-storey building, but during the construction period it was redesigned in order to increase the number of in-patient beds, making it a 4-storey building today. This was probably done because of the main structure's capacity to withstand four storeys. The building's structural seismic safety was not significantly decreased.

The emergency department was enlarged, and a new gynaecological block constructed, after the completion of the hospital in 1982. Since these are 1-storey buildings, the overall structural vulnerability of the hospital has not been altered by these projects.

Soil Condition, Foundation Type and Structural Systems in the Buildings

Topographical maps show that the hospital is located 1,320 metres above sea level. Geo-technical investigations conducted at a neighbouring site in Jawalakhel Chowk, show that the soil profile is good in terms of strength capacity, compared with most of the quaternary soils within Kathmandu Valley. Silty-sand and sandy-silt layers were found inter-layered from 4.5 to 14.5 metres under ground level. Below 14.5 metres, clay and silt layers were found.

The water table was found to be 13.5 metres under the surface, but the hydrostatic water table level may be below contour level 1,300 metres. This means that liquefaction is not expected to be a problem for Patan Hospital.

In the 2- and 4-storey buildings, strip-footing foundations were used to support the outer columns and spread-footing foundations to support staircases, shear-walls, and the central columns. No depth girders were used to connect the central and outer columns.

The foundation was constructed 2 metres below the ground floor. The foundation depth is sufficient to provide a good fix-end condition to prevent the building overturning. However, the lack of foundation girders is considered to be a vulnerability factor, which can induce damage to the ground floor due to soil-structure interaction during moderate to high intensity earthquakes (MMI = VIII–IX).

In the construction of the 1-storey buildings, spread footings were used to bear the columns. The 1- and 2-storey buildings have reinforced concrete (RC) structural systems classified as special-moment-resistant-frames (SMRF) of high ductility behaviour.

The main building is a 4-storey dual-system composed of a reinforced concrete moment-resistant-frame-structure and three shear walls in staircases. The beams connecting the shear walls to the frame structure are fragile, so the dual system is considered to have moderate ductility behaviour.

The infill masonry walls are hollow-block-in-cement type. Most of them are of about 10 cm thick. Decorative bricks cover the walls' facades. This increases the infill walls' stiffness.

Some infill walls are out-of-frame, and are likely to fall down during earthquakes. The lack of confinement inside the building frames increases the non-structural vulnerability. This information was obtained from visual observations, interviews with hospital staff, and structural drawings.

Structural Vulnerability Factors in the Main Building (4-storey dual-system)

The different vulnerability factors that can influence the building's seismic performance are summarised in the following table:

Vulnerability Factors		Influence on the Building's Seismic Performance				
		High	Medium	Low	None	Not Known
Poor quality of materials	From construction stage					X
	Due to deterioration effect				X	
Plan Irregularities	Torsion irregularity	X				
	Re-entrant corners	X				
	Diaphragm discontinuity			X		
	Out-of-plane offsets				X	
	Nonparallel systems				X	
Vertical Irregularities	Soft storey			X		
	Mass irregularity			X		
	Geometric irregularity	X				
	In-plane discontinuity				X	
	Weak storey			X		
First-storey weakness				X		
Short column effect				X		
Lack of redundancy of columns or bearing walls					X	
Pounding effect among structures		X				
Lack of seismic joints where necessary		X				

Structural Vulnerability Assessment

The buildings have seismic joints which have been closed using mortar and tiles to prevent insects. Other joints have not been closed yet, but since all seismic gaps were designed with a very short length they are not expected to work properly either open or closed.

The weak beams that connect the staircase walls to the main building's frame structure will reduce overall ductility performance and result in damage during an earthquake. All three staircases are weakly integrated into the main building's frame structure, and one stiff reinforced concrete shear wall was used in each staircase.

At the end of the staircases, walls are connected to the frame structure by two beams; the one located in the corner is very weak. During strong ground shakings, it can be expected that only the central beam will be able to transfer the forces and link the wall to the frame. In such a soft condition, the end staircases will experience big horizontal drifts and develop large non-structural damage in their masonry facades.

The central-staircase's shear wall is slightly asymmetric and ground shakings will introduce some torsion into the interacting structures which can be critical to the building's corners and the staircase's weak columns.

In one of the three staircases' corners, weak columns were built with a size of 25 x 25 cm from the foundation to roof level. In the other staircases' corners, infill masonry walls are poorly connected to the shear wall in a 90 degree angle. Such masonry walls located in the building's corners may experience heavy damage during earthquakes of intensity VII and above.

A RC wall supports the central staircase on one side, and two 25 x 25 cm columns on the other. This change in rigidity and strength makes the central staircase less secure than the moment-resistant-frame in the main building. Such weak columns can fail under shear stresses induced by moderate to high intensity earthquakes (MMI = VIII^{+}-IX), and the stairs will start to work as a cantilever structure inducing an overturning moment that will bend the wall and significantly increase non-structural damage. In such a situation, the entire brick-facade that is covering the RC wall, and is poorly connected to it, is expected to collapse.

The central staircase's RC wall is located outside the main building and is not well integrated into its frame structure, being connected to the cantilevered building slabs by two steel bars. The shear wall will interact with the building's frame and transfer stress to the main-building's floor diaphragms. It will tend to cut into the main building like a knife, bending the main structure while inducing shear stresses to the corners and neighbouring columns. The extent of the structural damage to the slabs and neighbouring columns of the RC wall can only be estimated following detailed quantitative analysis. Heavy structural damage can occur and even a collapse of the shear walls' structures is possible during high intensity earthquakes (MMI = IX).

Because of the good size of the building's outer columns (25 x 50 cm) and their very good redundancy, it can be expected that the main building's frame structure will be able to withstand an MMI = IX intensity earthquake, regardless of the extent of structural damage.

