REPORT ON DETAILED SEISMIC ASSESSMENT & RETROFIT DESIGN OF BHAKTAPUR HOSPITAL, BHAKTAPUR, NEPAL

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(NHSSP-III)

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EXECUTIVE SUMMARY

Introduction

This report summarizes the detailed seismic assessment and retrofitting design of the buildings of Bhaktapur Hospital, Bhaktapur – a priority hospital for retrofitting and rehabilitating works selected under the Nepal Health Sector Support Programme (NHSSP) Health Infrastructure work stream. The retrofitting process involves the selection of priority hospitals, collection and review of existing drawings and documents, on-site field condition assessment, materials testing - including non-destructive (NDT) and destructive (DT) testing- geotechnical investigations, detailed seismic assessment, and design of suitable retrofitting solutions.

The report briefly describes the condition assessment (qualitative assessment) of the buildings and its preliminary recommendations, as well as results of geotechnical investigations of the hospital site, NDT and DT testing of building materials. Based on these studies, a detailed seismic assessment (quantitative assessment) of each building was conducted, using numerical analysis to identify potential structural weakness and relative vulnerability. This was followed by the selection and design of retrofitting options.

Condition assessment

The hospital campus consists of three buildings blocks from 10 – 34 years old. Of these, one is unreinforced brick masonry building and reinforced block masonry building, while the remainder one is RCC framed buildings with brick masonry. A preliminary level of condition assessment (qualitative assessment) was performed through visual inspection by the expert team, with on-site verification and desk review of previous study documents and existing as-built drawings. The major conclusions and recommendations based on these results are as follows:

- The impact of the 2015 Gorkha Earthquake appears to have been minor.
- Repair and maintenance of the buildings appear to be inadequate, leading to degradation of the built fabric.
- All the three buildings located at the Hospital complex are suitable for retrofitting, if these buildings meet their intended functional requirements as per current standards. However, the final decision shall be made only after the detailed seismic assessment with upgrading functional requirements of the building and economic considerations for retrofitting of these buildings.
- The hospital seems to be very busy and construction for retrofitting will need a proper decantation strategy

Detailed Seismic Assessment - Quantitative Assessment

The detailed seismic assessment (DSA) was performed to determine the probable strength of the lateral load resisting system and to compare with expected seismic demand on the members. It is basically based on structural modeling and analysis using commercial structural analysis commercial structural analysis Finite element based ETABS software. Both static (linear static) and dynamic (response spectrum method) analysis were performed during numerical analysis based on Nepal's building code and Indian Standard (IS) codes. Non-structural components were assessed for position pretensions to prevent them from any potential falling hazards during seismic event.

Recommended works

Based on the detailed seismic assessment and analysis, the following deficiencies in the building blocks are noted:

RCC Framed Building – Maternity Building:

- The building did not comply with the codes' requirements for storey drift. The seismic gap required between adjacent blocks was found to be sufficient.
- Most structural members failed to meet checking the earthquake demand capacity ratio as required by the codes.

Masonry Buildings:

- Most of the masonry buildings are safe in storey drift.
- The buildings are not safe in tensile and shear in both in-plane and out of plane earthquake loading while found to be safe in compression.
- Foundation of the main building found to be unsafe and required a strengthening of it.

Retrofitting solutions

Two main retrofitting options were put forward to increase lateral stiffness of buildings: first, the use of Reinforced Cement Concrete (RCC) shear walls, and second, the application of the splint and bandage technique. After consultation meetings with the Department of Urban Development and Building Construction (DUDBC) in February 2018, it was agreed to apply RCC shear walls with column jacketing for use on RCC framed buildings. and the splint and bandage technique together with wall jacketing, will be used for masonry buildings.

To address the above mentioned deficiencies as well as functional requirements, the following retrofitting solutions for each block are recommended:

S.No.	Building Blocks	Proposed Retrofitting Solutions
1	Main Block	Separation of buildings introducing seismic gaps to improve configuration of the building, Increasing wall length and closing of openings, develop load path, splint and bandage with wall jacketing, strengthening the foundation, Steel bracing to improve stability of free standing wall and parapet wall
2	Maternity	Adding RCC shear walls at four locations with concrete jacketing of existing columns, Anchorage for non-structural elements
3	Emergency	Addition of roof bands, steel columns at intermediate level, bands at sill level and Splint at gavel wall, Anchorage for non-structural elements

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1 INTRODUCTION

1.1 BACKGROUND

The third Nepal Health Sector Support Program III (NHSSP) is an initiative of the Nepal Ministry of Health (MoH), financed by the UK Department for International Development (DFID). The NHSSP is intended to support the goals of Nepal's National Health Sector Strategy (NHSS), and assist the MoH in building a resilient health system to provide good quality health services for all.

The program has five work streams: health policy and planning, procurement and public financial management, service delivery, evidence and accountability, and health infrastructure.

The Health Infrastructure work stream of the NHSSP has three Key Performance Areas (KPAs):

KPA 1: Building a strong policy environment, to ensure that the MoH and DUDBC adopt and implement relevant codes, standards, and guidelines for construction and maintenance of health facilities and infrastructure

KPA 2: Enhancing the capacity of the MoH, DUDBC, and the private sector (including contractors and construction professionals) to be efficient, technically competent, and capable of implementing resilient design, construction, and maintenance.

KPA 3: Building resilient and effective health infrastructure and ensuring that health infrastructure is retrofitted, rehabilitated, maintained, and monitored in earthquake affected and vulnerable districts, and that facilities are resilient to future seismic shocks, environmental impacts, and other natural disasters.

Under KPA 3, at least two hospitals will be retrofitted and rehabilitated, and be treated as demonstration models to inform the roll-out of the retrofitting and rehabilitation programme and design work in the future. Based on multi-criteria and scoring system developed by the Health Infrastructure team Key, level of future earthquake risk based on geographical location, accessibility by the general population, hub hospitals status for future emergencies, type and range of hospital services provided, utilization rate based on MoH statistics, and location and catchment area Bhaktapur hospital and Western Regional hospital are selected under KPA 3 for seismic assessment and retrofitting design.

This report summarizes the detail seismic assessment of Western Regional Hospital, Pokhara, and thereby retrofitting design and recommendation as a result of the study of design and drawing, physical verification, structural analysis and evaluation in reference with standards, codes and practice and earthquake resistant design criteria.

1.2 OBJECTIVE

The main objective of the task is to evaluate the seismic safety of the existing buildings with detail retrofitting design.

Other specific objectives are:

- To perform material test and geotechnical investigation test based on recommendation drawn by condition assessment.
- To perform detail seismic analysis using structural analysis software to better understands the building behavior against the lateral forces.
- To determine the probable strength of the lateral load resisting system and compare with expected seismic demand on the members.
- To recommend either retrofitting is required or not. If required, further detail retrofitting design is performed.

1.3 METHODOLOGY

Undertaking retrofit works is far from being a single activity; rather, it is a feat of multitasking accomplishments, each of which is essential in order to achieve successful execution of a retrofit project. The proposed retrofitting procedure in the program includes a net of activities as shown in Figure 1.

