Nepal Health Sector Support Programme III
(NHSSP – III)

Retrofitting Codes and Practices Preliminary Report

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Executive Summary

Despite being one of the most disaster-prone countries in the world, Nepal does not have any stringent building codes and standards and at the same time, is struggling with implementation of the codes and standards constructed before the adoption of modern seismic codes. This has caused a serious threat to the buildings in Nepal, especially the health centres and hospital buildings, as these buildings have to serve as a foremost lifeline during major earthquake events. The resilience of these buildings was exposed during the April 25 earthquake that caused massive damages and losses to health infrastructure and disruption of healthcare service delivery. Facilities that had been constructed or retrofitted to higher standards performed better in earthquake.

In order to continue improving and restoring health facilities after the 2015 Gorkha earthquake, it is essential to select and adopt the most appropriate seismic standards for public health facilities. These standards include specific requirements for structural and non-structural works and form a part of the 'Building Back Better / Building Back Smarter' approach adopted by the Government of Nepal (GoN) in response to the 2015 Gorkha earthquake as well as the UN Sendai Framework for planning for disaster risk reduction.

Currently, there areno specific standard requirements for seismic evaluation and retrofitting design and construction of the buildings, especially for health infrastructures, in Nepal. Most of the design professionals and engineers follow the Nepal National Building Codes (NBC) or Indian codes (IS code) developed for the new building constructions. In addition, there are some seismic evaluation and retrofitting guidelines and tools in Nepal. However, these codes and guidelines have many gaps and there is no uniformity in the current practices. Under UKAid/DFID funding,the Nepal Health Section Programme(NHSP) - III is providing support to Ministry of Health (MoH) and Department of Urban Development and Building Construction (DUDBC) to develop a comprehensive seismic retrofitting and rehabilitation standard requirements for Nepal.

This report serves as a roadmap for development of a robust seismic retrofitting and rehabilitation standards for health facilities in Nepal. It summarizes a preliminary investigation of existing codes, standards and practices used in Nepal as well as other countries like India, USA, New Zealand, Turkey and Japan for retrofitting and rehabilitation of hospital buildings.Based on the review and consultation with local experts and concerned authorities, major weaknesses, knowledge gaps and area for improvements in Nepal standard codes and practices are identified and analysed in relationship to other countries' codes and standards. The report also highlights the improvement needed in both Seismic Design code (NBC:105), which is under review by DUDBC as well as seismic evaluation and retrofitting design standards in Nepal. It includes structural as well as non-structural components with functional part of the buildings especially focused on health infrastructure. At the end of the report, it proposes a plan with time frame to develop a comprehensive seismic retrofitting and rehabilitation standard for health infrastructures in Nepal under NHSP-III.

Contents

List of Acronyms

ADB	:	Asian Development Bank
ASCE	:	American Society of Civil Engineering
ATC	:	Applied Technology Council
BRB	:	Buckling Restrained Bracing
CP	:	Collapse Prevention
DBE	:	Design Based Earthquake
DFID	:	Department for International Development
DL	:	Dead Load
DoA	:	Department of Archeology
DoHS	:	Department of Health Services
DUDBC	:	Department of Urban Development and Building Construction
EL	:	Earthquake Load
FEMA	:	Federal Emergency Management Agency
FRP	:	Fiber Reinforced Polymer
GoN	:	Government of Nepal
IIT	:	Indian Institute of Technology Kanpur
IBC	:	International Building Code
IO	:	Immediate Occupancy
IoE	:	Institute of Engineering
IS	:	Indian Standards
LL	:	Live Load
LS	:	Life Safety
LSM	:	Limit State Method
LTA	:	Lead Technical Advisor
MCE	:	Most Credible Earthquake
MCE	:	Maximum Considered Earthquake
MoH	:	Ministry of Health

MoHA	:	Ministry of Home Affairs
MPPW	:	Ministry of Physical Planning and Works
MRT	:	Mandatory Rules of Thumb
MoUD	:	Ministry of Urban Development
NBC	:	National Building Code
NNBC	:	Nepal National Building Code
NEA	:	Nepal Engineers' Association
NHSSP	:	National Health Sector Support Programme
NRA	:	National Reconstruction Authority
NSC	:	Non-Structural Components
NSET	:	National Society for Earthquake Technology
NSRRSCC		Nepal Seismic Retrofitting and Rehabilitation Standards Coordination Committee
RC	:	Reinforced Concrete
RCC	:	Reinforced Cement Concrete
SAARC	:	South Asian Association for Regional Cooperation
SERA	:	Senior Earthquake Resilient Advisor
SL	:	Service Load
SLS	:	Serviceability Limit State
SMT	:	Senior Management Team
SW	:	Shear Wall
PBD	:	Performance Based Design
PDNA	:	Post Disaster Needs Assessment
ULS	:	Ultimate Limit State
UNDP	:	United Nation Development Programme
UN-HABITAT	:	United Nations Human Settlements Programme
UNISDR	:	United Nation International Strategy for Disaster Reduction
URM	:	Unreinforced Masonry
USA	:	United State of America
WHO	:	World Health Organization
WSM	:	Working State Method

1.0 Introduction

1.1 Purpose

This report is a scoping document for developing seismic retrofitting codes/standards for health infrastructure in Nepal. It summarizes a preliminary investigation of existing codes, standards and practices used in Nepal as well as other countries like India, USA, New Zealand, Japan and Turkey for retrofitting and rehabilitation of hospitalbuildings. It includes current knowledge on the seismic design and analysis of structural as well as non-structural components with functional part of the buildings especially focused on health infrastructure. Based on the review and consultation with local experts and concerned authorities, major weaknesses, knowledge gaps and area for improvements in Nepal standard codes and practices are identified and analysedin relationship to other countries' codes and standards. This investigation also assesses the degree to which standards are being observed, and how this may relate to issues of awareness of such codes and standards, as well as different facets of quality control, inspection and enforcement during the planning and construction process.

Therefore, the main purpose of the preliminary report on the seismic retrofitting and rehabilitation codes and practicesis to provide underlying basis for more detailed work in developing seismic retrofitting and rehabilitation standards for health infrastructures in Nepal.

1.2 Context and Rational

Nepal is among the twenty most disaster-prone countries in the world. Several factors such as its geographic structure, complex geology, frequent tectonic movements, and unfavourable climate conditions make this country vulnerable to a wide range of natural hazards. Its geophysical location on the Alpine-Himalayan seismic belt, where approximately 17 percent of the world's largest earthquake occur(Ulak, 2015), makes Nepal the eleventh most earthquake-prone country in the world. In the two largest earthquakes (2015 Gorkha earthquake) alone, on April 25 and May 12, nearly 31 districts were affected, causing massive damage, fatalities and causalities. 14 out of 31 districts are classified as severely affected and remaining 17 as moderately affected.The health sector was severely affected from damages and losses to health infrastructure and disruption of healthcare service delivery, along with the deaths of 8,702 persons (45 percent male and 55 percent female) and injuries to 22,303 individuals. More women and girls died than men and boys, partly because of gendered roles that disproportionately assign indoor chores to women (PNDA,2015).

According to Ministry of Home Affairs (MoHA), 2017, total of 446 public health facilities (consisting of five hospitals, 12 Primary Health Care Centres, 417 Health Posts, and 12 others) and 16 private facilities were completely destroyed and a total of 765 health facilities or administrative (701 public and 64 private) structures were partially damaged. Nearly 84 percent (375 out of 446) of the completely damaged health facilities are in the 14 most-affected districts. The Health Infrastructure Information System (HIIS) updated in August 2016 showed that 191 facilities in these 14 districts were extensively damaged or destroyed to the extent that they required replacing, while further 291 facilities required rehabilitation or retrofitting. The total monetary value of damages and losses due to the earthquakes in health sector is estimated to be NPR 7.5 billion out of which the share of the public sector is 81.5 percent, the rest being in the private sector, including non-governmental and community owned service providers.

According to study reports (PDNA, 2015, MoHA,2016), the damages exposed the weaknesses of houses that did not have any seismic-resistant features or were not in accordance with the building codes. The disaster also highlighted that rural areas have been more adversely affected than towns and cities due to their inferior quality of houses. According to HIIS database, there are more than 70% of hospitals and health infrastructure located in the rural area.The limited numbers of bigger public and private hospitals arelocated in the cities. In the rural area, significant number of unreinforced masonry buildings constructed of stone or brick in mud mortar exist throughout the country. These buildings are highly vulnerable to even moderate earthquake and require immediate attentionbased on the hazard and risk assessment conducted by MoHA and DFID's studies. Most of the existing big hospitals in cities are also vulnerable toseismic risks and recommended for retrofitting as well as rebuild (Turner & Townsend, 2015).

In order to continue improving and restoring health facilities after the 2015 Gorkha earthquake, it is essential to select and adopt the most appropriate seismic standards for public health facilities. These standards include specific requirements for structural and non-structural works and form a part of the 'Building Back Better / Building Back Smarter' approach adopted by the Government of Nepal (GoN) in response to the 2015 Gorkha earthquake.

While Nepal National Building Code (NNBC) and/or Indian Standard (IS) codes have been adopted in Nepal for seismic design and analysis as structural standards, revision of the more than two decades old NNBC codes has not been conducted with the passage of time. Recently, GoN was also considering revising and upgrading the existing national policies, codes and standards for seismic resilience.

For retrofitting and rehabilitation of buildings, there are different approaches and practices in Nepal. However, there are no specific standard requirements for seismic evaluation, retrofitting design and construction of health infrastructures. In the current situation, most of the design professionals and engineers follow the same NNBC or IS code developed for the new building constructions. In addition, the current India/ Nepal building code do not have detail provisions to design and mitigate non-structural damages. For high priority structure like hospital buildings, the vulnerability of non-structural and functional features can lead to severenon-structural and functional damages and indirect losses afterthe events which may far exceed the loss caused by the structural damages.

Further, to bringallexisting structures up to the level of new code is not always technically and financially viable since it will make significant impact to existing facilities, which have to remain functional without any interruptions. In this context, the development of seismic retrofitting and rehabilitations standards focused on critical facilities like hospitals is essentials.

1.3 Scope of the Report

The scope of the report isas follows:

I. Review of the current version of the Nepal Seismic Building Codes NBC 105, recently published Seismic Retrofitting Guidelines of Buildings in Nepal and other available standards.
II. Review the current knowledge and practices on the seismic design and analysis of structural as well as non-structural building components for retrofitting and rehabilitation of buildings in Nepal;
III. Review and compare codes and standards of other countries (eg.US, Japan, India, New Zealand);
IV. Carry out a preliminary investigation of existing codes, standards and practices used in Nepal, and to identify weaknesses, gaps and areas for improvement;
V. Prepare and propose asystematic plan for developing seismic retrofitting and rehabilitation standards for health infrastructures in Nepal.

1.4 Methodology

The methodology followed in developing the report was basically two folds: firstwas a desk-based review and comparison of the buildings codes and seismic retrofitting and rehabilitation standards and practices in Nepal withother countries including India, US, New Zealand, Japan and Turkey for comprehensive seismic assessment and retrofits of building.Thesecondcomponent waskey informant interviews with relevant officials from the Department of Health Services (DOHS), Department of Urban Development and Building Construction (DUDBC), National Reconstruction Authority (NRA) and other relevant government departments, universities' professors, and suitable non-governmental organisations as well as national practice designers and experts to secure their experiences and recommendationsfor improvements or corrections.

2.0 Review of Current Codes/Standards and Practices In Nepal

The following section summarizes the current codes, knowledge and practices on the seismic design and analysis of structural as well as non-structural building components for retrofitting and retrofitting and rehabilitation of buildings in Nepal.

2.1 Nepal National Building Code (NNBC)

Lying in one of the most seismically active regions of the world, Nepal has a long history of earthquakes; however, the country has not learnt lessons from the earthquakes that it has been subjected to from time to time. After the destructive earthquake of M6.8 that struck the eastern Nepal in 1988, the need for national building code was first realized. Consequently, the Nepal National Building Code (NNBC) was developed by the Department of Urban Development and Building Construction (DUDBC) of the Ministry of Physical Planning and Works (MPPW) with the assistance of United Nation Development Programme (UNDP) and United Nations Human Settlements Programme (UN-HABITAT) and enacted in 1994. The code was made mandatory in 2003 as a legally binding document in all 130 municipalities.