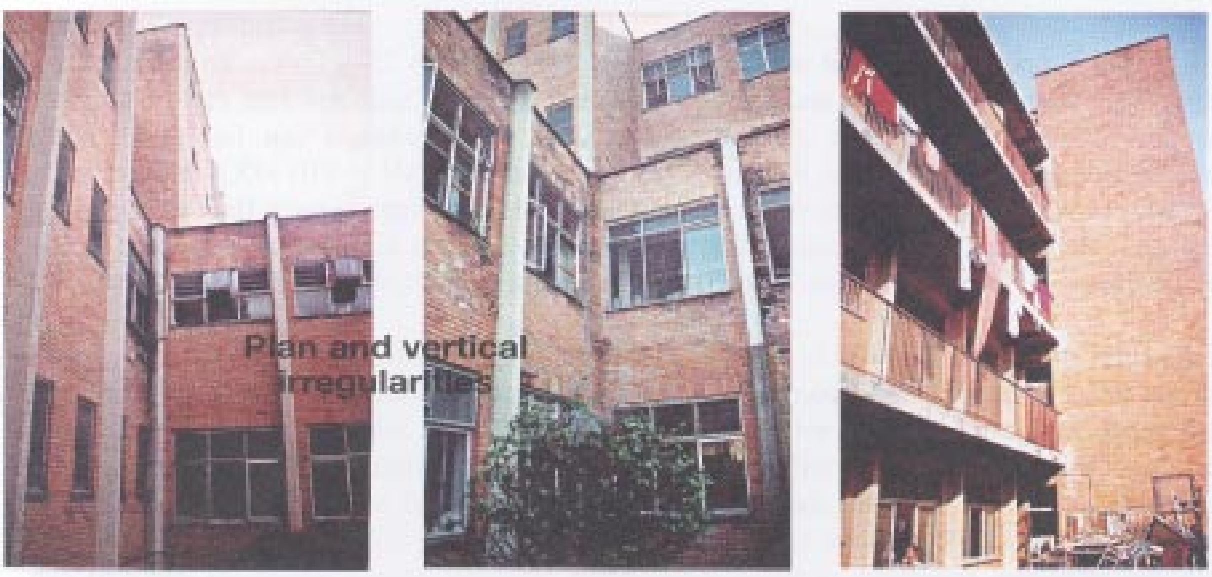
The probability of a general collapse of the building is very low. Most of the structural damage will be concentrated on the staircases, and in outer and re-entrant corners.

In the 1- and 2-storey buildings the size of the inner and outer columns are 35 x 35 cm and 25 x 35 cm, respectively. These dimensions are considered large enough to withstand an earthquake of intensity MMI = IX with slight to moderate damage.

On top of the main building there are big water tanks with a total capacity of 40,000 litres. If the water tanks are full, the big load, which is being applied to the structure at the top, will play an essential role in the main building's dynamic response to an earthquake. The dynamic effect induced by these heavy water tanks needs to be evaluated in detail in a quantitative analysis. Taking into account Patan Hospital's structural configuration and the vulnerability factors described previously, the structural vulnerability assessment is summarised as follows:

Structural Vulnerability Assessment

Modified Mercalli Intensity Scale			
MMI = VI	**MMI = VII**	**MMI = VIII**	**MMI = IX**
No Damage	Negligible to Slight Damage	Slight to Moderate Damage (damage of some outer columns in main building and staircases can be expected)	Moderate to Heavy Damage (collapse of staircase structures is possible)



Left and Centre: *Outer and re-entrant corners, and a closed seismic joint between the main 4-storey building and the surgical block, which is a 2-storey building. The vertical and plan irregularities due to the building setback in elevation and irregular plan shape can also be seen.* ***Right:*** *Reinforced concrete wall covered by a masonry wall with decorative bricks that are not well connected to the RC wall and can easily fall down during an earthquake of intensity MMI = VII or above. The RC wall of the main staircase is attached to the main building's floor slabs, and is not well connected to its moment-resistant-frame-structure.*

SEISMIC PERFORMANCE OF LIFELINE SYSTEMS

Main Features of the Lifeline Systems

The lifeline systems' main features were obtained from visual observations and interviews with relevant hospital staff. The results are as follows:

Electricity

There is one 11kV feeder line connected directly to a power station. This feeder has been reliable, although sometimes the power supply is interrupted. There are three manually operated emergency diesel generators, but only two of them are working. These backup generators can provide most of the energy required by the hospital, they each have a capacity of 63kVA. Supply can be ensured to operating theatres, the emergency department, other critical facilities, and also some in-patient areas.

Water

There is a water treatment plant, and a deep bore hole supplying the hospital's water. To store water, there are tanks located on the top floor of the main building which have a capacity of 40,000 litres. On the roof there are solar panels for water heating, however most of the rooms in the hospital do not have hot water because the solar panels do not provide enough energy.

Sewerage

Hospital sewerage is connected to the city network without major problems. Main sewerage problems are related to items put down in the lavatory pans. Sometimes there are problems in the neighbourhood sewage system, and people tend to think that it is the hospital's fault. Patan Hospital does not accept responsibility for it.