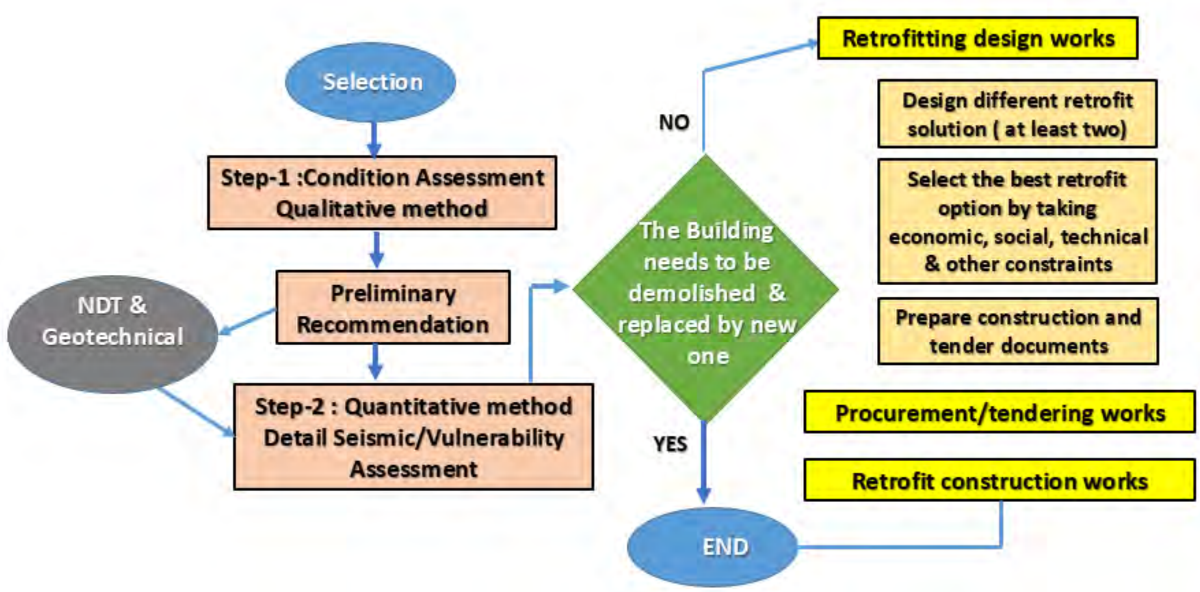


Figure 1: Flowchart of overall process of detail seismic assessment and retrofitting design

The major activities/steps of the procedure are as follows

1. Selection of hospitals
2. Condition Assessment of the health facilities of prioritized Hospitals
3. Onsite Investigation
4. Details seismic assessment
5. Retrofitting design
6. Procurement/tendering works
7. Retrofitting construction works

This report includes step 2 to 5. The details discussions of these steps are presented in the following sections.

2 DESCRIPTION OF HOSPITAL

The hospital is located in Bhaktapur Municipality, Provision-1, Nepal. The latitude of the hospital is 27° 40' 21" N and longitude is 85° 25' 19" E. It is situated near Siddha Pokhari. The location map and site plan of the hospital are shown in **Error! Reference source not found.** and **Error! Reference source not found.**, respectively

Figure 2: Location Map of Bhaktapur Hospital

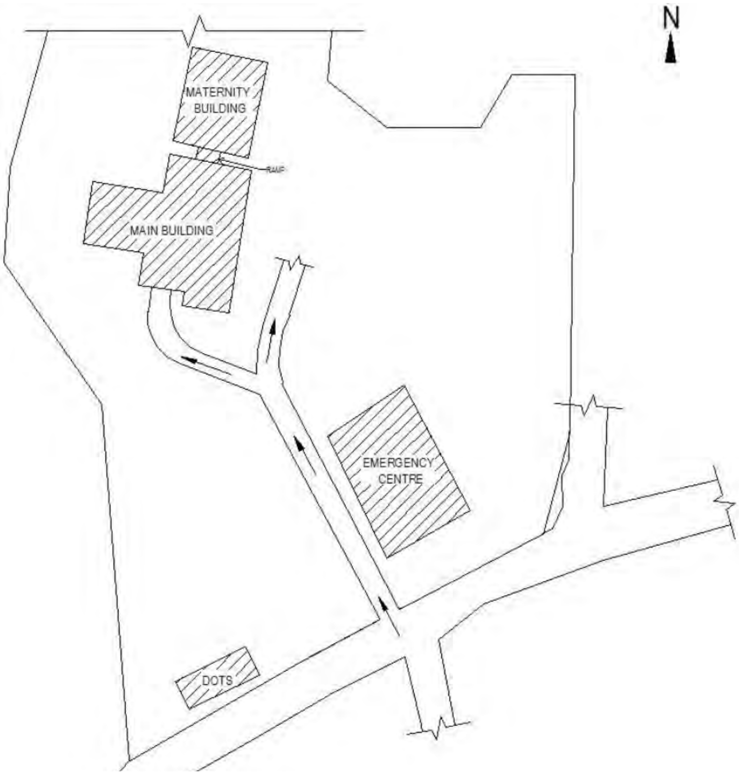


Figure 3: Site Plan of Bhaktapur Hospital

2.1 BUILDING TYPOLOGY

The table below presents building typology in the hospital campus. The table also includes a few other details

Table 2-1: Building Typologies

S. No	Block	Vertical load bearing structural system	Year of construction
RC Framed with masonry infill wall Panels			
1	Maternity Block	Three-story high cast-in-place RC frame building with unreinforced, untied brick masonry infill (both external and internal walls)	NA
Load bearing masonry buildings			
1	Main Block	Three-story high brick masonry building in cement mortar with cast-in-place RC floor slab/ roof. One more story under addition with brick external and internal walls and light metal roof.	NA
2	Emergency Block	One-story high reinforced concrete block masonry building with light metal roof on steel truss	NA

2.2 DESCRIPTION OF BUILDINGS

2.2.1 MATERNITY BLOCK

The maternity building is a rectangular three-story reinforced concrete structure with unreinforced masonry infill. It has five bays in the longitudinal direction, and two bays on one either side of a central corridor, in the lateral direction. There is a reinforced ramp at the southern elevation, which connects to the main hospital building. It is a RCC structure with brick cement mortar as infill wall. All the floors are concrete slabs. The building has no significance damage in structural and non – structural elements. Reinforcement of roof slab and column rebar on roof is exposed. 230mm of brick wall stretches from the first landing to roof level. The first landing of the staircase is a cantilever slab projecting about 500mm outside from the columns. Figure 4 shows photograph of the Maternity Block.

Figure 4: Photographs of Maternity Block

The year of construction for building was not known during the site visit, however, according to the site surveillance the building is in operation from around 5 years. This building is used for the maternity operations and other related issues. There are operation room, female/ male ward, cabins, toilets and nurse room in the ground floor. In the first floor there are delivery room, Antoinette room, patient room, stores and toilets. In the second floor there are meeting hall, administration room, doctor's room, office rooms and toilets.