There are 23 different NNBCs both regulation and guideline (see list of NBC in Annex -1) that govern the design, construction, alteration, and maintenance of a structure in all regions of the country. These codes serve as a tool for the improved performance of the built environment to earthquakes and other natural hazards. In current NBC, there are 4 levels of designs:

a) International state of art -aim of this level we can use most sophisticated level of design, the present code should not bar anyone who can produce high level of engineering;
b) Professionally engineered building: These are the standard code requirements that all professionally qualified engineers will recognize and follow when designing structures in Nepal. It covers all major structures such as hospitals, meeting halls, factories, multi-story buildings and larger residential building etc.;
c) Rules of thumb: This section recognizes that it is not practical at present to insist that professionals design all small buildings, and pre-engineered design plan can be used with rules of thumbs without sophisticated calculations; and
d) Advisory guidelines: non-engineered constructions employing traditional materials.

2.1.1 Seismic Design Code of Nepal

The NBC 105, 1994 is the code for the seismic design of buildings in Nepal. Besides, the following codes are the other documents.

- NBC108 Site consideration for seismic hazards
- NBC201 Mandatory rules of thumb reinforced concrete buildings with masonry infill.

- NBC202 Mandatory rules of thumb load bearing masonry
- NBC203 Guidelines for earthquake-resistant building construction low strength masonry
- NBC204 Guidelines for earthquake-resistant building construction earthen building.
- NBC205 Mandatory rules of thumb reinforced concrete buildings without masonry infill.

These codes are not complete and heavily rely on the relevant Indian Standards for theircompleteness. Most of the engineers use Indian Standards, considering whole Nepal as seismic zone V as per the Indian standards and including seismic loading standards for design of buildings in Nepal. The Indian Section loading standard IS1893-1984 had designated Kathmandu as seismic Zone V (most hazardous seismic zone in I to V scale). However, Kathmandu has been dropped from the current Indian seismic loading standard IS1893-2002.

The NBC documents 201, 202 and 205 are the Mandatory Rules of Thumb (MRT) illustrated guidelines for ready-to-use documents. It includes details for various structural and non-structural elements to achieve acceptable minimum seismic safety requirements. The MRT includes information about slopes, foundations, structural systems with materials used, connections between walls and floors and the location of openings, all required for typical seismic designs. In the rural as well as most of the cities, buildings are designed and constructed with the detailing and safety measures specified in these MRT because of lack of qualified structure engineers and require high-level trainings to enable to do design analysis and calculation as per Seismic codes.

In addition, NNBC 109:1994 covers the structural design aspect of unreinforced masonry elements in buildings. It also deals with some aspect of earthquake resistant design of buildings. Reference to seismic zoning, seismic coefficients, important factors and performance coefficients are adopted as per NNBC 105-94 Seismic Design of Buildings in Nepal. The Code is fundamentally based on Indian Standard IS:1905-1987 Code of Practice for Structural Use of unreinforced Masonry (Third Revision)

There is no specific code for the seismic evaluation and retrofitting design of existing buildings. The seismic performance of existing buildings is evaluated in relation to the performance criteria in use for new buildings. The provisions of this standard are strongly correlated with the design criteria of new buildings contained in NBC 105 and IS 1893 (Part 1). Engineers are using the IS 15988 : 2013 - Seismic Evaluation and Strengthening of Existing Reinforced Concrete Buildings — which is the current standards for RC buildings in India. Some engineers in Nepalalso use FEMA310 of FEMA356 as a guideline for seismic evaluation and retrofit of existing structures.

Since the code has been more than two decades old, there are lots of changes in technologies, standards and practices as well as a substantial advancement in the knowledge related with seismic resistant design of buildings and structures during the period. Revision of the codes has not been conducted with the passage of time. Based on the lessons learnt from the large earthquakes in the recent years and changes in seismic design provisions in building codes of different countries in last 20 years, review of some building codes are in progress in Nepal. Under the Asian Development Bank’s financial support, DUDBC is going to review NBC 105,1994. NHSSP-III will liaise with DUDBC to incorporate seismic standards required for health infrastructures in the reviewed NBC 105 as well as other NBCs.

2.2 Seismic Retrofitting Guidelines of Buildings in Nepal, 2016

Recently DUDBC/MoUD has released a Seismic Retrofitting Guideline of Building in Nepal. This is a guiding document for the design professionals with the primary purpose of providing analysis and design methodology for use in the seismic evaluation and retrofitting of the existing buildings in Nepal. This manual is being prepared in three separate volumes providing retrofitting guidelines for adobe structure, masonry structure and RCC structure covering both theoretical and practical aspects of retrofitting. It basically focuses on the seismic retrofitting and strengthening techniques. It refers "Seismic Vulnerability Evaluation Guideline for Private and Public Buildings' adopted by DUDBC.

2.2.1 Volume – I: Adobe and Low Strength Masonry Structures

The primary purpose of this document is to provide an analysis and design methodology used in the seismic evaluation and retrofit of the existing adobe and low strength masonry buildings in Nepal. This guideline includes concept of repair, restore and retrofitting of buildings, common damages in adobe and low strengthen masonry structures; and retrofitting techniques on different elements with some hand calculation and construction techniques with sketches and photos. For the techniques, it includes both engineering as well as local technologies and materials such a bamboo, PP band and recycle tyres etc.

2.2.2 Volume – II: Masonry Structures

This guideline is basically focused on load bearing masonry structures especially brick masonry buildings. It also includes common damages and failure patterns in masonry structures, retrofitting criteria, Analysis process and methods, and retrofitting and strengthening techniques in different components of the masonry buildings. It briefly discusses different analysis methods – Elastic analysis (both linear static and linear dynamic procedures), inelastic analysis (non-linear static) and non-linear analysis as well as performance base behaviour of masonry structures. It includes the hand calculation of buildings to check stress and design retrofitting measures.

2.2.3 Volume – III: RCC Structures

This guideline is basically focuses on structural evaluation and retrofitting design moment frame RCC structures. For the structural evaluation, it briefly discusses three tier evaluation based on FEAM – Rapid Visual Inspection/ assessment; preliminary assessment; and details assessment. The detailed evaluation procedure is based on determining the probable strength of lateral load resisting elements and comparing them with the expected seismic demands. It also briefly describes about the required three performance level of structural and non-structural components. It further illustrates seismic retrofitting strategies for improved performance in the future earthquake. Strategies relate to modification or control of the basic parameters that affect a building's earthquake performance. These include the building's stress, strength and deformation capacity, ability to dissipate energy. Various strategies that are discussed for reducing the seismic risk inherent are:

- Introduction of shear wall
- Buttress perpendicular to an external wall

- Building retrofit with infill windows
- Diaphragm strengthening
- Column/ beam jacketing
- Dampers and base isolation
- Mass reduction

In order to provide a clear approach about structural vulnerability analysis, this guideline puts forward five examples addressing retrofit of engineered RC frame building, occupancy change from residential to health clinic, stress check based on FEMA 310, strength based approach and performance analysis. Use of force-based approach is most prevalent approach for designing of retrofitting of existing buildings. Displacement-based approach is still not common even some guidelines have highlighted the needs.

2.3 Seismic Assessment Guidelines, Tools and Documents

Building assessment and retrofitting guidelines have been developed for Nepal under various projects. The following Seismic vulnerability assessment guidelines, tools and documents are available in Nepal.

2.3.1 Seismic Vulnerability Evaluation Guidelines for Private and Public Buildings, 2011

DUDBC along with UNDPreleased a Seismic Vulnerability Evaluation Guidelines for Private and Public Buildings in 2011. This guideline has two parts. Part-I covers the process and methodology of vulnerability assessment at a pre-disaster phase whereas part-II shall be used for post disaster damage assessment. It is prepared based on the experience in assessing hundreds of institutional, private and public buildings, hospital and school buildings. This Guidelines is based on FEMA310 “Handbook for the Seismic Evaluation of Buildings”, ATC 40 “Seismic Evaluation and Retrofit of Concrete Buildings”, FEMA 356 “Pre-standard and Commentary for the Seismic Rehabilitation of Buildings” and IITK GSDMA Guideline on “Seismic Evaluation and Strengthening of Existing Buildings”. Since it is the only official guideline in Nepal, most of the engineers are using this guideline for the seismic assessment of buildings.

2.3.2 Guidelines for Seismic Vulnerability assessment of Hospitals, 2004

The National Society for Earthquake Technology – Nepal (NSET) with World Health Organisation (WHO) hasjointly released a Guideline for seismic vulnerability assessment of Hospitals in 2004. It is a well-crafted document which deals various aspects hospital safety including structural, non-structural and content. It is common practice to focus on building structure during assessment process, however this document goes beyond that and addresses the issues which are crucial for functioning of a hospital after an earthquake. The guideline presents methodology for Tier 1 (preliminary) structural assessment and visual assessment of non-structural components. The Tier 1 assessment method is based on FEMA set of assessment documents. It basically follows IS 1893 for seismic force calculations for preliminary assessment of an example building. It assumes the example building as limited ductile, but does not substantiate for this assumption. Further to this, the guideline does not account for partial safety factor for loads as required by IS1893. This would give non-conservative result.

2.3.3 Tools for the Assessment of School and Hospital Safety for Multi-hazards in South Asia, 2012

UN-Habitat in partnership with UNISDR and South Asian Association for Regional Cooperation (SAARC) has developed Toolkits that can facilitate the assessment of the safety of critical infrastructures, focusing on schools and hospitals in South Asia. These tools have two tool-kit for both school and hospital buildings. ToolKit-I is designed for assessment of New buildings whereas ToolKit-II is for Retro-maintenance assessment of existing buildings. The Excel-based toolkits have structured questionnaire and detailed field information in four components for the assessment – planning, architectural, structural and non-structural for four different hazards – Earthquake, Wind, Flood, Fire. These toolkits are developed for top management (Director Generals along with the line directors) and end-users (school teachers, hospital staffs and maintenance people).

3.0 Overview of International Codes and Standards

3.1 Indian Standards

The IS 15988: 2013 - Seismic Evaluation and Strengthening of Existing Reinforced Concrete Buildings — Guidelines is current standards in India. The seismic performance of existing buildings is evaluated in relation to the performance criteria in use for new buildings. The provisions of this standard are strongly correlated with the design criteria of new buildings contained in IS 1893 (Part 1). There are two levels of evaluation – Preliminary evaluation and detailed evaluation. The preliminary evaluation is a quick procedure to identify the potential earthquake risk of a building and to screen buildings for detailed evaluation. In this evaluation, there are configuration-related checks and strength-related checks. The detailed evaluation procedure is based on determining the probable strength of lateral load resisting elements and comparing them with the expected seismic demands. The detailed evaluation is compulsory forbuildings more than 6 storey; building located on incompetent or liquefiable soils and/or located near (less than 15 km) active faults and/or with inadequate foundation details; and buildings with inadequate connections between primary structural members. In addition to the general evaluation, there is Ductility and Detailing Related Evaluation. The evaluation is basically focused for the building - Moment Resisting Reinforced Concrete Frame Buildings, Concrete Shear Wall Buildings, and Reinforced Concrete Frames with Masonry Infill Walls. Besides, seismic strengthening options and strategies at a general level are also included. The evaluation describes a methodology for the design of the strengthening measures as modifications to correct reduce seismic deficiency identifying during the evaluation procedure.

However, this guideline focuses on the conventional strengthening measures on RC buildings. It does not provide enough details on how to capture potential failure modes and estimation of strength. The document allows an existing building be assessed for reduced remaining life (i.e. less seismic force because of reduced exposure). To our knowledge, there is no specific Indian Standards exist for seismic assessment and mitigation of masonry buildings as well as hospital facilities. The IS 13827:1993 - 'Improving Earthquake Resistance of Earthen Buildings' – Guidelines and the IS 13828:1993 - 'Improving Earthquake Resistance of Low Strength Masonry Buildings – Guidelines' can be used for seismic assessment of masonry buildings as a checklist to verify whether existing masonry buildings comply with current code requirement or whether strengthening measures should be introduced to upgrade the structure and increase its resilience.