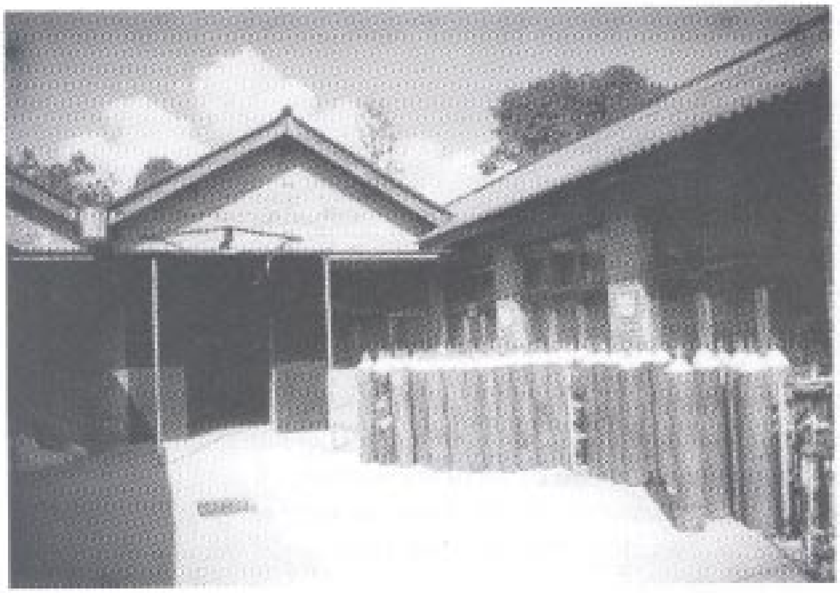
Steam

Electric generators supply steam to autoclaves in the central sterilisation supply department and the emergency department. A central boiler unit does not exist.

Medical gases

There is a small oxygen room, and there is also a pipeline to supply oxygen to the intensive care unit. This line is not fitted to the building; it is short and is connected via a window. Oxygen is provided to other essential and critical facilities such as operating theatres and the emergency department in cylinders. Air and suction are provided by electrical units.

The oxygen room stores 10 cylinders. Most of the cylinders are stored outside, some are full and others empty, waiting for replacement from outside the hospital. These cylinders are not restrained to prevent overturning. The hospital is planning to build a central room for oxygen to cope with the hospital's requirements, but the location has not yet been decided and there are financial problems related to this construction.



Oxygen cylinders storage area.

To reduce non-structural vulnerability it is necessary to keep all of the slender equipment which can be harmful to people well-fitted and restrained against overturning.

Telephone, paging, intercom and alarms

The hospital has a central alarm and speaker system. Some staff have mobile phones provided by the hospital. Telephone lines are connected to a PABX system.

Roads

Kumaripati Road is the only main access road to the hospital and this accessibility is not sufficient, but can be considered fair for local standards. The main problem is that an earthquake from intensity MMI = VII and above could cause a traffic jam in Kumaripati Road and make the access to the hospital difficult.

Internal transportation

There are two lifts but they cannot be operated by the backup power. The lifts are well-maintained, as is most of the equipment within the hospital. There are no signs of poor maintenance.

The two staircases at either end of the main building are always closed. The central staircase is quite big, and enables a quick, smooth evacuation from the main building in the event of an emergency. However, these staircases are structurally vulnerable, as described in the previous section, and people staying here during earthquakes of intensity MMI = VIII and above may be injured.

Internal transportation is not good enough. While evacuating the building, people may create traffic jams in the corridor on the ground floor, which connects the staircase to the main and gynaecology buildings.

Waste disposal

It is not known how waste disposal is carried out. There is no information regarding an incineration unit.

Hazardous materials

Hazardous materials are only used in the laboratories.

Non-structural Vulnerability Assessment

In Patan Hospital the following features of non-structural vulnerability were found:

a) Problems related to the seismic joints. Vertical and plan irregularities will result in a concentration of stresses in outer and re-entrant corners. This will cause cracks in the facades of the masonry walls and pieces of the decorative bricks may fall down during small to moderate intensity earthquakes (MMI = VII–VIII). Very heavy non-structural damage can be expected during moderate to high intensity earthquakes (MMI = VIII–IX), which can lead to the collapse of facade walls.

b) The three staircases are not well integrated to the moment-resistant-frame-structures, and are connected to them by weak elements. This is expected to cause very heavy non-structural damage in the masonry wall facades of the staircases. Also, heavy structural damage can occur and even lead to the collapse of such masonry walls during strong ground motion shaking (MMI = VII^{+}-IX).

c) In the 2-storey building, the masonry facade walls on the second floor, where the operating theatres are located, are prone to non-structural damage. These walls are located beside a pounding area where the four- and two-storey buildings interact along their short seismic gap, and define a setback with vertical and plan irregularities that induce the concentration of stresses and damage.

Based upon the main lifeline systems' features and the structural vulnerability assessment described in the previous section, a non-structural vulnerability assessment was conducted for earthquakes of various intensities. The results are shown in the following table:

Non-structural Vulnerability Assessment

Modified Mercalli Intensity Scale			
MMI = VI	**MMI = VII**	**MMI = VIII**	**MMI = IX**
None to Negligible Damage	Slight to Moderate Damage	Moderate to Heavy Damage	Very Heavy Damage

HOSPITAL RELIABILITY ASSESSMENT

The resilience capacity of Patan Hospital is considered to be good compared with most of the public hospitals in Kathmandu Valley.

Patan Hospital has a disaster protocol which assigns responsibilities to the staff, a social vision and a good management system. It can be expected that the staff will try to keep the hospital services available for the community.

Based upon the structural and non-structural vulnerability assessments described in the previous sections, a hospital reliability assessment was made for earthquakes of various intensities. The results are shown in the following table:

Patan Hospital Reliability Assessment

Modified Mercalli Intensity Scale			
MMI = VI	**MMI = VII**	**MMI = VIII**	**MMI = IX**
Fully operational	Fully operational or partially operational (depending upon the reliability of city utilities network, and the extent of non-structural damage)	Partially operational (based upon a good resilience and despite the extent of structural and non-structural damage).	Out of service (due to the extent of structural and non-structural damage)

EMERGENCY PREPAREDNESS AND RESPONSE

Patan Hospital is one of the four major hospitals in Kathmandu Valley, and after Bir, Army and Teaching hospitals, it is the forth in importance from a disaster management perspective.