2.2.2 MAIN BLOCK

Main hospital building is a three-story unreinforced masonry building with concrete slab. It is T – shaped building constructed in brick masonry with cement mortar. Due to the ground profile and topography of the area, the main entrance of the hospital is on the southern face of the first floor. The southern part of ground floor is semi-underground with a rear entrance in the northern face of the same floor.

The front faced has been recently constructed with steel roof truss and ramp on steel frame. (Refer **Error! Reference source not found.**and **Error! Reference source not found.**). In addition to this, the new added story with steel framed roof, clad in CGI was under construction during 2015 earthquake in Nepal. After this event, the construction of the top floor was stopped and now it is being used as a store room.

This building is used for the outdoor patient department (OPD), general therapy and other related issues. There are operation theatre, preparation room, store, machine room, wards, changing rooms and toilets. In the first floor there are dental OPD rooms, X-Ray room, medicine supplier room, surgical room, physiotherapy room, offices and toilets. In the second floor there are OPD rooms, staff rooms, store rooms, nurse room, Ear Nose Throat (ENT) medical room, and endoscopy room.

Figure 5: Main Block

2.2.3 EMERGENCY BLOCK

The Emergency Block is a one story reinforced masonry building with hollow concrete blocks in cement mortar. The roof of the building is made up of steel truss and CGI sheet resting on the walls. Buttress walls are constructed at the corners and also along the wall facing east and west direction (**Error! Reference source not found.**) shows a photograph of the Emergency Block.

Figure 6: Front Facade of Emergency Block

3 CONDITIONAL ASSESSMENT

3.1 BACKGROUND

The condition assessment of the building is a preliminary assessment of existing building of the prioritized hospitals. This qualitative assessment of the buildings includes visual inspection from the expert team with on-site verification and desk review of the past studies documents and existing as-built drawings. This section summaries the methodology of assessment and its findings and recommendations.

3.2 METHODOLOGY

The methodology for condition assessment includes the following components

3.2.1 REVIEW OF PAST DOCUMENTS

The available as-built drawings of the hospital buildings that prepared by DFID's Hospital retrofitting project were collected from concerned authority and reviewed to understand the building's details and complexity for on-site assessment. The details were verified in the field during assessment. Besides, the available past studies reports, data, maps and other information related to the hospital buildings were collected from concerning authority and then review these documents. The NHSSP team has reviewed all collected documents and develops check-list for the assessment before field visit. The reviewed documents are presented in references

3.2.2 IN-SITE CONDITIONAL ASSESSMENT

A team of Engineers from NHSSP, MoH and DUDBC have conducted on-site condition assessment of the buildings of the Hospitals in different time. On Sep, 2018, a team led by International Expert from Miyamoto New Zealand was conducted detailed assessment. The on-site assessment was one of a capacity enhancement activity of the programme for technical staffs of the MoHP and DUDBC. The assessment strategy was developed based on an initial appraisal of the complexity of the Building and reviewed it as the assessment progresses. Besides, different engineer team from NHSSP, PCU and DUDBC were also assessed the buildings with addition field verification during NDT/DT, foundation exploration and detailed assessment with retrofitting design review process.

During these processes, the buildings were observed for common deficiencies such as structural member's cracks, water seepage, spelling of concrete, exposure of rebar, rusting of rebar, settlements in grounds, as well as other structural and non-structural deficiencies.

3.3 SUMMARY OF FINDINGS

Some of the common observations made during field inspection are presented as follows.

3.3.1 WATER SEEPAGE

Most of the buildings of WRH have serious seepage issues due poor drainage system and lack of maintenance as shown in the following photos.

Figure 6: Seepage in Maternity and Main building

Water seepage, lack of maintenance of water and sewage pipes, growth plats on the building and other environmental factors are causing deterioration of the building. It is likely that the low drainage capacity and high moisture content in the bearing soil is also contributing to deterioration of the building

Figure 7: Sewage problem in Main building

3.3.2 CORROSION

Growth of plants on stair roof, spalling of concrete in the cantilever slab of the top floor and corrosion of slab rebar were observed

Figure 8: Corrosion in Main and Maternity blocks

3.3.3 CRAKS & DAMAGES

No significant cracks were observed in all the buildings. Only minor cracks were visible in the infill masonry panels that have slightly debonded from the surrounding concrete frame in Maternity Building. Cracks were observed in the lintel of door entrance of the main building. In Emergency block, a vertical cracks next to the buttresses were observed in the exterior wall of the building.

Figure 9: Cracks in walls

Some major cracks, especially at the joint of roof truss and wall were found in top floor walls of main building that was added later

Figure 10: Cracks at truss and wall joints of Main Blocks

Spalling of plaster in the corner of the foundation was observed in the Maternity Block. It is possible that this deterioration could be due to the Settlement of ground during an earthquake. However, the major cause of this spalling was not known at site and shall be verified only after the detail investigation

Figure 11: Settlement cracks in Maternity Block

3.3.4 POOR CONSTRUCTION

In top floor of main building that was added later, poor construction of wall and truss were observed as shown in the photos

Figure 12: Construction errors in Main Block

3.3.5 LOAD PATH & CONFIGURATION

The shape of the Main Block is T – shape in its plan. The ratio of length of wing and length of building, A/L = 26.70 / 39.38 = 0.67 > 0.2. Hence, the Main Block has plan irregularity as per Indian Standard IS1893-2016 .In addition, discontinuity of the load paths in the building was observed

3.3.6 NON-STRUCTURES COMPONETS

The tall shelves were kept unbraced / unanchored as shown in various areas of the hospital

Figure 13: Oxygen Cylinder Kept Unbraced

Shelves Kept Unanchored in the passage

Parapet of the main block were braced using the steel strut as shown in following figure.

Figure 14: Parapet wall achorage

It was observed that electric fitting were very poor and hazardous and deficies

Figure 15: Electric fittings at Main and Emergency blocks

There were some deficiencies in the part of false ceiling of Emergency block as shown in the following figures.

Figure 16: False ceiling of Emergency block

3.4 CONCLUSION

Site visit and inspection of the building were conducted by the expert engineer team in order to have a preliminary idea on the building typologies and their existing conditions. The following are the conclusion based on the condition assessment of the buildings.

- The impact of the 2015 Gorkha Earthquake appears minor. Some damages in partition walls of Maternity building. No major damage to the other buildings was observed during the condition assessment. However, more detail observations shall be made during the detail condition/seismic assessment.
- Water leakage and seepage issues are of the critical issue in the most of the blocks of the hospital campus.
- Repair and maintenance of the buildings appear very infrequent and poor which has led to degradation of the buildings.
- Lack of adequate anchorage and support of non-structural components are critical in the major buildings.
- Poor drainage, electrical wiring as well as other HVSC system were observed.
- The hospital seems to be very busy and construction for retrofitting will need a proper decantation strategy.