Seismic design codes in India

India has the following seismic design codes - IS 1893 (Part 1) : 2002 'Criteria for earthquake resistant design of structures: Part 1 General provisions and buildings', IS 4326 : 1993 'Code of practice for earthquake resistant design and construction of buildings' and IS 13920 : 1993 'Ductile detailing of reinforced concrete structures subjected to seismic forces — Code of practice. These codes are under revision and a draft version has been released recently.

In this revision version of IS 1893 (Part 1): 2016, the following significant changes have been included:

I. Design spectra are defined for natural period up to 6 s;
II. Same design response spectra are specified for all buildings;
III. Bases of various load combinations have been made consistent, with those specified in the other codes;
IV. Temporary structures are brought under the purview of this standard.
V. Importance Factor provisions have been modified;
VI. A provision is introduced to ensure that all buildings are designed for at least a minimum lateral force;
VII. Buildings with flat slabs are brought under the purview of this standard;
VIII. Additional clarity is brought in on how to handle different types of irregularity of structural system;
IX. Effect of masonry infill walls has been included in design of frame buildings;
X. Method is introduced for arriving at the approximate natural period of buildings with basements, step back buildings and buildings on hill slopes;
XI. Torsional provisions are simplified; and
XII. Simplified method is introduced for liquefaction potential analysis.

3.2 USCodes and Standards

The current seismic retrofit standard in the US is the 2013 edition of American Society of Civil Engineers (ASCE) ASC 41-13 and the next edition (ASCE 41-17) is scheduled for release in early 2018. ASCW 41 is a well-known seismic retrofitting standard that is used worldwide. In some countries, the standard is used as the de-facto document for retrofitting, whereas, some countries have developed their own retrofitting standards which are closely based on the provisions of ASCE 41.

In 1997, FEMA 273 for seismic rehabilitation of existing building was published. This document, more than ten years, in development, introduced the concept of systematic assessment and retrofit and incorporated the concept of performance based engineering. FEMA 273 included contribution from many well-known representatives from academia and practice and has served as the basis for the seismic retrofit standards in the US since. The document was intended for application anywhere in the US. Systematic rehabilitation was addressed by explicitly defining the following: a) seismic hazard risk at the building site, b) identifying what level of seismic intensity (how large of an earthquake) to consider, c) requirements for assessing the existing condition of the building; d) requirements for structural analysis techniques to be used to do such assessment; e) acceptance criteria to be used for common construction material (steel, concrete, masonry, and wood) and for common building systems (moment frames, walls, braced frames, etc.), and f) target acceptance performances for the building depending on the level of seismicity. The introduction of performance based design was a radical departure from the prescriptive requirements specified in building codes that attempt to assign system performance factors to structural systems and then base the adequacy of design on a reduced level of earthquake forces based on the empirical performance factors.

Following the publication of 1997, the document was widely used in retrofitting of vulnerable buildings in the US. In 2000, 2006, and 2013, the seismic retrofitting standards were updated to incorporate the knowledge learned from other earthquakes and from research conducted in the US and worldwide.

The concept of performance-based design (PBD) is critical for seismic retrofitting and is discussed here. The engineer in collaboration with the owner and jurisdiction, select a performance level. An example of performance level is collapse prevention (CP), which implies building is unlikely to collapse for a selected level of earthquake. Another example is immediate occupancy (IO) implying that meeting this performance goal will likely results to minor physical damage to the building and thus building could be re-occupied in short time. Once a performance target is selected, then one needs to decide at what earthquake intensity, such a performance is desired. For example, one could select the dual performance of life safety (LS) which is in between CP and IO for a strong earthquake and CP for a rare earthquake. This dual performance level is the basic performance goal specified explicitly in ASCE 41-13. The LS performance for a strong earthquake is the implied target of buildings for new building codes.

ASCE 41-13 allows variation on the selected building performance and seismic intensity. The objective is to encourage the retrofit of buildings and at the same time ensure a higher performance can be selected for critical buildings. So for example, for a voluntary retrofit, the owner can decide that only CP at a strong earthquake needs to be met. Conversely, the state might (and indeed require) an enhanced performance of IO and LS for strong and rare earthquakes, respectively, when retrofitting key hospital facilities.

By using PBD, the seismic retrofitting codes in the US provide engineers and stakeholders with valuable tools.

- First, theyserve as a communication tool in decision-making that allows the project tem to decide within the allocated resources, schedule, jurisdiction requirements, and consideration of all buildings in a profile, what performance target is optimal.
- Second, by moving away from the prescriptive requirements, the project team has a much better understanding of expected building performance.
- Third, since evaluation is member by member and not the building as a whole (as is done when performance modifies are used in the building codes), the team can approximately identify, what type of damage would be expected and which structural elements are more likely to experience damage in an earthquake. This would allow the project team to readily identify the most vulnerable components and to device seismic retrofit options that target this shortcoming.
- Distinction is made between brittle and ductile modes of damage. Ductile types of damage for which building components have more reserved capacity and resiliency and thus, even though damage has occurred, it is not sudden or catastrophic. An example would be yielding of beams when subjected to bending. By contrast, brittle modes of failure. Such modes happen suddenly and can have catastrophic consequences that lead to building collapse and loss of life. An example is the cursing of concrete columns that could lead to pancaking of an entire floor in a building. In PBD, a higher tolerance of damage is allowed for ductile modes of damage, whereas, little or no allowance is made for brittle modes of damage.

Another key aspect of the US seismic retrofit standards is the consideration of performance of non-structural components (NSC). These are architectural (e.g., partitioned walls), mechanical, (e.g., plumbing) and electrical (e.g., generators) that are not counted to provide resistance to earthquake loading but are key to functionality of the building. For typical buildings, NSC form more than 50% of a building asset and theirloss of function can lead to the building being in-operational for a long period after an earthquake. This applies even for a well-designed building that was relatively undamaged in the earthquake. The US standard explicitly addresses the performance requirement for the NSC and has requirements for anchorage of NSC to the building. The objective is to mitigate the widespread damage witnessed in the past and recent earthquakes worldwide. NSC are especially critical for hospital buildings that house critical and expensive medical equipment. Therefore, proper assessment and retrofit of NSC and their anchorages are a key part of seismic retrofitting for the health facilities.

3.3 Japan Codes and Standards

The guideline and code for seismic evaluation and retrofit in Japan has evolved along with the upgrade of Japanese building code (i.e., law for building new structure). These codes were revised based on lessons learned from major seismic damages, research accomplishments of structural engineering and technology development of earthquake engineering (e.g., damper devices, base isolation, etc.) in the world. Current codes consist of the state-of-the-art knowledge in engineering and the accumulated experience of historical seismic damage.

The first modern building code in Japan was established in 1924 after the Great Kanto earthquake which induced tremendous loss for lives, buildings and economy in 1923. The major item which the code introduced was the minimum coefficient of horizontal seismic force, 0.1, to design building. This is a similar concept to the current base shear coefficient. This minimum requirement came from the maximum acceleration, 0.3g, during Great Kanto earthquake and the assumed safety factor of material strength, 3. Also, this code included several detailing specifications according to building materials. In addition to this code establishment, some lateral force resisting systems became popular after this earthquake such as concrete shear wall and steel frame reinforced concrete. Many brick and masonry building were severely damaged by this earthquake whereas the steel frame reinforced concrete building with shear wall suffered only slight damage. The building code was slightly updated based on research in 1932. Several regulations for concrete mixing, strength and allowable stress of concrete and steel member joints were included, and the horizontal seismic coefficient was revised to 0.2 from 0.1 along with the adoption of new concept of permanent and temporary load combination and allowable stress (the difference between them is twice) in 1950. On the other hand, with the progress of structural engineering to analyze high-rise structure, the limitation of building height, 31m, was eliminated from the code in 1968. When Tokachi-oki earthquake happened in 1968, many reinforced concrete buildings were extensively damaged due to lack of shear strength of concrete frame members. The code then introduced the minimum requirement of shear reinforcement in terms of both the minimum rebar amount and spacing for concrete frame members in 1971. For example, the minimum spacing was revised from 300mm to 100mm, one third, at that time. About seismic evaluation guideline, a methodology (i.e., guideline) to diagnose reinforced concrete building was developed in 1977 based on several earthquake damage records, and similar guidelines for steel buildings, wooded buildings and steel frame reinforced buildings were established in 1979and 1986, respectively. These guidelines have been continuously updated considering research accomplishments and earthquake damages. In 1981, major technical revision to design buildings was adopted in the building code. This revision was carefully researched and reviewed for several years. An earthquake in 1978, Miyagiken-oki earthquake, facilitated this review process because this earthquake induced severe damage in north-east regions of Japan, Sendai in Miyagi prefecture. The major changes consisted of two levels of design seismic force (i.e., strong force to secure building safe and ductile from yielding under inelastic status and moderate force to keep building in elastic state), design seismic force identification considering building natural periods, seismic shear coefficient, the concept of building irregularity in horizontal and vertical direction (i.e., eccentricity, soft story, weak story, dimension irregularity, story drift limitation), structural ductility concept according to lateral force resisting system. During the 1995 Kobe earthquake, this revision effectively worked for the buildings designed under this new code compared to the buildings constructed before this code update. The 1995 Kobe earthquake caused tremendous damage especially to the buildings designed before 1981. The seismic evaluation and retrofit activities for existing buildings were conducted in Japan and the new law for seismic evaluation and retrofit was then enacted in 1995. This earthquake also made the base-isolation technology very popular in Japan in addition to the energy dissipating/absorbing damper system because a building with this system barely suffered any damages even when it was located close to the severe damaged areas. As mentioned above, the seismic evaluation and retrofit code have been periodically updated. The current regulation on seismic evaluation and retrofit in terms of seismic force is almost at the same level as the current building code to design new buildings, and it basically claims to estimate ductility, strength, yielding mechanism (e.g., flexure yield possesses more ductility than shear yield, beam yield is better than column yield in terms of building mechanism, etc.) of all elements for lateral force resisting system.

The latest law to facilitate seismic evaluation and retrofit of buildings in Japan was revised and enforced in 2013. Since 1995 when the first law was established, this law has not been able to force any building owners to conduct seismic evaluation and retrofit. However, the current law states that the owners of three specific groups of buildings built before 1981 (when Japanese building code was revised drastically) have to do seismic evaluation at least, which means seismic evaluation for those buildings became mandatory. Those three types of buildings are the buildings being larger than 5,000m^2 and higher than 3 stories, the essential facility buildings (including major medical facilities like hospitals) where many people gather, and the buildings with a certain height built along the major evacuation streets. The owners of these buildings have to do seismic evaluation and report the result to the local government, and the institution makes those results public to share with people. Therefore, most likely, the owners of buildings which don't possess enough seismic capacity start doing retrofit planning and construction. This is because the buildings including new-built which meet to the current Japanese building code after seismic evaluation and/or retrofitting can show a kind of certification at the building entrance, and this system works well to both owners and users. The owner facilitates seismic upgrade and people can use without any concerns about seismic performance.

The basic methodology and workflow to perform seismic evaluation and retrofit design is to conduct site survey and dimension check, to do condition assessment, to collect as-built information such as drawings and calculations, to conduct seismic evaluation and to plan and design seismic retrofit if needed. The major items of seismic evaluation areto estimate ductility and strength of each member such as columns, beams, walls, braces and slabs and to simulate the yielding locations at the larger seismic forces and specify a building collapse mode (i.e., yielding mechanism). This analysis confirming building collapse mode is usually done by several methods such as collapse mechanism method, pushover analysis, spectrum analysis or non-linear time history analysis. Then, if any deficiencies were found, the retrofit design will be most likely performed through the same methodology and assure the robust and/or ductile collapse mode at a large earthquake being same as design level. The code also introduces a lot of methodologies and examples of seismic strengthening such as BRB, FRP, SW, Column-beam strengthening, Damper, Base-isolation, etc. The strengthening details are also included in the code and periodically updated to reflect the latest technology.