It is called upon to play a very important role in Lalitpur Municipality in the event of an emergency, where it is the only public facility available. This has to be taken into account in any emergency planning and preparedness process. It is also a reason why more Government support to this hospital is desirable.

Like most of the hospitals in Kathmandu Valley, but maybe to the greatest extent, this hospital suffers from a lack of ambulances and other means of external transportation and communication.

In the context of an earthquake contingency plan the following issues should be considered:

a) There is a plan to build a trauma room. The Government should support this project, and its structural design needs to be designed to withstand an intensity MMI = IX earthquake.

b) Patan Hospital can, in the event of an emergency, be supported by the B&B private hospital. The Emergency Department Chief at Patan Hospital is also running the emergency department at B&B and these two main hospitals in Patan are fairly closely situated. National policies aimed at involving private facilities in disaster management should be considered a priority.

c) A triage area can be placed in the out-patients hall located beside the emergency department rooms. Up to 200 victims can be managed here at any one time. Thirty four beds can be added to the emergency department rooms.

d) The hospital does not have tents available in the event of a mass casualty inflow, nor do they have enough space outdoors to erect a large number. Outside, near the emergency department rooms, there is a small area of 20–50 square metres where a small number of tents can be erected.

e) Most of the emergency department cases are from road accidents, burns, heart attacks, and similar. The emergency department is trained in managing mass casualties of less than 40 persons at the same time. This is considered good for local standards, but there is no experience in the hospital of a large inflow of victims such as happens in the event of an intensity MMI = VII or above earthquake.

f) As mentioned earlier, Patan Hospital has a Disaster Protocol, which assigns responsibilities and commitments to key staff personnel in the event of an emergency. This protocol is basic, but a good starting point for further emergency planning, such as the distribution of a detailed earthquake contingency plan. The plan is also more than most of the other hospitals in the valley have, and a good experience to be shared among the other hospitals.

Unfortunately, communication and co-operation between this hospital and the other main hospitals such as Army, Bir and Teaching hospitals could be improved. Patan Hospital seems to work in isolation under its own protocols. This study considers this a weak link in the necessary efforts of making an integrated disaster response within the health sector in Kathmandu Valley. Patan Hospital's experiences regarding the emergency planning process should be shared and its capacity integrated with the health sector's planning process, which need to be considered as a priority for society.

Further emergency planning is necessary and feasible under earthquake scenarios of intensity MMI = VII-VIII as the emergency department is not sufficiently prepared to successfully attend an incoming mass causality inflow from earthquakes of this kind. During intensity MMI = VIII-IX, the inflow of mass causalities will be very large. Because there is not enough space in the hospital, the Royal Nepal Army will be required to support the diversion of overflow patients to other health facilities and to keep order.

If an earthquake of intensity MMI = IX strikes, the expected extent of damages may be large enough to put this hospital out of service. The medical staff will take care of their in-hospital emergency requirements and probably not be able to provide much support to the community.

MAIN CONCLUSIONS AND RECOMMENDATIONS

Non-structural Aspects

A detailed non-structural assessment is necessary. It should strongly emphasise the architectural elements in the outer and re-entrant corners of the main building and its staircases. This assessment should be based upon the results of a quantitative structural analysis.

From visual inspection, it can be concluded that the fragility of the staircases' masonry walls can be reduced by anchoring the masonry walls to the RC walls using bolts. The doors in both staircases at the end of the building should be permanently open to avoid crowding of people in the main building's core area at ground floor level.

It is necessary to increase earthquake preparedness. Most of the medical staff do not know how to proceed in mass casualty incidents with more than 200 victims, and there is no contingency plan to deal with earthquakes of intensity MMI = VII and above. Training in mass casualty inflow of less than 50 cases is considered very good, but this kind of emergency is only comparable with an intensity MMI = VI earthquake.

It is also recommended that a ramp is added to the hospital to provide an alternative route from the main building for the potential evacuation of people confined to bed. This will reduce the dependency on the lifts, which are not reliable in the event of an earthquake.

For the future construction of a central oxygen plant and an indoor pipeline network, it should be considered to incorporate countermeasures to reduce the non-structural vulnerability, as mitigating risks from the original design is always much more economical and secure than to do it afterwards. Flexible connectors should be used whenever the oxygen pipelines pass through a seismic joint.

Since there is no complex equipment installed in Patan Hospital, the non-structural vulnerability level of the existing lifeline facilities is low. The most important action is to ensure that the backup generators will work properly if the external power supply is interrupted. Fuel supply sources to the emergency generators should be increased.

The road access to the hospital is not good enough. Appropriate co-ordination with the army will be necessary to ensure accessibility to the hospital in the event of moderate to high intensity earthquakes.

Structural Aspects

A detailed structural analysis needs to be conducted in order to quantitatively assess the building's behaviour during high intensity earthquakes (MMI = IX), to ensure that the outer frames will withstand such ground shaking, and to provide data to reduce the architectural non-structural damage to the facades.

Such a structural assessment needs to include a study of the following issues:

a) The stability of the water tanks and the dynamic effect on the main building's structure resulting from a load of approximately 40 tons located on the top storey.

b) The stability of the staircases during an earthquake.

c) The construction of a new ramp next to one of the main-staircase's facade masonry walls, where a second reinforced concrete shear wall can replace the weak columns. The ramp can either be structurally connected to the staircase or separated by a seismic joint. A detailed structural analysis should investigate which of these possibilities will be most beneficial to the main building's overall seismic behaviour.