From the qualitative assessment and based on the past studies results, it is concluded that all the theree buildings located at the Bhaktapur Hospital complex are appropriate for retrofitting other than few minor projected sheds attached with the main blocks, if these buildings meet their intended function in the changed scenario such as modern medical technology and population pressure, and also if the buildings meet their hospital's Master Plan requirements. However, the final decision shall be made only after the detail seismic assessment with upgrading functional requirement of the building and economic considerations for retrofitting the buildings

3.5 RECOMMENDATION FOR FUTURE WORKS

After the preliminary assessment of the existing building structures, basic ideas for seismic assessment were developed which is required for the retrofit analysis and design. The following recommendations have been made which are considered to be of utmost importance before carrying out the retrofit design:

- A detail seismic assessment of the hospital buildings is necessary to capture major deficiencies and weaknesses in the buildings for the analysis and design of the retrofit.
- Geological and geotechnical parameters were lacking in the past studies and are required for the design of the retrofitting. Hence, it is recommended to carry out necessary geotechnical

investigations of the site to understand geotechnical conditions of the site and acquire geotechnical parameters with liquefaction potential.

- Investigation of the existing foundation systems of the building structures in recommended.
- The destructive and nondestructive test results for construction material properties, building component section details (e.g. reinforcement size, configuration and detailing), are not available (for all fifteen blocks) from the past studies. Such test results are essential for the detailed assessment and retrofit design of the building structures. Hence, it suggested to carry out a comprehensive destructive and non-destructive tests
- Efforts need to be made to retrieve structural drawings of the buildings for realistic assessment and retrofitting design of the buildings. In absence of these, very conservative assumptions have to be made which may result in expensive retrofitting solutions. Some of the blocks especially the first floors do not seem to be that old, hence it might be possible to find the structural drawings of these building, if efforts are made.

4 ON-SITES INVESTIGATION

The on-site investigation includes the material testing, geotechnical investigation, foundation exploration, seismic separation and any variations and deterioration. For an evaluation for material parameters and condition for building material, destructive and non-destructive testing was conducted. In addition, geotechnical investigation and foundation exploration were also conducted to understand the geotechnical parameters of the hospital sites and foundation condition of the buildings. This section summarized the tests and on-site investigation with necessary test results.

4.1 NON-DESTRUCTIVE & DESTRUCTIVE TESTING

This activity aims to understand the type, properties, conditions, and strengths of the materials used in the construction of the hospital. Non-destructive tests shall be carried out in most of the locations, whereas destructive tests shall be prescribed only when the non - destructive tests are not sufficient to derive the input parameters for design.

The following destructive and non-destructive tests have to be carried out for two typology buildings of the Hospital:

1) Reinforced Concrete Cement Structures
    - Ferro Scan Test
    - Schmidt Hammer Rebound Test
    - Ultrasonic Pulse Velocity Test
2) Load Bearing Masonry Structures
    - Penetrometer Test
    - Bed joint shear test
    - Brick/stone test

The material testing was conducted by G. S. Soil & Materials Engineers (P) Ltd at a given location. The results from the test were used to calculate the material parameters like modulus of elasticity, density and Poisson's ratio. These stress values were also used as permissible limits to check the developed stress calculated from the numerical model. The testing details and test results are presented in the separate report as an Annex A. The summary of the test results are as follows:

4.1.1 FERRO SCAN TEST

Ferro Scan test are conducted at few selected locations in column, beams and slab. And rebar exposure test are also conducted to verify the test data. The sample results of rebar detection test are presented in below. The detail test result, test sheet and test pictures are presented in separate Annex A.

4.1.2 SCHMIDT HAMMER TEST

Schmidt hammer test are conducted at few selected critical locations in column, beam and slab of the building. The results of Schmidt hammer test are presented in Table 2 below. The detail test result, test sheet and test pictures are presented in separate Annex A.

Table 2: Summary of Schmidt Hammer Test Result

S.N.	Floor and Location	Schmidt Hammer Result (Mpa)	Remark
1.0	Ground Floor		
	Grid A-1	29.00	
	Grid C-2	28.00	
	Grid D-3	28.00	
	Grid A-1/2	27.00	
	Grid C-2/3	28.00	
2.0	First Floor		
	Grid A-2	27.00	
	Grid E-3	27.00	
	Grid A/B-2	28.00	
	Grid E-2/3	28.00	
3.0	Second Floor		
	Grid A-1	28.00	
	Grid A-3	29.00	
	Grid B-4	29.00	
	Grid C-2	29.00	
	Grid E-3	28.00	
	Grid A-2/3	27.00	
	Grid B-3/4	27.00	
	Grid C-2/3	26.00	

From the above test results, it shows that shear strength of brick masonry wall varies from 26.00 – 29.00 MPa.

Mean of the test data = μ = 27.824

Standard deviation = $\alpha = 0.883$

Shear Strength as per test result = 27.824±1*0.883 = 26.941/28.706 MPa

Knowledge factor = $k = 0.7$

Allowable compressive strength of concrete = 18.858 / 20.094 MPa

Figure 17: Photograph showing Schmidt Hammer Test

4.1.3 ULTRASONIC PULSE VELOCITY TEST

Ultrasonic pulse velocity test are conducted at few selected critical locations in column, beam and slab of the building. The results of Ultrasonic pulse velocity test are presented in Table 3 below. The detail test result, test sheet and test pictures are presented in separate Annex A.

Table 3: Summary of Ultrasonic pulse velocity Test Result

S.N.	Floor and Location	Ultrasonic Pulse Velocity Test Result	Remark
1.0	Ground Floor		
	Grid A-1	3.22 (Medium)	
	Grid C-2	3.31 (Medium)	
	Grid D-3	3.12 (Medium)	
	Grid A-1/2	3.40 (Medium)	
	Grid C-2/3	3.33 (Medium)	
2.0	First Floor		
	Grid A-2	3.35 (Medium)	
	Grid E-3	3.43 (Medium)	
	Grid A/B-2	3.31 (Medium)	
	Grid E-2/3	3.35 (Medium)	
3.0	Second Floor		
	Grid A-1	3.16 (Medium)	
	Grid A-3	3.09 (Medium)	
	Grid B-4	3.11 (Medium)	
	Grid C-2	3.17 (Medium)	
	Grid E-3	3.09 (Medium)	

	Grid A-2/3	3.31 (Medium)	
	Grid B-3/4	3.35 (Medium)	
	Grid C-2/3	3.40 (Medium)	

Figure 18: Photograph showing Schmidt Hammer Test

4.1.4 IN-SITU BED JOINT SHEAR TEST

Bed shear joint test are conducted at few selected critical locations at wall mortar joint of the building. The results of bed shear joint test are presented in Table 4 below. The detail test result, test sheet and test pictures are presented in separate Annex A.