The seismic evaluation and retrofit design for nonstructural components -are also specified in guideline. Those components are, for example, partition, ceiling, mechanical equipment, water pipe, electrical rack, air duct, and so forth. The seismic damage to those components negatively effects on functionality of building and injures occupants by overturning furniture and blocked evacuation routes. Also, the long restoration/repair time increase indirect (i.e., secondary) seismic loss, for instance through business interruption. Indeed, at the Niigata earthquake in 2007, a car parts factory suffered seismic damage, and its manufacture machines were broken. So their production lines were stopped even though the building didn't suffer severe damage. Since the parts were only produced at the factory, most of Japanese car companies couldn't operate their car assembly lines at that time and it induced huge economic loss to those industries. Based on those experiences, the seismic demand level to existing capacity of nonstructural components is at least at thesame level as the current code requirement if the retrofit design is conducted. In retrofit process, building owners can choose an appropriate performance level in terms of functionality from several options in guideline (i.e., seismic demand levels) and engineers design retrofit members to meet the demand based on the selected level. Many details and examples to strengthen seismic performance of nonstructural components are introduced in guideline and continuously updated and are shared with owners, architects, contractors and engineers.

3.4 New Zealand Codes and Standards

New Zealand standards are based on performance requirement. The design seismic force defined by New Zealandseismic loading standard is based on probabilistic seismic hazard assessment (which accounts for probability of triggering an earthquake shaking), hence it can define seismic force based on return period (larger the return period – larger the design seismic force or vice versa as the small earthquakes are frequent). In accordance with New Zealand and other international standard, usually ordinary buildings (such as residential building, etc.) are designed for 475-year return period earthquake; where as a normal hospital would be designed for 1,000-year return period earthquake. However, facilities classified as post-disaster facility (such as major hospital) would be designed for 2,500 years return period earthquake. It should be noted that a post-disaster facility in New Zealand is designed for 1.8 times larger seismic force compared to a similar residential or office building.

Considering life safety-risk posed by the older buildings, including buildings associated with health facility, the New Zealand Building Act requires all buildings excluding small residential buildings, must have at least one-third of seismic capacity of what is required for a new building. The building not meeting this criterion has to be brought to this level or demolished. The one-third criteria have been set considering elapsed life of buildings, seismic capacity of the existing building structure, cost and hardship of retrofitting these buildings. However, considering high risk posed by parapets, gables, facades, etc., the Act also requires these to be fixed immediately.

Seismic Assessment of Existing Buildings - Technical Guidelines for Engineering Assessments (http://www.eq-assess.org.nz/): This guideline (formally known as Redbook) was initially developed by the New Zealand Society for Earthquake Engineering (NZSEE) for assessment and retrofitting design of URM buildings in 1970s. The last comprehensive version that included different types of building materials and structural systems such as steel, RC, URM, timber buildings was published in 2006. The document was applicable for all types of occupancy. The Guideline has been extensively used for seismic assessment and retrofitting design. The document is currently being updatedand was released for public hearing/ comments late in 2016. The revised Guideline is scheduled to be released in July 2017 under Ministry of Business, Innovation and Employment (MBIE). Once released, it will have statuary status. Considering its statutory charter, complexities involved with assessment and retrofitting and to help adaptation of a uniform approach by engineers, MBIE and NZSEE are delivering countrywide trainings and seminars on the Guideline document and assessment process since 2014.

The document is divided into three parts:

- Part A – Assessment Objectives and Principles: discusses philosophy, approach,
- Part B – Initial Seismic Assessment
- Part C – Detailed Seismic Assessment: presents seismic assessment methodology for URM, RC, Timber, steel, etc.

The Guideline embraces the latest research and very comprehensive in its approach. It provides fundamentals on assessment and clear guidance to its user. The main focus of the Guidelines is on understanding of the existing building structure, their characteristics, basic deficiencies, damage patterns and introduces the concept of systematic assessment that would lead to appropriate retrofitting methods. .

Although all of the clauses included in the document may not be directly applicable in Nepal because of the inherent differences in building typologies and deficiencies (for example, RC frame building in Nepal are always build with unreinforced masonry infill walls irrespective of the building size, whereas in New Zealand only one or two storey existing RC frame buildings are clad or partitioned with masonry walls, in New Zealand there are no masonry buildings with mud mortar, etc.), it would still be a veryuseful and comprehensive document to have for clarity of philosophy, approaches and methodology. The document could be adapted with necessary changes to suit Nepalese stock of buildings.

The Redbook included contribution from many well-known representatives from academia and industry and has served as the basis for the seismic assessment and retrofitting standards in the NZ from its inception. The document was intended for application anywhere in the New Zealand. The document provides: a) how to use the Seismic loading standard for defining seismic loading for a building for a given site (important buildings such as hospitals are assessed for higher seismic force so they remain functional even during large earthquakes), b) approach for understanding of building structures and assessing the existing condition of the building; c) methods for identifying deficiencies by visual inspection so these could be quantified later and issues addressed; d) material characteristics, e) requirements for structural analysis techniques to be used to do such assessment; e) methods for deriving seismic force reduction criteria for different types of material (steel, concrete, masonry, and wood) and for common structural systems (moment frames, walls, braced frames, etc.) and failure modes (ductile vs brittle) – brittle buildings have to be assessed and retrofitted for larger seismic force; f) method for how to arrive at element level capacity demand ratio, g) approach to decide what is acceptable and what is not and method for selective retrofitting.

The presentation of the Guideline document acknowledges that the assessment process is not reverse of "new" design. It also acknowledges that graduates of structural engineering may not have been trained for seismic assessment and retrofitting of the existing buildings (as is the case in Nepal, New Zealand or India and many other countries), any sophisticated method cannot always be implemented properly by engineers. Further to the above, it also recognizes large majority of the building structures would not require sophisticated approach, anyway. Accordingly, it takes a very balanced approach. It provides ample room for use of sophisticated approaches (such as displacement-based approaches, time history analysis), but at the same time provides clear guidance to the engineers to undertake simple analysis which would provide a conservative result.

Another key aspect of the Guideline is that one full Section has been dedicated for safeguarding secondary or non-structural building elements (walls, parapets), services (electrical, mechanical, water supply system, etc.) and contents (shelves, etc.) as their safety is important for continual function of a building. These non-structural components and services are equally important for continual operation of a hospital facility, hence they need special attention.

3.6 Turkish Codes and Standards

Turkish Earthquake Code (TEC2007) which is the current seismic design, performance evaluation and retrofit code in Turkey was enforced in 2007. Recently, the draft version of new seismic design and retrofit code was published in 2017.

TEC2007 can be divided in three main parts: earthquake loads, seismic detailing and seismic retrofit. The code defines the design level earthquake and associated response spectrum. Code suggests linear analysis methods such as equivalent lateral force, modal superposition and time-history for design purposes.

Since the Turkish reinforced concrete and steel design codes do not have seismic detailing sections, TEC2007 provides thorough information about seismic design of reinforced concrete and steel structures. Reinforced concrete section concentrates on seismic detailing of sections and design of shear walls. Steel section covers seismic design procedures and shows details of pre-qualified steel connections for intermediate and special moment frames. Connection details are mostly based on FEMA310.

Seismic Performance evaluation and retrofit section of TEC2007 is based on performance-based design philosophy. The code suggests only detailed performance evaluation method and does not include a rapid assessment methodology. The detailed assessment method uses the nonlinear analyses methods such as pushover and time-history as the main procedure. However the code also provides an evaluation method based on linear analysis methods.

The code provides guideline for nonlinear modelling by stating strain limits for concrete and steel for each performance level. Furthermore, the code also briefly explains the fundamentals of nonlinear pushover analysis and provides required background information. The code uses a similar method to FEMA356 for nonlinear static procedure. Performance acceptance criteria are defined in the code for each performance level.

In addition to performance evaluation procedures, the code also has a section about strengthening procedures with fibre reinforced composites (FRP) for retrofit purposes. The section is focused on the use of FRP for increasing ductility, shear and axial load capacities of reinforced concrete sections. Moreover, the section also provides information regarding the use of FRP for strengthening of infill walls.

2017 Draft Turkish Building Earthquake Code

The draft version of new Turkish Earthquake Code was published in 2017 to receive feedback from academics and professionals. The new code brings some significant changes compared to 2007 code. Some of the changes are presented below:

- Response spectrum of ASCE7 has been adopted and spectral acceleration maps have been added to the code
- Four earthquake levels are available where previous code had only DBE and MCE levels
- Displacement-based design is introduced
- Capacity design is explained in more detail
- Seismic design procedures for precast concrete structures, cold-formed steel structures, timber structures and masonry structures have been added
- Tall building definition is more clear and performance-based design is made compulsory for tall buildings
- Seismic design of base-isolated structures has been added
- Seismic retrofit section is enhanced

4.0 Comparison with International Codes and Practices

4.1 National Building Code: Seismic Code

I. Seismic Design Methods

The IS 1893 (Part 1): 1984 described two methodsfor arriving at seismic force on the building - Lateral Force Method and the Response Spectrum Method. However, the Standard provided design spectra for ductile RC bare (no infill walls) frame building. The forces have to be adjusted for less ductile building or brittle buildings by enhancing force level by apply K-factor (structural performance factor). The IS 1893 (Part 1): 2002 includes the Seismic Coefficient Method.In line with changing seismic force format at international level, the Standard provided elastic spectra. It required application of R-factor (Response Reduction Factor) to the spectra for arriving at design seismic force. In the recent draft IS 1893 (Part 1): 2016 has the Equivalent Static Method, the Response Spectrum Method and the Time History Method are adopted. Alsoi the American codes, the New Zealand Codes and the Eurocode 8, the dynamic analysis procedure includes the Time History Analyses (linear and nonlinear). It should be noted that the seismic hazard map included in the IS1893 is not based on any probabilistic analysis, rather it is based on the past damaging earthquakes.

The present Nepal NNBC 105, Nepal describes two methods for calculation: **Seismic Coefficient Method** and **Model Response Spectrum Method**. The Seismic Coefficient Method is a static method whereas Model Response Spectrum Methodis a dynamic method. The bulks of seismic resistant buildings areanalyzed and designed using equivalent static lateral forces to represent the effects of earthquakes on buildings. It is from the assumption that equivalent static forces can be used to represent the effects of an earthquake by producing the same structural displacements as the peak earthquake displacement response. The application of this method is limited to reasonably regular structures. The present code restricts the use of this method for structures up to 40 m height, and should also mention the condition of regularity. This method is easy to apply, transparent and provides equilibrium of actions at a joint

The Modal Response Spectrum Method is basically used for normal structures over 40 meters high and with irregular configuration. Due to absence of definition and classification of irregularity, the users of the code will be confused. The dynamic analysis is confined to the response spectrum method. The Time History Analyses (linear and nonlinear) is not covered in Nepal codes.

II. Seismic coefficient and Response reduction factor

In NBC 105: 1994, the seismic coefficient is estimated using all the principal code factors (V = ZICKSW) except the factor (C) representing the effect of local soil conditions on the spectral response of the ground. This effect has been considered, like in other codes, in the response spectra drawn for different (basically three) types of soil.

The formula for determination of seismic coefficient has been changing in the seismic Standards around the world to make the process more transparent.Earlier, the seismic standards provided design spectra for ductile buildings (typically bare RC frame building) which required application of K-factor for enhancing seismic force based on construction materials, structural system and expected ductility. The latest Standards provide elastic spectra. It has been a trend in the codes of the world to drop the performance factor K and replace it by reciprocal of R, response reduction factor, a factor dependent on the building type and its ductility level. The relation used in deriving static lateral forces in different codes is presented in the following Table 1.