Appendix 11

STRUCTURAL VULNERABILITY ASSESSMENT OF BHAKTAPUR HOSPITAL

LOCATION AND PROFILE

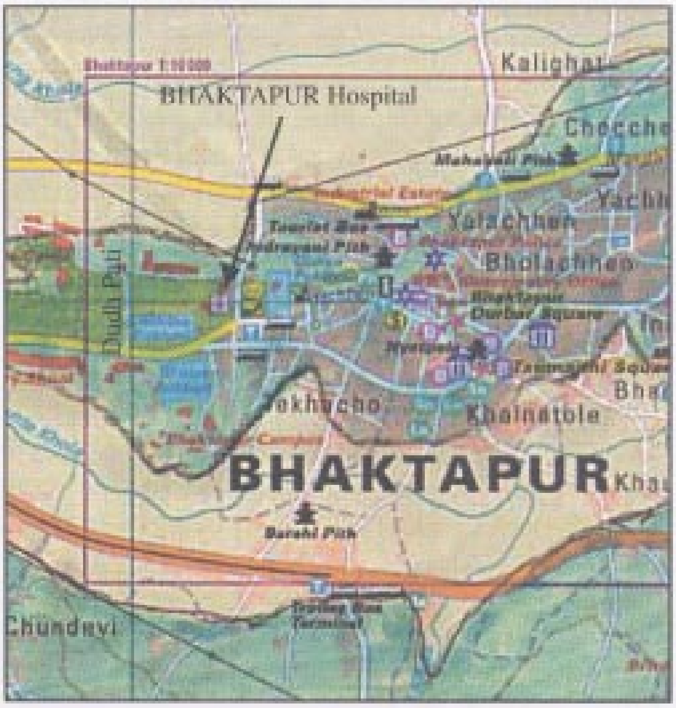
Bhaktapur Hospital is located in Bhaktapur Municipality, in Dudh Pati, Ward 17. It is a governmental facility, the main and only general public hospital in Bhaktapur District. It serves a population of 226,000 inhabitants.

The hospital offers many medical services like radiology, gynaecology, and ultrasound. Most of the critical facilities are available in small numbers, such as operating theatres and an emergency department. The hospital has no intensive care unit.

Medical Profile

Classification: General Public District Hospital.
Staff: 11 doctors and 25 nurses.
Critical and essential facilities: ED, OT, radiology, pathology, and gynaecology.
Total number of beds: 50.
Bed occupancy rate: 30 – 60% most of the year. 60 – 100% during summer.
OT rooms: 2 (one of them is for minor surgery in ED).
Observation beds in ED: 7 and another 7 can be placed in the emergency building.
Beds in ICU: There is no ICU.

Ambulances: 1.
Annual ED patients: 7,172 cases during 2000, and 9,072 in 2001.



SEISMIC PERFORMANCE OF THE BUILDINGS

General Composition of the Buildings

Bhaktapur Hospital operates in a 3-storey building that easily can be identified by its brick facades and "L" configuration plan.

This structure will be referred to as the main building. It was constructed in 1978 as an administration block for a major hospital complex. Later, a neighbouring building was used to house the Cancer Hospital, and the General District Hospital remained in this administration building, which is adequate for the facility.

A few months ago a new 1-storey building was constructed to house the emergency facilities for mass casualty accidents, but it is not in operation yet. In this study it will be referred to as the emergency block.

Soil Condition, Foundation Type and Structural Systems in the Buildings

Topographical maps show that the hospital is located approximately 1,325 metres above sea level. Two river streams flow some 600-800 metres to the North and South. The riverbeds are below the 1,300 metre contour line.

At Bhaktapur Dubar Square, a renowned site located 1.5 Km to the East at an altitude of almost 1,335 metres, a JICA project conducted a geo-technical investigation 30 metres in depth. During the last day of drilling, the water table level was found 24.5 metres down, but topographical conditions suggest that the hydrostatic water table level is deeper.

Despite the fact that there were no geo-technical or soil investigation reports available for the site of Bhaktapur Hospital, it can be concluded, based upon the site's geomorphologic conditions and the soil profile obtained by the JICA project, that the soil profile is predominantly composed of silt-clay layers of soft to medium consistency. The soil at the site does not have any potential liquefaction risk.

Bhaktapur city is located on an approximately 40 metre-high soft hill. The dynamic characteristics of its soil profile can produce amplification of earthquake intensities from the bedrock to the ground surface.

This phenomenon is expected to be very large in the event of earthquakes of small intensities (MMI = VI-VII) and long period-waves. The ground shaking can be amplified by a factor of 2 to 4, and Bhaktapur will experience one-degree higher intensity than much of the Kathmandu Valley.

Such site effects may occur in many cases. Most of the seismic sources in Nepal produce shallow earthquakes and are far enough from Kathmandu to induce motions with long-period-waves in the valley.

In the main building, it is believed that strip footings are used as the foundation for the masonry walls. The foundation depth is not known to this study. The main building has a bearing-wall structural system made of brick in cement non-reinforced masonry.

The shear walls bear reinforced concrete (RC) slabs. Wall thickness is 35 cm. Despite the fact that the masonry strength is unknown, it is a normal practice in Kathmandu Valley to prepare the mortar by mixing 1 part cement with 6 parts sand.

The emergency block was constructed with spread footings and foundation girders, but the foundation depth is not known to this study. Its structural system is made of hollow-block-in-cement reinforced masonry. Based on a visual inspection, this building is considered to be very safe during earthquakes as its roof is very light and the structural system is earthquake resistant.

This information was obtained from visual observations, and interviews with hospital staff.