Table 4: Summary of Bed Joint Shear Test

S.No.	Floor	Location	Shear Strength (MPa)	Remarks
1	Ground	Grid D/E-1	0.37	
2	Ground	Grid K-7/8	0.39	
3	Ground	Grid Q-1/2	0.31	
4	First	Grid L-3/4	0.34	
5	Second	Grid A-1/2	0.39	
6	Second	Grid Q-1/2	0.38	

7	Third	Grid L-3/4	0.33	
8	Third	Grid A-1/2	0.31	

From the above test results, it shows that shear strength of brick masonry wall varies from 0.31 - 0.39 MPa.

Mean of the test data = μ = 0.3525

Standard deviation = $\alpha = 0.034$

Shear Strength as per test result = 0.325±1*0.034 = 0.318/0.386 MPa

Knowledge factor = k = 0.7

Allowable shear strength = 0.223 / 0.271 MPa

4.1.5 COMPRESSIVE STRENGTH TEST FOR BRICK MASONRY

Flat jack test are conducted at few selected critical locations at wall mortar joint of the building. The results of the flat jack test are presented in Table 5 below. The detail test result, test sheet and test pictures are presented in separate Annex A.

Table 5: Summary of Compressive Strength Test of Brick masonry

S.No.	Floor	Location	Compressive Strength (MPa)	Remarks
1	Ground	Grid F-1/2	3.83	
2	Ground	Grid E-6/7	3.64	
3	Ground	Grid F-8/9	3.27	
3	Ground	Grid G-12/13	3.95	
4	First	Grid C/D-1	3.64	
5	Second	Grid E-7/8	3.76	
6	Second	Grid F/G-11	4.07	
7	Third	Grid E/F-10c	3.83	
8	Third	Grid A/B-12C	3.58	

From the above test results, it shows that compressive strength of brick masonry wall varies from 3.27 – 4.07 MPa.

Mean of the test data = μ = 3.730

Standard deviation = $\alpha = 0.2333$

Shear Strength as per test result = 3.730±1*0.233 = 3.497/3.963 MPa

Knowledge factor = k = 0.7

Allowable compressive strength of brick masonry = 2.448 / 2.774 MPa

4.1.6 PENETROMETER TEST

Penetrometer test are conducted at few selected critical locations at wall mortar joint of the building. The results of the flat jack test are presented in Table 6 below. The detail test result, test sheet and test pictures are presented in separate Annex A.

Table 6: Penetrometer Tests of Cement Mortar of Existing Structures

S.N.	Penetrometer Test				Remark
	Ground Floor	First Floor	Second Floor	Third Floor	
1	3.27	3.43	3.88	3.53	
2	3.59	3.31	3.63	3.31	
3	3.57	4.00	3.45	3.53	
4	3.67	3.45	3.49	3.45	
5	3.57	3.96	3.33	3.84	
6	3.70	3.94	3.45	3.78	
7	3.57	3.68	3.70		
8	3.49	3.67	3.65		
9	3.51	3.55	3.63		
10	3.53	3.55	4.06		
11	3.47	4.08	3.68		
12	3.51	3.65	3.61		
13	3.41	3.88			
14	3.53	3.39			
15		3.60			
16		4.10			

From the above test results, it shows that compressive strength of cement mortar varies from 3.27 – 4.10 MPa.

Mean of the test data = μ = 3.617

Standard deviation = $\alpha = 0.207$

Shear Strength as per test result = 3.617±1*0.207 = 3.410/3.824 MPa

Knowledge factor = $k = 0.7$

Allowable compressive strength of mortar = 2.387 / 2.677 MPa

4.2 DETAILED GEOTECHNICAL INVESTIGATION

The aims of geotechnical investigation are to understand the geology and engineering properties of existing soil at the Bhaktapur Hospital. Three bore holes of 20m depth were investigated during this investigation. The locations of the bore holes are as shown in Figure . The intent of this test is to get: a) Soil classifications and site subsoil characterizations, b) Liquefaction susceptibility of the site, and c) Bearing Capacity of the Soil.

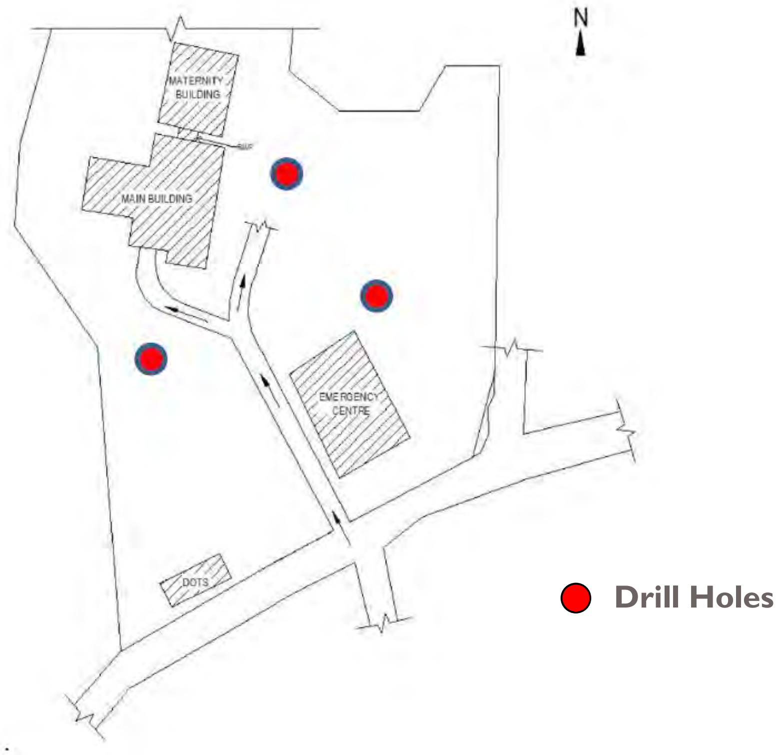


Figure 19: Location of Drill Holes for Geotechnical Investigation

Geotechnical investigation of the site has been carried out and all the design parameters have been considered accordingly. In this study, geotechnical parameters like bearing capacity and density have been considered according to the investigation report presented in Annex B.

Summary of findings from the geotechnical investigation has been presented in Table 7 below.

Table 7: Bearing Capacity at Hospital Site

Footing size in m	Depth of footing in m	Allowable bearing by Terzaghi's method in kN/m^2	Settlement in mm, 40mm	Allowable bearing capacity in KN/m^2	Modulus of Sub Grade Reaction in KN/m^3
2.0 x 2.0	1.5	126.0	34.2 mm	126.0	11053.0
2.0 x 2.0	2.0	137.0	38.0 mm	137.0	10816.0
2.5 x 2.5	1.5	134.0	36.0 mm	134.0	11167.0
2.5 x 2.5	2.0	145.0	40.0 mm	145.0	10875.0

4.3 FOUNDATION EXPLORATION

A engineer team of DUDBC and NHSSP has conducted foundation exploration work in Bhaktapur Hospitals.

Foundation excavation works are done at a place for understanding the existing condition of the foundation and the soil nature of ground. Following findings are observed during foundation excavation.