Table 1 Base Shear calculation in different codes

NBC 105:1994	IS 1893-2002	ASCE 7-10	NZS117.5	TEC-2007
V= Cd*Wt , **Cd= CZIK** Where, V= Base shear Cd= Horizontal seismic force coefficient C= Basic Seismic Coefficient for fundamental time period Z= Seismic Zone factor I= Importance factor K= Structural Performance factor	**V_B = (Z/2)*(I/R)*(Sa/g) *W** Where, V_B= Base Shear, W= seismic weight Z= Seismic zone factor I= Importance factor R= Response reduction factor Sa/g= Average response acceleration coefficient	**V= S_{DS}/(R/I_e)W ≤ S_{D1}/(TR/I_e)** Where, V= Base Shear, W= effective seismic weight I_e = Importance factor R= Response modification factor S_{DS}= Design spectral response acceleration parameter at shorter period, S_{D1} = Design spectral response acceleration parameter at 1s, T= fundamental time period	$V_b = C_h(T)ZRN(T,D)\frac{S_P}{K_{\mu}}W$ Where, Cd(T): Spectral shape factor V_b= Base Shear, W= seismic weight Z= Seismic zone factor R = Return Period factor based on Importance of a building N(T,D) = factor for accounting for near-field effect Kμ = Ductility factor (based on usable ductility of a building) Sp: structural performance factor (accounts for redundancy, over strength, over design)	V= A_0*I*S(T)*(1/ R) *W Where. V = Base shear, A_0=Effective ground acceleration coefficient I = Building importance factor, W = Total weight of building calculated by considering live load participation factor, R = Structural Behaviour Factor, S(T)=Spectrum coefficient

III. Seismic Hazard Level and Response Spectrum

NNBC 105: 1994 present the seismic zone map with different zonal factor for selected municipalities as in Figure 1, but it does not give any elaborate information on the seismicity of the country. Most of the international codes presented the maps showing epicenters of past earthquakes, principle tectonic features, geological features including principal lithological groups, and seismic zones. Recently drafted IS 1893 (Part 1): 2016 also updated the seismic zonation map. The seismic zoning map presented in

NNBC105 is based on probabilistic seismic hazard assessment for Nepal which included seismic sources located in Nepal and an area 150km beyond Nepal boarder.

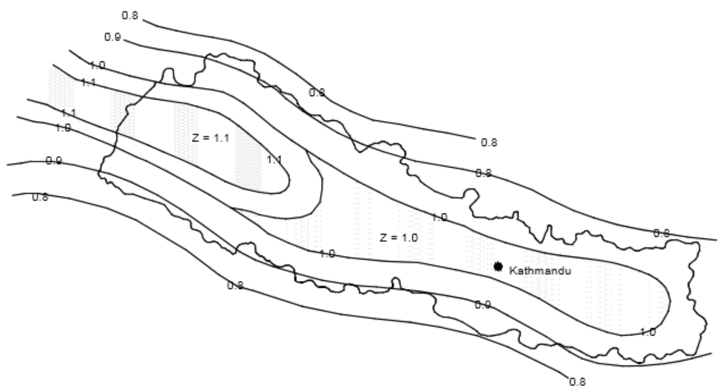

Figure 1 Seismic zonal map adopted in NBC 105, 1994

Recently Department of Mines and Geology, Nepal and other studies (Pandey et al. (2002)) have presented seismic hazard map of Nepal as a result of probabilistic seismic hazard analysis. The document presents the contour of seismic hazard at the bedrock of Nepal for a return period of 500 years, indicating 10% probability of exceedance in 50 years.

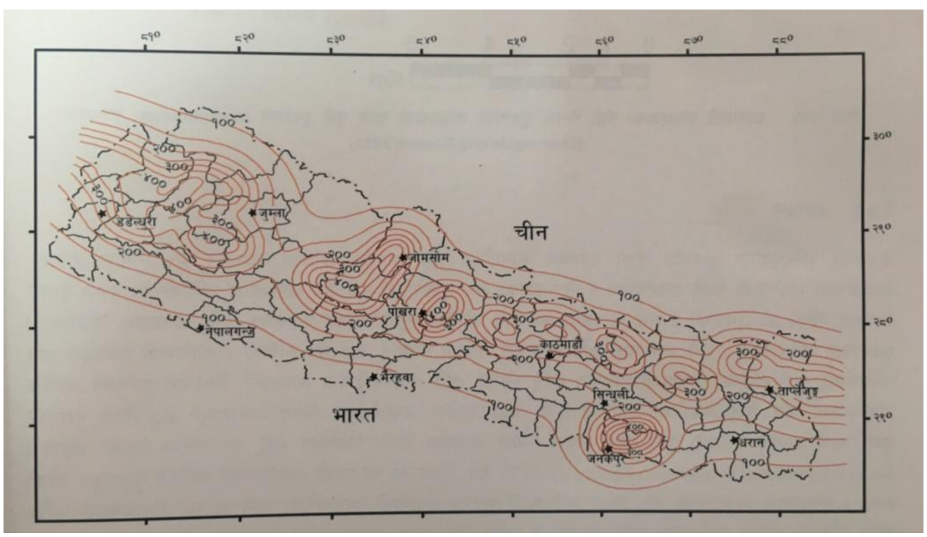

Figure 2 Seismic hazard map of Nepal (Pandey et al., 2002)

The seismic loading in NBC 105: 1994 is set at a seismic hazard level having a return period of 300 years, which corresponds to a probability of exceedance less than 10% in 30 years life of a building The seismic hazard level was set to be at a level approximately equal to that defined in the Indian Standard, that is, IS 1893: 1984, which has already been revised into IS 1893 (Part 1): 2002 with a different value of design earthquake value. The NBC 105: 1994 set lower design earthquake level than usually used by international standards considering its affordability, building typology, construction materials and structural system. In accordance with New Zealand and other international standard, usually ordinary buildings (such as residential building, etc.) are designed for 475-year return period earthquake, where as a normal hospital would be designed for 1,000-year return period earthquake. But in case of facilities classified as post-disaster facility (such as major hospital) would be designed for 2,500 years return period earthquake. It should be noted that a post-disaster facility in New Zealand is designed for 1.8 times larger seismic force compared a similar residential building. In US system, the 475 and 2,500-year return period earthquakes are termed Design Basis Earthquake (DBE) and Most Credible earthquake (MCE). Indian seismic loading standard uses the terms DBE and MCE to define magnitude of the earthquake force, but does not define return periods associated with these terms. It is because Indian seismic loading standard is not based on probabilistic seismic hazard assessment. Considering changed scenario of Nepal and changed international practices, there is a need fora major revision of NBC105.

The provisions in the present code have been developed in reference with mainly buildings with natural periods 3 seconds. The response Spectrum adopted by NBC 105 is shown in the Figure 1 and have the following features;

- Long period up to 3 second;
- Spectra employing for three different soil with 5 % damping factor

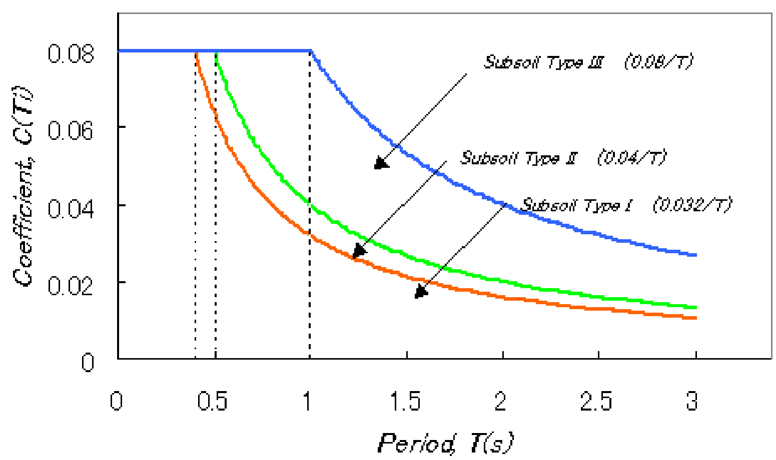

Figure 3 Response Spectrum adopted by NBC 105, 1994

The design spectrum of NBC is similar to that of IS code, but differ in the normalization of the values of what has been termed as Spectral Acceleration Coefficient (Sa /g) in IS1893: 2002 and Basic Seismic Coefficient (C) in NBC105: 1994. Recently IS code in draft IS1893: 2016 change the response spectrum for 6 sec.

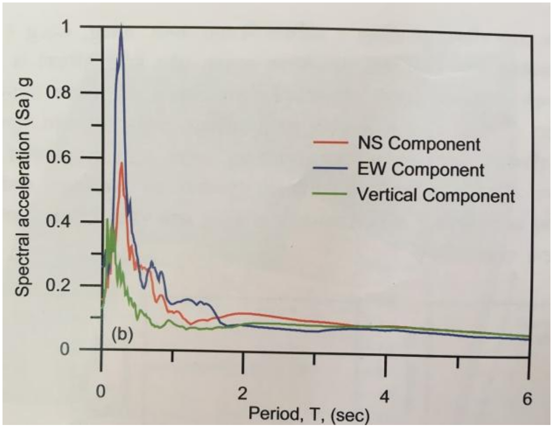

Figure 4 Response Spectrum recorded on rock site of Tribhuwan University

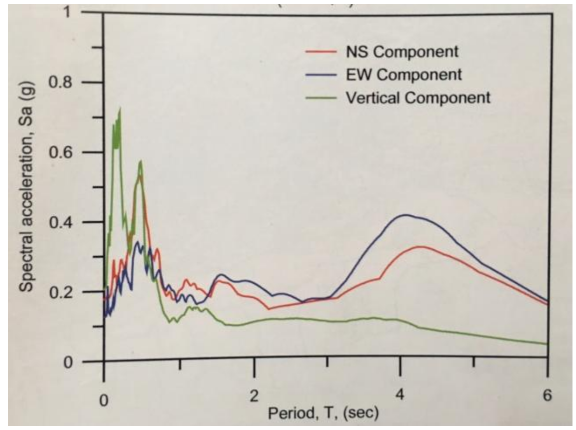

Figure 5 Response spectrum recorded on soft soil site of Department of Mines and Geology

Based on a set of ground motions from two recording station in Kathmandu – Lainchaur and Kirtipur, the 5% damped acceleration response spectra of three direction are shown in the figures below. From the response spectra, it can be seen that the induced ground motions peak at period of 0.26 and 0.6 seconds for NS and EW components on rock site (Kirtipur), whereas peak at periods 0.3 sec (N-S component) and 4.5 s (both N-S and E-W components) on soft site (Lainchaur). In addition, the induced ground motion exceeded the design demand for structures of all periods (except for stiff structures with a period less than 0.3 sec). The recent studies mentioned that the calculated design peak ground acceleration on the soft soil site in the Kathmandu Valley was estimated to be 0.36g which is approximately double that of the recorded peak ground acceleration during the 25 April earthquake. Also, the induced demand was unusually high for structures with natural periods ranging between 4 and 6 seconds. Despite spatial variation of ground motions, the earthquake spectra illustrated in Figure 5 partially explains the significant damage that was observed in tall and flexible reinforced concrete (RC) frame structures in the Kathmandu Valley.

The comparison of response spectrum of NBC 105, IS 1893, 2002 and NZS1170.5 is presented in Annex 4.

IV. Design load combinations

The NBC 105 provided partial load factors for both Limit State Method (LSM)and Working Stress Method (WSM) because the Indian reinforced concrete, steel, masonry and timber Standards followed either LSM or WSM or both. The design load combination factors for both the WSM and LSM respectively are too small compared to other standard building codes (IS code). For example, the dead load and live load factor as 1 and 1.3 in the NBC 105 appear to be un-conservative. The uncertainties due to non-uniformity of materials, workmanship, and quality control seem to be ignored in the load factor for dead load. The uncertainties in overloading is covered by maximum 1.3 may not be practical in case of Nepal. Similarly the maximum load factor value for seismic load considered is just 1.25, both in combination with 0.9 times dead load, and in combination with dead load plus 1.3 times live load. The value of 1.25 is too low in view of the large uncertainties involved in assessment of the seismic load. The earthquake load combinations of the codes compared here are shown in the Table 2.