Structural Vulnerability Factors in the Main Building

The different vulnerability factors that can influence the main building's seismic performance are summarised in the following table:

Vulnerability Factors		Influence on the Building's Seismic Performance				
		High	**Medium**	**Low**	**None**	**Not Known**
Poor quality materials	From construction stage	X				
	Due to deterioration effect				X	
Plan Irregularities	Torsion irregularity		X			
	Re-entrant corners		X			
	Diaphragm discontinuity		X			
	Out-of-plane offsets			X		
	Nonparallel systems				X	
Vertical Irregularities	Soft storey				X	
	Mass irregularity				X	
	Geometric irregularity				X	
	In-plane discontinuity				X	
	Weak storey				X	
First-storey weakness					X	
Short column effect					X	
Lack of redundancy of columns or bearing walls					X	
Pounding effect among structures					X	
Lack of seismic joints where necessary			X			

Structural Vulnerability Assessment of the Main Building

The 3-storey bearing wall structure has a good redundancy of walls to withstand small to moderate intensity earthquakes (MMI = VII–VIII).

The masonry structure is not reinforced and the cement mortar is weak due to the normal practice in Kathmandu Valley, mixing cement with a large amount of sand, generally resulting in masonry of poor quality. This is a determining factor in assessing the building as being unable to withstand an intensity MMI = IX earthquake.

Taking into account the building's structural configuration and the vulnerability factors described in the previous section, the structural vulnerability assessment is summarised as follows:

Structural Vulnerability Assessment

Modified Mercalli Intensity Scale			
MMI = VI	MMI = VII	MMI = VIII	MMI = IX
Negligible Damage	Slight to Moderate Damage	Moderate to Heavy Damage	Heavy to Very Heavy Damage (building collapse is possible)

The emergency block. An earthquake resistant building with 7 observation beds. This is a new facility constructed in 2001.

It is not operating yet, because of a lack of furniture, medical equipment and electricity supply. It is of high priority to make it operational.

SEISMIC PERFORMANCE OF LIFELINE SYSTEMS

Main Features of the Lifeline Systems

The lifeline systems' main features were obtained from visual observations and interviews with relevant hospital staff. The results are as follows:

Electricity

The hospital is connected to one 11kV feeder line, which is not always reliable. In the main building, electricity is provided in low voltage and its transformer does not work well. The emergency block has a new transformer, but the electricity had not been plugged into the feeder.

There is only one manually-operated emergency diesel generator. The backup generator can provide the energy required in some areas such as the operating theatres and the emergency department.

Water

There is no well at Bhaktapur Hospital. Water is supplied from the city network, which is enough to supply the hospital's daily demand. There is no quality control or alternative system.

Sewage

Hospital sewage is not connected to the city network. The hospital has a sewage septic tank that is leaking / overflowing and therefore causing problems. The low permeability of the subsoil, and the small capacity of the septic tank may be the cause of these problems.

Normally, there are no problems with water drainage. During the monsoon season, water and humidity on the ground floor can affect the hospital, but no critical services have been troubled before now. The sewage system is not connected to the emergency block yet.

Steam

Electric generators supply steam to autoclaves at the central sterilisation supply department and the emergency department. There are 2 autoclave units for sterilising, one big and one small.

Medical gases

There is no central oxygen room at the hospital. Oxygen is provided to all facilities in 30 – 40 oxygen cylinders. Air and suction are provided by electrical pump units.

Telephone, paging, intercom and alarms

There are no intercom, paging or alarms and only a few telephones can be operated. The staff's private mobile phones are not available for calling.

Roads

There are two access roads to the hospital from the Shakaput Old Road and Arniko Highway, which connect Bhaktapur to Kathmandu. There are three other roads connecting the hospital to Bhaktapur city. The accessibility to the hospital is considered as very good for local standards.

Internal transportation

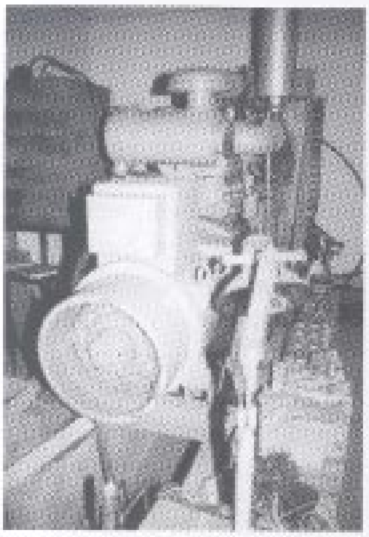
The main building has one internal staircase and two doors for external access. There is no lift, but it might not be necessary since most of the critical facilities are located on the ground floor. Internal transportation is not a problem; the building is not large and can be evacuated easily.

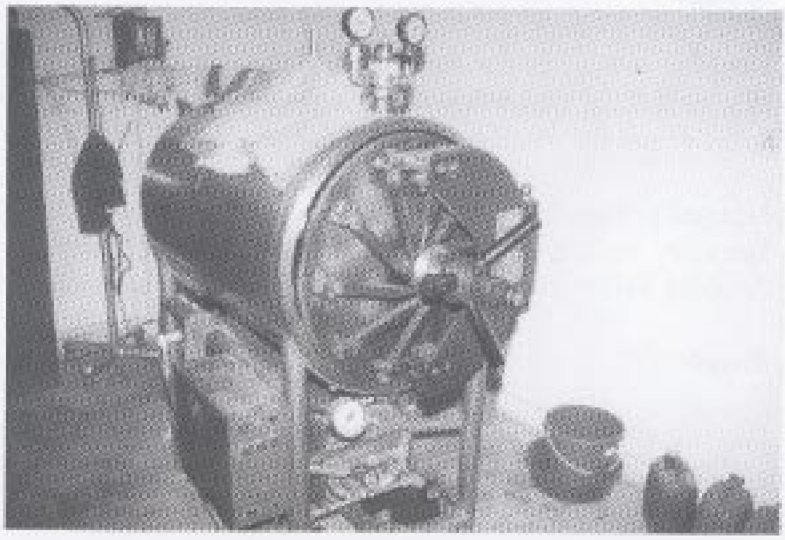
Waste disposal

There is no incineration unit.