- Tie beam is not found during excavation.
- Step wall foundations of brick masonry in cement sand mortar with concrete pad is found.
- The foundation depth, size and thickness are found as present in figure below.
- Water seepage in foundation is found.

Foundation Excavation

Foundation Measurement

Back Filling

Water Seepage in Foundation

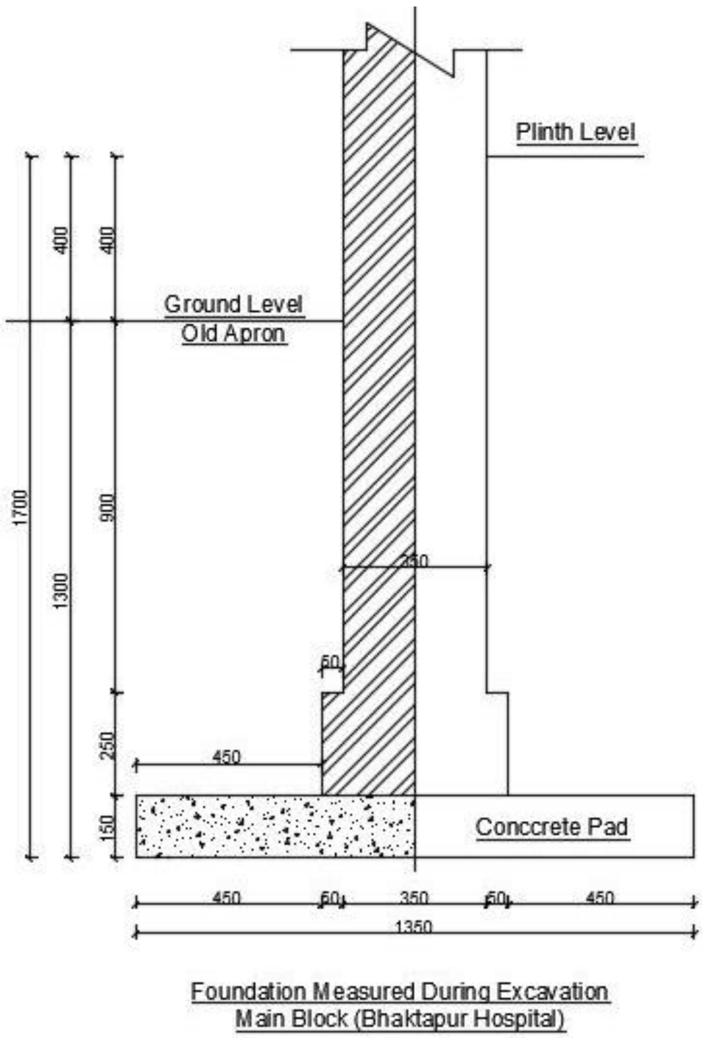
Figure 20: Foundation Exploration of Masonry Block

Table 8: Findings of Foundation Excavation

S.N.	Description	Finding (Bhaktapur)
1	Soil Type	Silty Clay
2	Foundation Depth	1300mm
3	Foundation Size	1350 mm
4	Footing thickness	150+250=400 mm

Note: There is water seepage and water supply lines running found during foundation exploration.

Figure 21: Water Supply Pipe Lines



5 DETAILED SEISMIC ASSESSMENT

5.1 BACKGROUND

The Detailed Seismic Assessment (DAS) is performed to assess the seismic behavior of the buildings It is a qualitative assessment and more comprehensive assessment than the conditional assessment described in previous chapter. In this process, the probable strength of the lateral load resisting system is determined and compared with expected seismic demand on the members. The DSA process is based on the Indian Standard Code of Practice and Nepal building codes (NBC).

5.2 METHODOLOGY

The detailed seismic assessment is basically based on structural modeling and analysis. For the modeling of the building, commercial structural analysis Finite element based ETABS software was used. The RC framed buildings are analyzed initially using the Indian Standard Code of Practice. As per reviewers' advices for the consistency with masonry building, the buildings are also analyzed based on NBC. The detailed seismic assessment includes the following process.

1. Selection of material/design parameter and analysis approach
2. Load assessments.
   A. Dead load
   B. Live Load
   C. Seismic Load
3. Numerical Modeling
4. Results and discussion
5. Finding and Recommendation

5.3 MATERIAL PARAMETER

As discussed in the Chapter 4, destructive and non-destructive tests are conducted in the field to find the existing condition and engineering parameter of building material. Some building parameters obtained from tests are compressive strength of cement sand mortar, shear strength of stone masonry, compressive strength of concrete and rebar size and number. The test results adopted for further analysis are tabulated below.

Table 9: Parameter Adopted from NDT Test

S.N.	Parameter	Test Result	Adopted Value	Units	Remark
1	Compressive strength of cement sand motar	3.410	2.387	Mpa	As per IS Code, M2 Mortar Grade

2	Shear Strength of Stone masonry Wall	0.318	0.223	Mpa	Applying knowledge factor as per IS Code 15988
3	Compressive strength of concrete	26.941	M15	Mpa	Applying knowledge factor as per IS Code 15988
4	Compressive strength of brick Masonry	3.497	2.448	Mpa	Applying knowledge factor as per IS Code 15988

The material parameters adopted for analysis of buildings are listed below.

Table 10: Mechanical Properties of Concrete (As Per IS Code)

Concrete grade:(M)	M15	M20	M25	
Young's modulus for Concrete:	19365	22360	25000	N/mm^2
Poisson's ratio for concrete :	0.2			
Unit Weight:	25			KN/m^3
Cha. Compressive Strength:	15	20	25	N/mm^2

5.4 CODE AND STANDARD

The following Indian Standard Codes of Practices, Nepal Building Codes and other guidelines are considered for creation of mathematical model, analysis and check of the structure:

- IS 456:2000 Plain and reinforced concrete : Code of Practice
- IS 1893:2002 Criteria for earthquake resistant design of structures
- IS 13920:1993 Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces – Code of Practice
- IS 875:1998 (Part I) Code of Practice for Design Loads (Part I: Dead Loads)
- IS 875:1998 (Part II) Code of Practice for Design Loads (Part II: Imposed Loads)
- IS 1905:1987 Code of practice for Structural use of Unreinforced Masonry
- IS 15988 : 2013 Seismic Evaluation and Strengthening of Existing Reinforced Concrete Buildings – Guidelines
- IS 13935 : 2009 Seismic Evaluation, Repair and Strengthening of Masonry Buildings – Guidelines
- Nepal Building Codes

5.5 LOAD AND LOAD CASES

5.5.1 DEAD LOAD

The loads on the building are based on Indian codes of Practices. The unit weight of different structural and non-structural elements are derived from IS 875 Part 1 and presented in Table 11. The load calculations are based on actual measured drawings.

- The weight of infill walls are calculated based on measured drawings and applied on beams as line weight in kN/m.
- Partition wall load are assigned as uniformly distributed area load in slab as area load in kN/m2.
- Floor finishing load are calculated for Mosaic tile finishing and assigned as area load in slab assuming 40 mm thick concrete screeding and 12.5 mm thick plaster and 25 mm thick tile.