Table 2 Comparison of load combination, Design Hazard level & Site Classification

	NBC 105	IS 1893-2002	ASCE 7-10	TEC-2007
Load combination	I. DL + 1.3 LL + 1.25 E II. 0.9 DL + 1.25 E III. DL + 1.3 SL + 1.25 E	I. 1.5(DL+LL) II. 1.2(DL+LL ±EL) III. 1.5(DL ±EL) IV. 0.9DL ± 1.5EL	I. 1.4D II. 1.2D+1.6L III. 1.2D+1L ± E V. 0.9D ± E	I. 1.4D+1.6L II. D+L±E III. 0.9D±E
Design Hazard Level	The seismic loading is set at a seismic hazard level having a return period of 50 years, which corresponds to a probability of exceedance less than 45% in 30 years.	- specifies design hazard as 0.5 times the MCE hazard (Z/2) but it does not specify probability of exceedance for design seismic hazard or for MCE hazard.	- specifies seismic hazard at maximum considered earthquake (MCE) and corresponding probability of exceedance is 2% in 50 years. A factor of 2/3 is recommended to scale the MCE hazard to design seismic hazard.	Specifies design hazard considering earthquake with the probability of exceedance of 10% in 50 years.
Site classification	Three soil types (I, II, III).	Three soil types (I, II, III).	Five soil types (A- E)	Four soil types (Z1,Z2,Z3,Z4)

Besides, it remains silent when two dimensional earthquake related shaking is required to be considered or when building is torsionally irregular.

The New Zealand seismic standard requires strong compliance with capacity design approach. It is performance based standard and requires buildings to be designed for Serviceability Limit State (SLS) and Ultimate Limit State (ULS). The SLS is considered to avoid damage to the building during more frequent earthquake (typically 25 years return period for residential buildings) and expectation are that the building can continue to be used as originally intended without repair. Hence, to achieve this limit state, level of stress or strain within the building components is kept low. The ULS is considered to ensure life-safety during a major earthquake (typically 475 years return period for residential buildings). NBC105 and IS1893 do not require checking for SLS explicitly. It considers that once ULS is accounted for the building will automatically meet SLS requirement.

V. Allowable soil bearing pressure

The provision of increasing allowable soil bearing pressure by upto 50% whenever earthquake forces are considered along with other design forces need to be elaborate clarifying the condition when to follow the above mentioned provision depending upon the soil type (hard, medium or soft), foundation types (piles, raft, combined, isolated and well) etc.

VI. Deformation

The primary clause for deformation due to earthquake forces is the storey drift limitation, which shall not exceed 0.004 times the storey height. For the purpose of displacement requirements only, the seismic forces obtained from the fundamental time period of the building by static or dynamic approach may be used. The separation between two adjacent buildings or two adjacent units of the same building must be provided by a distance equal to the sum of the calculated storey displacements multiplied by 5/k or by R, if the performance factor k is replaced by response reduction factor R. It shall further be supplemented by the provision that if the floor levels of the two adjacent units or buildings are at the same elevation levels, the factor 5/k or by R may be further replaced by 10/k or R/2 respectively.

VII. URM infilled wall

Unreinforced Masonry (URM) is the most common partitioning material in framed buildings in Nepal and many other countries. In design practice, these infills are treated as nonstructural- elements and their stiffness, strength and interaction with the frame is frequently ignored, primarily because of difficulties in simulation and lack of modelling guidelines in design codes. The Nepal building code as well as many other national codes do not provide explicit insight into the anticipated performance and associated vulnerability of infilled frames. Ignorance of the interaction between the infill and the frame generally does not affect the gravity load resisting system in which all the gravity loads are resisted by frame elements. However, it is clearly showed that the behaviour of the structure under earthquake shaking is significantly affected by the presence of URM infills. In addition, the recent studies suggest that the presence of URM infillscould result in a significant increase in the seismic vulnerability of RC frames and their effect needs to be properly incorporated in design codes. The period of vibration of frame buildings is substantially reduced by the presence of these infills. The inclusion of infills significantly increases the damage probability of the frame buildings irrespective of design level. Even the frame buildings designed and detailed as per Indian codes have a 50% probability of complete damage under Maximum Considered Earthquake (MCE) in the same seismic zone for which they were designed for. They can induce soft/ weak storey, short column effect, over stress of columns, etc.

In the IS 1893-2016 draft code, the provision for the estimation of in-plane stiffness and strength of URM infill walls has been introduced. The code further recommends the URM infill walls to be modelled as using equivalent diagonal struts.

VIII. Non-structural components

For high priority structure the vulnerability of non-structural and functional features can lead to severe functional and indirect losses aftermath of the events which may far exceeds the loss caused by the structural damages. Non-structural components and systems are defined as those elements that are not intended to contribute to the seismic resistance of the building. They consist of architectural, mechanical, and electrical components, and provide weather protection, heating, cooling, lighting, and acoustic control. Damage to these components can be costly and can render the building functionally useless, even for well-designed buildings that are expected to perform satisfactorily during earthquakes. According to Miranda and Taghavi (2003), non-structural components make up approximately 82%, 87% and 92% of the total monetary investment in office, hotel and hospital buildings, respectively, in the United States. Adequate anchorage and support are critical to reduce damage to non-structural components. Seismic codes provide the design force for these components and specify design requirements.

The current India/ Nepal building code does not have detail provisions to design and mitigate non-structural damages. The International Building Code (IBC) in the United States references the ASCE 7 Standard for the seismic design requirements of nonstructural components. The NBZ1170.5 explicitly requires non-structural components to be designed properly and prescribes method for deriving earthquake force on these components. The most recent edition of ASCE 7-10 (ASCE, 2010) dedicated a chapter (Chapter 13) to the seismic design requirements of nonstructural components. FEMA, 2007 has presented a description of performance categories in term of structural and nonstructural building damages. Recently, D'Ayala D, et al (2015) has reviewed damages of non-structural components during earthquake and its impact on Hospital functionality as well as non-structures seismic retrofitting measures.

4.2 Guidelines for Seismic Vulnerability assessment of Hospitals

This document assumes the example building as limited ductile, but does not substantiate for this assumption. Further, the guideline does not account for partial safety factor for loads as required by IS1893. This would result in non-conservative result.

4.3 Structural Vulnerability Assessment of Hospitals in Kathmandu Valley, 2009

Good effort appears to have been placed to compile this document. The document is modelled on FEMA series of building assessment and retrofitting documents. Although the document name suggests "vulnerability evaluation" it also includes retrofitting options briefly.

It provides methodology for on-site intrusive investigation of existing buildings, preliminary assessment (Tier 1), and detailed seismic assessment. It presents both force-based and displacement-based methods for assessment of existing buildings. However this guideline also mixes up NBC105 and IS1893 for the estimation of seismic force, force distribution without any justification. Following IS1893, it assumes RC frame buildings as ordinary RC moment frame building, again without any justification and does not check effect of detailing deficiency. The guideline does not account for presence of infill walls on performance on the building structure.

The document provides one example of assessment of load bearing masonry buildings. However, the assessment does not account for potential failure mechanisms, which could lead to non-conservative strength estimation.

4.4 Seismic Retrofitting guidelines of buildings in Nepal, 2016

It provides aspects of repair, restoration and seismic retrofitting of an existing building including construction materials and techniques, but fails to provide design steps, detailing and norms of retrofitting techniques.

The Guideline has no philosophical drive or direction. It does not address issues that need attention. It lacks understanding and is too mechanical. The assessment methodology presented in the guideline takes very simplistic approach for assessment of RC buildings. It assumes RC buildings as bare ductile buildings, and ignores presence of brick infill walls and potential non-ductile detailing including deficiency gravity load details which is present in Nepal. The infill walls could lead to severe structural deficiencies such as plan irregularity, soft-storey mechanism, short columns to name a few.

A few examples have been presented following strength and displacement-based approaches. All these examples ignore presence of infill walls. However, as discussed above, in case of Nepalese RC frame buildings with masonry infill walls, the walls will control performance of the building. The examples present assessment of structure only, and does not suggest how to address secondary components such as face loaded infill walls, parapet, etc.

No separate code exists in Nepal for seismic evaluation and retrofit, thus these guidelines', the seismic evaluation and retrofit design are based on the standards and codes of NBC and IS 1893, 2002. As mentioned above, there are many standards that need to be revised and updated. IS 1893, 2002 is already revised. For masonry buildings, the evaluation and calculation is based on the FEMA 356, Rai, D.(2000) and Arya, A et al, (2003). These documents has alreadybeenrevised and updated. In the adobe buildings, most of recommended seismic measures are based on guidelines developed by the project and there is no scientific test verification. There are some strengthening measures using local and recycle materials, but theseneed to develop materials specification with some testing. In addition, there is no consideration of non-structural components of the buildings.

These guidelines briefly described the performance based seismic evaluation and retrofitting design especially in RC buildings. However there is lack of detail standards for this design approach. The IS 15988 : 2013 also includes a brief general description about the Performance based approach in an annex. However US, Japan, Turkey and New Zealand seismic retrofitting code and standard are based on the performance based design approach.

4.5 Guidelines for Seismic Vulnerability Assessment of Hospitals, 2016:

It is a well-crafted document which deals with various aspects hospital safety including structural, non-structural and content. It is common practice to focus on building structure during assessment process, however this document goes beyond that and addresses the issues which are crucial for functioning of a hospital after an earthquake. The guideline presents methodology for Tier 1 (preliminary) structural assessment and visual assessment of non-structural components. The Tier 1 assessment method is based on FEMA set of assessment documents.

It follows IS1893 for seismic force calculations for preliminary assessment of an example building. It assumes the example building as limited ductile, but does not substantiate for this assumption. Further to this, the guideline does not account for partial safety factor for loads as required by IS1893. This would result in non-conservative result.

5.0 Improvement of Codes and Standards In Nepal

The seismic retrofitting guidelines are intended to supplement the National Code while retaining the relevant provisions of the code. To produce a widely applicable document, the scope and material would be purposefully broad. The assessment and upgrade procedures presented are particularly relevant to hospital buildings in Nepal. Since most hospital buildings use masonry and some use reinforced concrete framing, the document will focus on these construction types and the appropriate retrofitting for the common deficiencies.

Correctly applying the provisions of the document is crucial in planning and implementation. Following aspects need to be considered:

- The seismic hazard for a site should be carefully developed by using modern seismic hazard maps, historical data, and site conditions.
- The structural system should be clearly defined, and properties that are specific to different systems, such as walls and frames, should be investigated.
- An investigation plan will be included for assessment of the condition of the as-built structure. The analytical model of the building should accurately represent the physical structure; however, considering uncertainties involved in this type of work, focus will still be on the performance rather than accurate modelling
- Appropriate analysis methods and performance levels should be selected.
- The proper design of critical members (frames, shear walls, and diaphragms) and their connections to one another is crucial for satisfactory seismic performance. The members should have adequate capacity and ductile detailing, and be anchored to provide a continuous and redundant load path.
- The upgrade configuration should be simple and regular, and meet aesthetic requirements.
- Good quality control is necessary to ensure that the upgrade is properly constructed.
- A regular and thorough maintenance schedule is required to ensure that the building retains its integrity over time. Corrosion of steel, concrete cracking and spalling, and foundation integrity should be monitored.
- Non-structural components (NSC) should also be addressed in the design and analysis. They are generally classified broadly according to their use. Adequate anchorage and support are critical to reduce damage to non-structural components. Seismic codes should provide the design force for these components and specify design requirements. Therefore, proper seismic assessment and retrofit design of NSC and their anchorages should be a key part in the seismic retrofitting and rehabilitation of the health facilities in Nepal.
- The current guidelines on assessment and strengthening of buildings are limited in scope. These need updating or even new ones have to be developed. They need to be more context

specificand address Nepali building types. These should include assessment and retrofitting methods for such as low strength masonry or similar building typology (such as stone in mud or similar) as it might not be feasible to replace all these buildings using modern buildings, although that would be desirable.