Hazardous materials

A few LPG cylinders are used for cooking and heating. There are also kerosene stoves available. The hospital does not operate hazardous materials; biopsies and laboratory tests are conducted at the Cancer Hospital.





Left: *Manually operated emergency-backup electricity generator.*
Right: *Main autoclave at the central sterilisation supply department (CSSD). In the event of a shortage of electricity from the city network, the autoclaves at CSSD will not be functioning. The backup generator can only supply electricity to operating theatres and the emergency department.*

Non-structural Vulnerability Assessment

In Bhaktapur Hospital the following features of non-structural vulnerability were found:

a) Vertical and plan irregularities can produce moderate to heavy non-structural damage in lifeline facilities during moderate to high intensity earthquakes (MMI = VIII-IX).

b) The buildings have very simple lifeline systems so during small earthquakes (MMI = VII) slight to moderate non-structural damage can be expected, but the hospital is likely to be able to function under such conditions.

c) The hospital is highly dependent upon city network facilities such as electricity, water and telephones, but utilities from the city network will probably not be available for days or weeks after moderate to high intensity earthquakes (MMI = VIII–IX). They are not considered sufficiently reliable under intensity MMI = VII earthquakes either.

d) The electricity generator backup is manually operated, and only one person is in charge and trained to operate it.

Based upon the main features of the lifeline systems and the structural vulnerability assessment described in previous sections, a non-structural vulnerability assessment was made for earthquakes of various intensities. The results are shown in the following table:

Non-structural Vulnerability Assessment

Modified Mercalli Intensity Scale			
MMI = VI	**MMI = VII**	**MMI = VIII**	**MMI = IX**
Negligible Damage	Slight to Moderate Damage	Moderate to Heavy Damage	Heavy to Very Heavy Damage

HOSPITAL RELIABILITY ASSESSMENT

The resilience capacity of this hospital may be considered to be bad. There is a lack of human resources and a great dependency on city network utilities. Emergency preparedness is poor and the staff are not trained in mass casualty management. Despite the fact that the construction work has been completed, the new emergency block cannot operate due to the lack of equipment and available electricity.

The extent of the damage expected in the city networks and the above mentioned factors will limit the hospital's potential for being fully functional in intensity MMI = VIII-IX earthquakes.

Based upon the structural and non-structural vulnerability assessments described in the previous sections, a hospital reliability assessment was made for earthquakes of various intensities. The results are shown in the following table.

Bhaktapur Hospital Reliability Assessment

Modified Mercalli Intensity Scale			
MMI = VI	**MMI = VII**	**MMI = VIII**	**MMI = IX**
Fully operational	Partially operational	Out of service	Out of service

EMERGENCY PREPAREDNESS AND RESPONSE

From a disaster management perspective, Bhaktapur Hospital is the fifth most important hospital in Kathmandu Valley. It is not a major hospital but is of strategic importance because it is located in a district where heavy damage to buildings is expected, due to the soil's amplifying effects, and where a large number of casualties can be predicted due to the large population of Bhaktapur city.

The hospital will be called upon to play an important role in the event of an earthquake, but as it functions today it is unlikely to respond according to community needs.

In the context of an earthquake contingency plan the following issues should be taken into account:

a) After its construction five months ago, the emergency block is still not operational. The Royal Nepal Army received this building from the US Army. Later, Bhaktapur Hospital requested the Royal Nepal Army to give them the building to use.

   These new facilities need furniture and medical equipment. The building's capacity is not sufficient; it was planned for 7 emergency observation beds, but in the event of an intensity MMI VII, VIII or IX earthquake a larger number of beds will be required.

b) The hospital has a new and well-equipped ambulance.

c) The staff has asked the Government for a new building. There is a plan to construct a 100-200 bed hospital and there is a piece of land available.

d) The hospital has a low occupancy rate during most of the year. During the monsoon season, the hospital can be fully occupied if there is an outbreak of any communicable disease. In such cases, it can be necessary to place extra beds in corridors.

e) Some equipment, including two endoscopies, X-rays, and ultrasound equipment, is relatively new.

f) Cancer Hospital, which is located beside Bhaktapur Hospital, has 25 beds that can be used in the event of an inflow of mass casualties.

g) Many people from Bhaktapur prefer to go to private health centres or travel to Kathmandu to receive medical care at Bir Hospital. Bhaktapur Hospital doesn't fulfil the demands of the community. This is an undesirable contrast: low use from the community during most of the year, while a big demand is expected during earthquakes.

h) The capacity of the emergency department is very small, but there is available space within the hospital and large green areas nearby where tents can be put up, if necessary.

i) Bhaktapur Hospital does not have an emergency plan.

j) The hospital needs but does not have an intensive care unit. In an earthquake scenario, the transport to Kathmandu of critical patients is not desirable and may be difficult due to traffic congestion.

k) There are no official links between The Royal Nepal Army and Bhaktapur Hospital.

The emergency department is not prepared to successfully attend incoming mass causalities from earthquakes of MMI = VI and above. It is estimated that the hospital has capacity to handle no more than 10 emergency cases at a time.

Emergency planning is necessary and feasible for earthquake scenarios from MMI = VI to VII. During intensity MMI = VIII-IX events, the incoming mass causalities will be very large. At the same time, the extent of structural and non-structural damage will be so large that the hospital probably will be out of service.

During such scenarios, traffic congestion or damage to infrastructure on the Bhaktapur – Kathmandu roads, may cause the isolation of Bhaktapur. This will result in a very poor emergency response and the loss of many lives, because people will be unable to get medical care during the first 48 hours.

It is of the utmost importance to strengthen the response capacity to support Bhaktapur in the event of intensity MMI = VIII-IX earthquakes.

It is also recommended that the medical care services are strengthened by building a new 120 bed hospital equipped with an emergency department, operating theatres and an intensive care unit. Such a hospital should be developed under a community based system.