The self-weight of the structural elements is automatically calculated by the software using the density assigned for the material. The detail loads are calculated on spreadsheets and are attached in Annex.

Table 11: Unit Weight of Materials Used

Type	Value
Reinforced Concrete	25 KN/m^3
Brick Masonry	19 KN/m^3
Screed	20.4 KN/m^3
Plaster	20.4 KN/m^3
Mosaic Tile	20.4 KN/m^3

5.5.2 LIVE LOADS

The live load considered for various usage of space are taken as per codal provision in IS: 875 (part 2), 1987. According to code the live load adopted for analysis of structure are presented in Table 12 below.

Table 12: Live Load used as per IS 875 (part II) – 1987

S.N	Area type	Load	Unit
1	Bed rooms/wards, dressing rooms, dormitories and lounges	2.00	KN/m^2
2	Kitchens, Laundry is and Laboratories	3.00	KN/m^2
3	Toilets and bathrooms	2.00	KN/m^2
4	X-ray rooms, Operating rooms	3.00	KN/m^2
5	Office rooms, OPD rooms	2.50	KN/m^2
6	Corridors, Passages, Lobbies and staircases	4.00	KN/m^2
7	Boiler rooms and Plant rooms	5.00	KN/m^2
8	Store	5.00	KN/m^2
9	Terrace live load (accessible)	1.50	KN/m^2
10	Terrace live load (non-accessible)	0.75	KN/m^2

5.5.3 SEISMIC LOAD

Response spectrum method is considered for the calculation of seismic demand for RC Frame structure. Seismic demand is calculated as per IS 1893:2002.

1. SEISMIC COEFFICIENT METHOD

To determine the seismic load, it is considered that the country (Nepal) lies in the seismic zone V according to IS 1893:2002. The soil type is considered as medium with 5% damping to determine average response acceleration. The building is analyzed as ordinary moment resisting frame with consideration of infill wall. Therefore the fundamental time period T_a is obtained by using the following formula:

Ta = $0.075h^{0.75}$ [Cl.7.6.1, IS 1893 -2002`]

Other factors considered for seismic load calculations are as follows

Zone factor, *Z* = 0.36 for Zone V [Table 2, Cl6.4.2, IS 1893 -2002]

Importance factor, *I* = 1.5 [Table 8, Cl6.4.2, IS 1893 -2002]

Response Reduction Factor = 3 for ordinary resisting frame (OMRF) [Table 6, Cl6.4.2, IS 1893 -2002]

Detail Calculation is presented in Table 14 below.

2. RESPONSE SPECTRUM METHOD

In the dynamic analysis using response spectrum, the contributions from the higher modes of vibration are taken into account by combining the peak response quantities (member forces, displacements, story forces, and story shears and base reactions) from each mode of vibration. The number of modes to be used in the analysis is determined by the requirement that the sum total of modal masses of all modes considered is at least 90 percent of the total seismic mass.

Response spectrum analysis is characterized mainly by four parameters: modal mass (M_k), modal participation factors ($Ø_k$), mode shape coefficient (φ_{ik}) and modal natural period (T_k). Modal mass (M_k) is a part of the total seismic mass of the structure that is effective in mode k of vibration, while modal participation factor ($Ø_k$) of mode k of vibration is the amount by which mode k contributes to the overall vibration of the structure. Similarly, mode shape coefficient (φ_{ik}) is the ratio of the amplitude of mass i to the amplitude of one of the masses of the system when vibrating in normal mode k, and the modal natural period (T_k) is the time period of vibration in mode k.

The design lateral shear force at each floor in each mode is computed in accordance with the IS: 1893 -2002 equations 7.7.5.4.The design base shear V_B (calculated from the Response Spectrum method) is compared with the base shear V_b (calculated by empirical formula for the fundamental time period). If V_B is less than V_b, all of the response quantities are multiplied by V_b /V_B as per Clause 7.

The following procedure is used to generate the lateral seismic loads.

1. User provides the value for Z, soil type, damping and spectrum curve as input. The spectrum curve is scaled down by Z value which is 0.36 in this case. Thus the maximum value of curve is 0.36 x 2.5 = 0.9.
2. For the initial run scale factor of 2.4525 multiplied by the value $\frac{I*G}{2*R} = \frac{1.5*9.81}{2*3} = 2.4525$ is chosen.
3. Program calculates time periods for all modes as specified by the user. The modes specified are such that at least 90% mass participations is ensured.
4. The program calculates design horizontal acceleration spectrum A_k for different modes.
5. The program then calculates mode participation factor for different modes.
6. The peak lateral seismic force at each floor in each mode is calculated.
7. All response quantities for each mode are calculated.

The peak response quantities are then combined as per method (CQC or SRSS or ABS) as defined by the user to get the final results.

The seismic weight is determined based on the following load factors. [Table 8, Cl.7.9.2, IS 1893 (Part 1):2002]

Table 13: Load factors for seismic weight

S.N	Load Type	Scale Factor
1	Dead Load	1
2	Live Load > 3	0.50
3	Live Load < 3	0.25
4	Roof Live Load	Nil

Table 14: Design Horizontal Seismic Coefficient as per IS 1893:2002

Seismic zone			V (Very Severe)-Nepal	
Seismic Zone factor	Z	Cl. 6.4.2, Table 2	0.36	
Type of Building			Hospital Building	
Importance factor	I	Cl. 6.4.2, Table 6	1.5	
Lateral load resisting system			Ordinary moment Resisting Frame	
Response Reduction factor	R	Cl. 6.4.2, Table 7	3	
Height of the building	h		9.48	m
Dimension of the building Along X	D_x		12.91	m
Dimension of the building Along Y	D_y		19.267	m
Time period of the building	$T=0.075h^{0.75}$	Cl. 7.6.2	0.405	sec
Soil type			Type II (Medium Soil)	
Average response accl'n coefficient	Sa/g	Cl. 6.4.2, fig 2	2.5	
Design Horizontal Seismic Coefficient	$A_h = \frac{Z}{2}\frac{S_a}{g}\frac{I}{R}$	Cl. 6.4.2	0.225	

Table 15: Design Horizontal Seismic Coefficient as per NBC 105:1994

Seismic zone			Bhaktapur	
Seismic Zone factor	Z	Cl. 8.1.6, fig 8.2	1	
Type of Building			Hospital Building	
Importance factor	I	Cl.8.1.7, table 8.1	1.5	
Lateral load resisting system			RC Frame Building	
Structural performance factor	K	Cl. 8.1.8, table 8.2	1	
Height of the building	h		9.48	m
Dimension of the building Along X	D_x		12.91	m
Dimension of the building Along Y	D_y		19.267	m
Time period of the building	$T=0.06h^{0.75}$	Cl. 7.3 (a)	0.324	sec
Soil type			Type II (Medium Soil)	
Basic seismic coefficient	C	Cl. 8.1.4, fig 8.1	0.08	
Design Horizontal Seismic Coefficient along X	$C_d = CZIK$	Cl. 8.1.1	0.12	

Finally, the seismic demand as per IS 1893: 2002 of 0.225 percentage of seismic weight is adopted for further analysis .