- As in typical practice, when retrofitting costs exceeds 40% of replacement, reconstruction will be recommended.However, this will be evaluated case to case basis. An attribute based method will be developed for decision making.
- There needs to be prioritization of the retrofitting work and techniques based on cost-benefit analysis, importance of building, and building typology[1]

On the other hand, Nepal building code has been more than two decades old and there are lots of changes in technologies, standards and practices as well as a substantial advancement in the knowledge related with seismic resistant design of buildings and structures during the period. Revision of the codes has not been conducted with the passage of time. Based on the lessons learnt from the large earthquakes in the recent years and changes in seismic design provisions in building codes of different countries in last 20 years, it should be revised soon. As discussed in the above section, the following issues should be incorporated in the revised Nepal Seismic Building Code.

- Update in the design method must be an optional provision for Time History Analysis which may require an analysis for critical facilities and high performance engineering retrofit techniques.
- Need necessary modification in the estimation of the seismic loading to compete with international codes including and replacing some factors (response reduction factors)
- The seismic loading standard should be modified and set for different buildings as per other countries standardsproviding clear guidance for typical Nepali building typologies. While setting seismic design standards for Nepal, affordability, available building materials and technology in Nepal should be considered. Generally, one death per 1,000,000/ year is internationally accepted rate of risk, however, ISO 31000:2009, Risk management – Principles and guidelines suggests that new building codes should regard to the costs and benefits of seismic retrofitting.
- Maps showing epicenters of past earthquakes, principle tectonic features, geological features including principle lithological groups, and seismic zones and PGA of different regions need to be included
- The provisions presented in the code are for mainly the buildings with short natural periods (upto 3 second). They need to include provisions for high rise buildings with long period structures based on the recent earthquake's lesson learns with earthquake ground motion level and damages.
- Considering the significant increase in the seismic vulnerability of RC frames, it is very important to give proper attention to the infill-frame interaction in the design of URM in-filled RC frame buildings and these need to be properly incorporated in design codes.
- Another very important issue is about the need tointroduce performance based design of buildings during earthquakes. It is high time to express the design procedures in terms of

[1] Over the time deficient/ weaker buildings could be removed as it would not make sense for retrofitting of stone-mud/ brick-mud masonry buildings to higher seismic standards because of economic (low floor area, high cost), and functionality.

performance base, so that the earthquake disaster risk is addressed in a more meaningful manner. Further to it, assessment methods have not developed enough for assessment of all types of Nepalese buildings following performance based approach. In this regard, both force-based and performance based approaches need to be included.

- Different design earthquakes and performance levels for various types of buildings in building codes needs to be defined
- Principles and details of retrofitting techniques both using conventional or advanced methods andmaterials need to be included in seismic design code. Conventional retrofitting methods/ techniques –such as adding RC infill walls to the structural system and jacketing of RC columns are common practices in Nepal. These result in an increase in the weight of the structure that produces larger earthquake forces. Furthermore, these methods require heavy demolition and construction work. In this context, there needs to be further exploration of cost-effective and sustainable innovative retrofitting methods (e.g.steel braceswith shear link)for hospital buildings that are very effective in reducing the detrimental effects of earthquakes on buildings and minimize the demolition or construction works when used for seismic retrofitting.

6.0 Proposed Plan and Process

To develop a comprehensive seismic retrofitting and rehabilitation standard for health infrastructures in Nepal under NHSSP-III, the following plan and process will be followed.

- A Nepal Seismic Retrofitting and Rehabilitation Standards Working Team (NSRRSWT) will be formed including national and international professional experts. The working team will be led by Senior Earthquake Resilient Advisor (SERA), and work closely with Lead Technical Advisor (LTA) of Health Infrastructures.
- A Nepal Seismic Retrofitting and Rehabilitation Standards Coordination Committee (NSRRSCC) will be formed including representatives of Ministry of Health, DUDBC, DFID and NHSSP Senior Management Team (SMT)members to monitor and guide the working team.
- A recommendation for seismic strengthening of the health infrastructures will be developed as a roadmap for development of a seismic retrofitting and rehabilitation standard for health infrastructures in Nepal. It is based on investigation of major weaknesses, knowledge gaps and area for improvements in current Nepal codes and practices comparing with other countries' codes and standards in the preliminary report.
- A consultation workshop will be organized to discuss the recommendation prepared by the working team as well as to consult with relevant officials, academics, professional experts and other stakeholders for valuable suggestions.
- Based on the comments and suggestions, working team will develop draft standards for Nepal.
- During the draft preparation phase, the working team will continuously consult with concerned authorities and experts. The coordination committee will also regularly monitor and provide necessary guidance to the working committee. SERA will regularly update the progress to Coordination committee as well as the SMT
- Once an initial draft of seismic retrofitting and rehabilitation is prepared and submitted to NSRRSCC, it should be circulated among the concerned stakeholders (mainly technical personnel) for valuable comments.
- A national seminar to deliberate and finalize the document with participation of maximum technical personnel will be organized.
- The working team will prepare and submit the final draft document to the NSRRSCC addressing and incorporating all the valid comments and recommendations
- NSRRSCC will support to DUDBC to peer review the final draft document submitted by the Working Team forming experts peer review panel. The peer review panel of national experts will be formed under DUDBC.
- Incorporating the comments and feedback of the peer review panel, the final documents will submit to DUDBC for official adaptation.

7.0 Time Frame

Activity Description	Inception			Rest of Year 1						
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kick off Workshop	■									
Formation of Working Team		■								
Collection of information and documents		■	■	■						
Engagement of key officials in the process		■	■	■	■	■	■	■	■	
Review of National and International code and standards			■	■						
Develop Prepare Preliminary Report and submit to DFID			■							
Formation of Coordination Committee				■						
Develop recommendation and submit DFID				■						
Consultation Workshops				■	■		■			
Develop First Draft Seismic Retrofitting and Rehabilitation Standards for Nepal					■	■	■	■		
Organization of nation seminar on Seismic Retrofitting and Rehabilitation Standards for Nepal									■	
Finalization of Draft Seismic Retrofitting and Rehabilitation Standards for Nepal									■	
Formation of Peer Review Panel and review the draft documents									■	■
Finalization of the standards										■
Dissemination and endorsement workshop										■
Submission to DUDBC for official endorsement										■

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Annex – 1:

List of Nepal National Building Codes

1	NBC 000: REQUIREMENTS FOR STATE-OF-THE ART DESIGN AN INTRODUCTION
2	NBC 101: MATERIALS SPECIFICATIONS
3	NBC 102: UNIT WEIGHT OF MATERIALS
4	NBC 103: OCCUPANCY LOAD (IMPOSED LOAD)
5	NBC 104: WIND LOAD
6	NBC 105: SEISMIC DESIGN OF BUILDINGS IN NEPAL
7	NBC 106: SNOW LOAD
8	NBC 107: PROVISIONAL RECOMMENDATION ON FIRE SAFETY
9	NBC 108: SITE CONSIDERATION FOR SEISMIC HAZARDS
10	NBC 109: MASONRY: UNREINFORCED
11	NBC 110: PLAIN AND REINFORCED CONCRETE
12	NBC 111: STEEL
13	NBC 112: TIMBER
14	NBC 113: ALUMINIUM
15	NBC 114: CONSTRUCTION SAFETY
16	NBC 201: MANDATORY RULES OF THUMB REINFORCED CONCRETE BUILDINGS WITH MASORNY INFILL
17	NBC 202: MANDATORY RULES OF THUMB LOAD BEARING MASONRY
18	NBC 203: GUIDELINES FOR EARTHQUAKE RESISTANT BUILDING CONSTRUCTION: LOW STRENGTH MASONRY
19	NBC 204: GUIDELINES FOR EARTHQUAKE RESISTANT BUILDING CONSTRUCTION: EARTHEN BUILDING (EB)
20	NBC 205: MANDATORY RULES OF THUMB REINFORCED BUILDING CONSTRUCTION WITHOUT MASONRY INFILL
21	206: ARCHITECTURAL DESIGN REQUIREMENTS
22	NBC 207: ELECTRICAL DESIGN REQUIREMENTS FOR (PUBLIC BUILDINGS)
23	NBC 208: SANITARY AND PLUMBING DESIGN REQUIREMENTS

Annex – 2:

List of Interviewed experts and organization

Name	Organization	Position
Raju Manandhar	DUDBC	Deputy Director General
Manoj Nakarmi	DUDBC	Section Chief
Prakrina Tuladhar	DUDBC	Senior Division Engineer
Sagar K. Joshi	NRA	Senior Division Engineer
Prof. Prem Nath Maskey	Institute of Engineering (IOE)	Professor
Dr. Purushotam Dangol	Department of Archeology (DoA)	Consultant (Structural Engineer Expert)
Dr. Rekha Shrestha	R & R Consultancy	Structural Engineer/Director
Manohar Rajbhandary	MRB & Associates	Managing Director
Nabin Malakar	NHSSP	Structure Engineer
Gyanendra Shakya	NHSSP	Senior Architect
Hem Shrestha	NSET	Structure Engineer
Dr. Sushil Bajracharya	IOE	Professor
Ravi Sharma Bhandari	Freelance	Structural Engineer
Satya Sundhar Shrestha	Pyramid Consultancy	Structural Engineer,

Annex – 3:

Comparison of Standards and Practices of Seismic Evaluation of Buildings

Standard	Nepal standard	Indian Standard	New Zealand standard	Remarks
Loading				
Dead load	NBC102	IS875 (Part I)	NZS1170.1	NBC102 refers to IS875 (Part I) -1987 for dead load. The IS 875(Part I) - 1987 is still valid. Dead load requirements of NZS1170.1 and IS875 (part I) are similar.
Live/ Imposed load	NBC103	IS875 (Part II)	NZS1170.1	NBC103 refers to IS875 (Part II) – 1987 for imposed load. The IS875 (Part II) - 1987 is still valid. Imposed load requirements of NZS1170.1 and IS875 (Part II) are similar.
Wind load	NBC104	IS875 (Part 3)	NZS1170.2	NBC104 recommends use of IS 875(Part 3) - 1987 with some amendments. Although Wind Map is not included in NBC104, it recommends 47m/s and 55m/s wind speed respectively for areas below and above 3000m altitude. IS875 (part 3) provides a comprehensive method for estimation of design wind load and is still valid.

Standard	Nepal standard	Indian Standard	New Zealand standard	Remarks
				Requirements set-out in NZS1170.2 are onerous than that of IS875 (Part III).
Earthquake load	NBC105 and Commentary	IS1893	NZS1170.5 and Commentary	NBC105 provides design spectra (inelastic spectra) for ductile buildings (typically ductile RC frame building), which should be magnified by K-factor (*structural performance factor appropriate for the structural type*) for less ductile system. The Standard provides a list of K-factors to be used for different building materials and structural systems. No information is provided on how the inelastic spectra can be converted into elastic spectra required for displacement based design/ assessment or design of base isolated buildings. IS1893 has been subsequently been revised in 2002. It now follows load reduction factor method, where seismic forces are reduced by R-factor (Response reduction factor) based on available structural ductility. Considering life-safety threat imposed by non-structural components in the building, NZS1170.5 requires these components to be restrained to the principle structure. It provides methodology for estimating seismic design forces for restring these components. NBC105 is limited in scope and does not provide enough guideline for various types of building Refer to the following sections for more details on comparison of these standards.