Main operating theatre. Less than 8 minor and major surgeries are conducted in the hospital per day. There is no intensive care unit.

An undesirable contrast: low demand from the community during most of the year, while a very big demand is expected during earthquake emergencies.

MAIN CONCLUSIONS AND RECOMMENDATIONS

Non-structural Aspects

A detailed non-structural assessment is necessary with specific emphasis on lifeline systems and equipment. This assessment needs to be supplemented with a detailed quantitative structural analysis.

Whilst not denying the need for a non-structural assessment, the following recommendations will improve the hospital's resilience, reduce its non-structural vulnerability, and increase the reliability of services:

a) The emergency block should be made operational as soon as possible and electricity and sewage connections need to be linked. Furniture and medical supplies must be allocated according to the building design.

b) Emergency department staff should be trained in earthquake emergency management.

c) A larger number of personnel should be trained to operate the electrical generator in the event of an emergency and two of them should always be available. A second electrical backup generator is needed for the emergency building.

d) Water tank reservoirs are necessary.

e) Radio communication system and mobile phones are required as alternative systems to the city network's telephone lines.

f) A new electricity transformer is needed in the main building.

It is also necessary to increase the staff's preparedness for earthquakes. Most of the medical staff is not aware of the earthquake risk and the possibility of a large casualty concentration in Bhaktapur.

It is vital to establish good co-ordination with the Royal Nepal Army as it is likely to be called upon to lead the emergency response and provide assistance to the hospital in the event of an earthquake.

Structural Aspects

A detailed structural analysis to quantitatively assess the buildings' behaviour during moderate to high intensity earthquakes (MMI = VIII-IX) is necessary. The results of such a study will probably indicate that it will be necessary to retrofit the existing facilities.

If a new hospital is constructed in the near future, the retrofitting of the existing building is a low priority. In that case, it can be used as an administrative block. The analysis should then only assess it as an ordinary structure.

REFERENCES

[1] US Army & NSET, 1998: Report from the Nepal-Earthquake-Assessment-Team.

[2] NSET, R. Patton & B. Thomas, 2000: A Report on Emergency Preparedness and Seismic Vulnerability of Bir Hospital.

[3] UNDP / UNCHS (Habitat), 1994: Seismic Hazard Mapping and Risk Assessment for Nepal.

[4] Nippon Koei & Oyo, 2001: The Study on Earthquake Disaster Mitigation in The Kathmandu Valley, Kingdom of Nepal, an interim report.

[5] Disaster Health Working Group, 2001: Emergency Preparedness & Disaster Response Plan for the Health Sector in Nepal – Part I: Hazard Analysis and Response Guidelines & Summary, second draft, Kathmandu, Nepal.

[6] National Geophysical Research Institute: A Probabilistic Seismic Hazard Map of India and Adjoining Regions, Hyderabad, India.

[7] International Lithosphere Programme (ILP), 1999: Global Seismic Hazard Assessment Programme (GSHAP) in Continental Asia.

[8] Munich Re. Group, 2001: World of Natural Hazards.

[9] NSET, 2001: The Study on Earthquake Disaster Mitigation in The Kathmandu Valley, Kingdom of Nepal, report on building inventory survey.

[10] International Code Council, 1997: Uniform Building Code UBC-97, USA.

[11] Geohazards International USA & NSET - Nepal, 1998: The Kathmandu Valley Earthquake Risk Management Project (KVERMP).

[12] B. Seed & M. Idriss, 1982: Ground Motions and Soil Liquefaction During Earthquakes, Earthquake Engineering Research Institute (EERI), USA.

[13] J. Argudo et. al, 1995: Structural Vulnerability of Hospital Buildings in Guayaquil, Universidad Catolica de Santiago de Guayaquil, Ecuador.

[14] IDNDR / ISDR, GHI & Municipality & Universidad Catolica of Guayaquil, 1999: The RADIUS Full Study Case in Guayaquil, Ecuador.

[15] Bay Area Regional Earthquake Preparedness Project (BAREPP), 1985: Reducing the Risks of Non-structural Earthquake Damage, A Practical Guide, California, USA.

[16] Pan-American Health Organisation, 1993: Mitigation of Disasters in Health Facilities, Volumes I – II – III – IV, USA.

[17] Federal Emergency Management Agency, 1989: A Handbook of Seismic Evaluation of Existing Buildings, FEMA – 178, USA.

[18] National Earthquake Hazard Research Project (NEHRP), 1997: Handbook for the Seismic Evaluation of Existing Structures.

[19] Ronal Hamburger, 1997: Performance-Based Seismic Engineering, The Next Generation of Structural Engineering Practice, EQE International Inc.

[20] Applied Technology Council, 1995: Guidelines and Commentary for Seismic Rehabilitation of Buildings, Report No. ATC-33.03, Redwood City, California.

[21] Building Seismic Safety Council & Federal Emergency Management Agency, 1995: NEHRP Recommended Provisions for Seismic Regulation for New Buildings, 1994 Edition, Report Nos. FEMA-222A (Provisions) and FEMA-223A (Commentary), Washington D.C.

[22] Structural Engineers Association of California (SEAOC), 1995: Vision 2000 - A Framework for Performance Based Design, Volumes I, II, III, Vision 2000 Committee, Sacramento, California.

[23] Organización Panamericana de la Salud, Oficina Regional de la Organización Mundial de la Salud, 2000: Fundamentos Para la Mitigación de Desastres en Establecimientos de Salud.

[24] JICA, 1989-1990: Ground Water Management Project in Kathmandu Valley, Kingdom of Nepal.

[25] J. Johansson, 2000: http://www.ce.washington.edu/~liquefaction/html/main.html What is soil liquefaction?, Department of Civil Engineering, University of Washington.

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