Standard	Nepal standard	Indian Standard	New Zealand standard	Remarks
Snow load	NBC106	IS: 875 (Part 4)	NZS1170.3	NBC104 has recommended use of IS875 (Part 4)-1987 with some amendments. NBC106 also provided a map of Nepal which has divides the country into five physiographic regions. However, the snow data available during preparation of NBC106 were very scarce, hence the Standard has suggested to collect local information before designing a structure sensitive to snow. This Standard would be required for designing structures in high Himalaya and high mountain regions, particularly for roof design f this is constructed of light structure. IS875 (Part 4) provides a comprehensive method for estimation of design snow load on roof.
Materials				
Unreinforced brick masonry	NBC109	**IS:1905-1987**	-	NBC109 recommends this Standard be read in conjunction with IS1905:1987. The current NBC109 is not complete for independent use. IS1905 basically address design for gravity loads. Construction of building structures using URM system is not permitted in NZ. A draft for revision of IS1905:1987 has been developed under IITK-GSDMA Project on Building Codes (http://www.iitk.ac.in/nicee/IITK-

Standard	Nepal standard	Indian Standard	New Zealand standard	Remarks
				GSDMA/EQ12b.pdf), but it has not been adopted by Bureau of Indian Standards.
Plain and reinforce concrete	NBC110	IS456 IS13920	NZS3101	NBC110 suggests use of IS456:1987 in conjunction with the amendments included into NBC110 so as to meet the conditions of Nepal. These amendments have been necessary to ensure compatibility of IS456 with the NBC105, particularly the partial safety factors for load. NBC110 suggests use of IS13920 for ductile detailing. IS456:1987 has been replaced by IS456:2000 with more focus on Limit State Design. IS456 suggests compliance with IS13920 for ductile detailing for earthquake-resistant construction. IS13920 suggests capacity design approach for shear design, but has not adopted yet strong column-weak beam approach to suppress failure of columns in RC frame buildings. NBC110 makes aware that any subsequent revisions to IS 456-1978 shall be not be applicable to NBC110 until specifically recognised by this Standard. Hence, IS456:2000 requires a review to confirm its compliance with NBC105. Compared to IS456, NZS3101 is more rigorous and requires full compliance with capacity design approach.
Steel	NBC111	IS800	NZS3404	The NBC111 suggests use of IS800:1984 in conjunction with the amendments included into NBC111 so as to meet the conditions of Nepal. These amendments have been necessary to ensure compatibility of IS800 with the Nepal Standard NBC105, particularly the partial safety

Standard	Nepal standard	Indian Standard	New Zealand standard	Remarks
				factors load. IS800:1984 was based on Working Stress Method and was not suitable for buildings requiring ductility. IS800 was revised in 2007. The current version includes a section on design and detailing of buildings for earthquake forces and requires strong column-weak beam approach to be followed. It recommends different R-factors (earthquake force reduction factor) for different structural systems based on ductility demand on the system. It has become much more comprehensive now. NZS3404 is strongly earthquake design biased and categorises structural systems in different Categories based on ductility demand on the system. Is requires capacity design approach to be followed with onerous requirements for shear and anchor design.
Timber	NBC112			Timber buildings are unlikely to be constructed for hospital buildings in Nepal, hence these have been not discussed here.
Non-structural components				
Non-structural components (engineering systems)	Guideline for Non-structural Safety in Health Facility	N/A	NZS4219	The NZS4219 sets out the criteria for the seismic performance of engineering systems (machines and equipment such as generators, ducts, hanging treys, tanks, life lines, etc) related to a building's function. It covers the design, construction and installation of seismic restraints for these systems. No such Nepal or Indian Standards exist. Considering dependence of hospital function on machines and equipment, complex network of lifelines, etc, non-structural components

Standard	Nepal standard	Indian Standard	New Zealand standard	Remarks
				should be restrained. A Guideline for non-structural safety in health facility was developed by the Ministry of Health and World Health Organisation in 2004. The document provides simple methods for restraining of machine and equipment, shelves, etc in the hospitals. However, it does not provide methodology for calculation of restraints which is essential for restraining larger equipment and machines.
Seismic Assessment and Retrofitting				
Seismic assessment of exiting building structures	Seismic Vulnerability Evaluation Guideline for Private and public Buildings, Part I: Pre-Disaster Vulnerability Assessment Guidelines for seismic vulnerability Assessment of Hospitals	Guidelines for Seismic Evaluation and Retrofitting of Buildings (IITK-GSDMA	The Seismic Assessment of Existing Buildings - Technical Guidelines forEngineering Assessments	It should be noted that seismic assessment of existing buildings requires in-depth understanding of existing building materials and structure, their behaviour during an earthquake. It should be understood that it is not reverse of design of new buildings. Format of the Nepalese seismic assessment guideline for initial assessment (Tier 1) of buildings is based on Federal Emergency Management Agency's (FEMA) format. The Nepalese guidelines for detailed seismic assessment provides methodology and examples for seismic assessment. However, these do not provide conceptual framework. Further, these directly jump to very complex analytical methods (displacement based methods), which renders its use as most structural engineers are unlikely to be trained to use these tools.

Standard	Nepal standard	Indian Standard	New Zealand standard	Remarks
				New Zealand guidelines provides very comprehensive conceptual framework and fundamentals for building assessment. The Indian guideline is based on FEMA format and provides provisions, commentary and a few examples for seismic assessment of buildings. However, it is limited to RC frame
Seismic retrofitting of exiting building structures	Seismic Retrofitting Guidelines of Buildings in Nepal	Guidelines for Seismic Evaluation and Retrofitting of Buildings (IITK-GSDMA Project)	No comprehensive guideline available	

Annex – 4:

Comparison of Seismic Standards

The New Zealand seismic standard requires strong compliance with capacity design approach. It is performance based standard and requires buildings to be designed for Serviceability Limit State (SLS) and Ultimate Limit State (ULS). The SLS is considered to avoid damage to the building during more frequent earthquake (typically 25 years return period for residential buildings) and expectation are that the building can continue to be used as originally intended without repair. Hence, to achieve this limit state, level of stress or strain within the building components is kept low. The ULS is considered to ensure life-safety during a major earthquake (typically 475 years return period for residential buildings). NBC105 and IS1893 does not require checking for SLS explicitly. It considers that once ULS is accounted for the building will automatically meet SLS requirement.

Figure 1 presents a comparison of design spectra in accordance with NBC105 for Kathmandu, IS1893 for seismic zone V (near northern part of Nepal's western boarder or south of Biratnagar) and NZS1170.5 for Wellington, New Zealand for a reinforced concrete ductile frame building located on stiff ground. For this study, seismicity of Wellington is considered similar to Kathmandu. Comparison has been made for RC ductile frame building, because the detailing requirements of all three standards for a reinforced concrete ductile are similar, although design requirements of New Zealand standard are more onerous and requires compliance with capacity design approach. The comparison has been made for design spectra because different standards scale down the elastic spectra to design spectra in different way. Further to this, what is more important is for what force a building has been designed for.

The areas of interest for most of the hospital buildings or other health facilities in Nepal are likely to fall in the area indicated by the rectangular box (Refer Figure 1). The differences for short period buildings (typically one to three storey RC frame buildings or masonry buildings with fundamental period between 0.1 and 0.3s building (plateau region) are substantial. The seismic design forces would be 1.35 times and 2 times more respectively for IS1893 and NZS1170.5 if compared with NBC105 (refer Figure 1) for ductile RC frame building. For buildings with fundamental period of 1s (typically 10 storey RC frame building) the design seismic forces estimated following IS1893 and NZS1170.5 would be similar whereas forces estimated following NBC105 would be 2/3rd of that of IS1893.

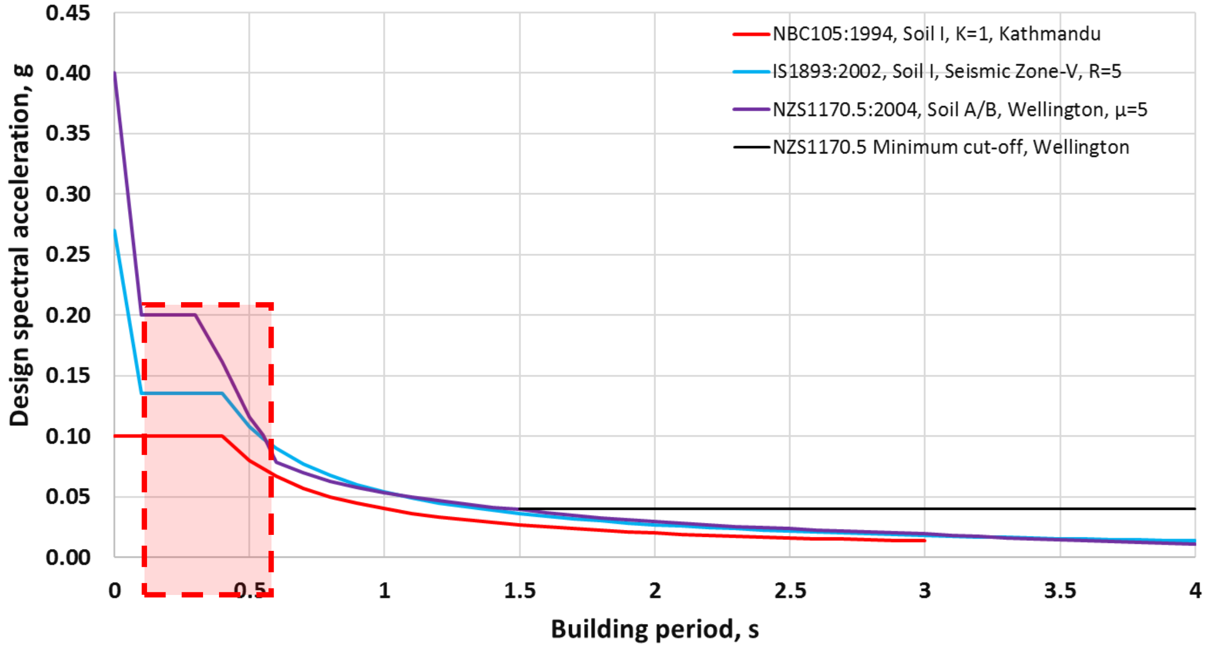

Figure 1. Design Spectra for Reinforced Concrete Ductile Bare Frame Building on stiff soil (note the NBC105, IS1893 and NZS1170.5 spectra respectively include a partial safety factor for loads 1.25, 1.5 and 1.0 as specified in respective Standards)

Generally, anything beyond fundamental period of 1s would unlikely be of much interest for hospital buildings in Nepal unless the building is base isolated or displacement based approach has been used for assessment or design of a new building.. For this case, a comparison of elastic spectra has been presented in Figure 2. The seismic elastic forces would be 1.54 times more for IS1893 if compared with NZS1170.5 at 2.5s.

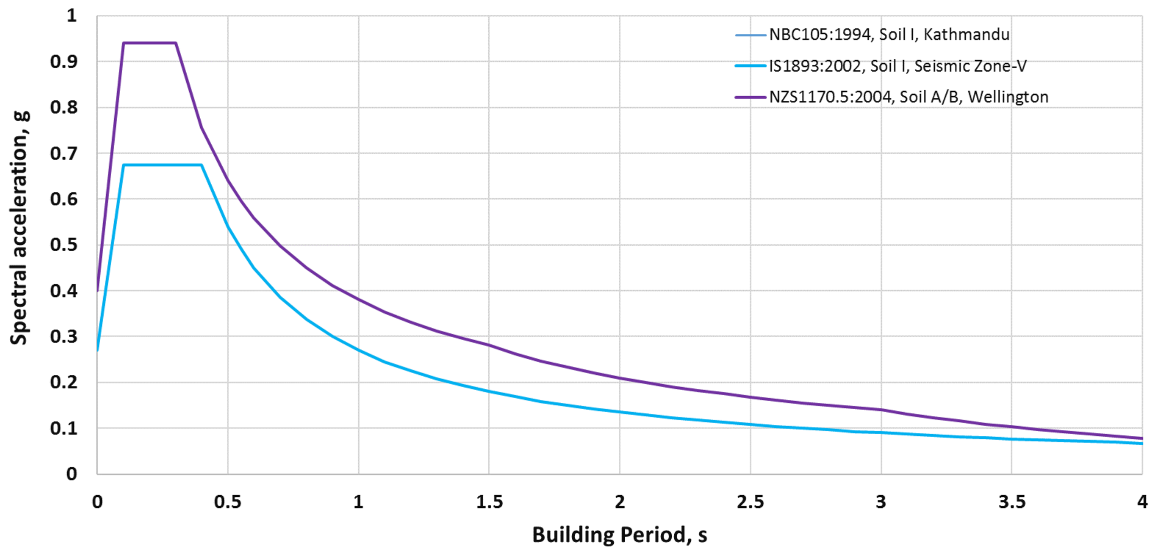

Figure 2. Elastic Spectra for Building on stiff soil (note the NBC105, IS1893 and NZS1170.5 spectra respectively include a partial safety factor for loads 1.25, 1.5 and 1.0 as specified in respective Standards)