5.6 LOAD COMBINATIONS

Limit State method of analysis and design is adopted for the RC frame buildings i.e. for T2 Typology. Load combinations for the analysis and design of structure are adopted as per IS 456: 2000 and IS 1893: 2002 for concrete structure and IS 800:2007 for steel. The design load combinations are the various combinations of the load cases for which the structure needs to be checked. As per IS code, since the structure is subjected to dead load (DL), live load (LL), wind load (WL), and earthquake induced load (EL), and considering that wind and earthquake forces are reversible, then the following load combinations have been defined.

1. For concrete structures:

    Static Load Combination:

    $1.5\ (DL + LL)$

    Seismic Load Combination:

    $1.2\ (DL + LL \pm EQ_x / EQ_y)$

    $0.9\ DL \pm 1.5 EQ_x / EQ_y$

    $1.5\ (DL \pm EQ_x / EQ_y)$

2. For Steel structures:

    Static Load Combination:

    $1.5\ (DL + LL)$

    Seismic Load Combination:

    $1.2\ (DL + LL) \pm 0.6\ EQ_x / EQ_y$

    $1.2\ (DL + LL \pm EQ_x / EQ_y)$

    $0.9\ DL \pm 1.5 EQ_x / EQ_y$

    $1.5\ (DL \pm EQ_x / EQ_y)$

5.7 STRUCTURAL MODELLING

The Structure is modeled using finite element method. A three-dimensional beam element having 12 DOF with 6 DOF at each node were used for modeling beams and columns in the building, while 24DOF shell element with 6 DOF at each node were used to model masonry/RC wall. Similarly, 8 DOF membrane elements with 2 DOF at each node were used to model slab. The structural models are prepared in finite element modeling software, ETABS 2016 V 16.2.1.

Following considerations is made during modeling, analysis and design.

- Centre line model of structure are done. The joint eccentricities are not considered.
- Beams, columns are modeled as line element and slab and walls are modeled as shell elements.
- Beam column joint are not modeled, assume continuous joint.
- Slabs are modeled as thin shell element.
- RC slabs are modeled as rigid floor. All loads such as imposed loads, partition wall load, floor finishing loads etc. are applied on slab as uniformly distributed area load.
- All the supports are fixed at plinth level. Fixed support conditions are assigned for columns while hinge supports conditions are assigned for masonry walls.
- Partition wall are not considered in modeling but their weight are calculated and applied as area load on slab panel.
- Staircase cover is not considered in modeling. But, load from staircase cover was calculated and applied at corresponding columns as point load.
- No ties beams are modeled. So ground floor wall and partition loads are not added, hence considered passing on the foundation directly.
- Structural member sizes are modeled as per field measurement.
- Crack section are modeled as per recommenced by IS 15988: 2013 Table 2.

The detail modeling parameters and assumptions made are described in following heading.

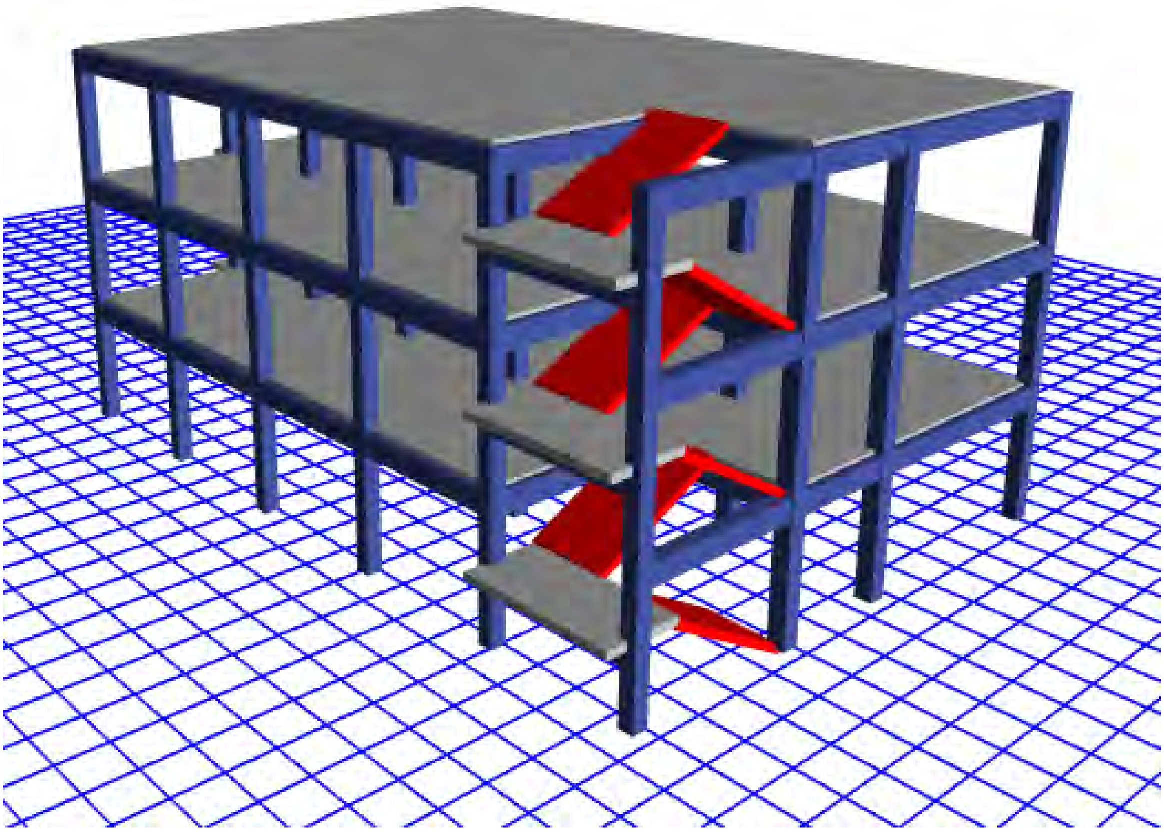


Figure 22: 3D Model of Building

5.8 METHOD OF ANALYSIS

The detail seismic evaluation is performed to determine the probable strength of the lateral load resisting system and compare with expected seismic demand on the members. The seismic demand is calculated based on IS1893 (Part 1) for lateral forces utilizing the factors for reducible seismic demands. (U=1 for Bhaktapur Hospital, as per IS 15988: 2013 for building with critical safety) Under this process a full building analysis is performed, the evaluation requirements are based on linear response spectrum analysis described on the subsequent section as per Indian standards Code.

However, the overall analysis steps include applying the external forces, calculating the internal forces in the members of the building, calculating the deformations of the members and building, and finally interpreting the results and recommendation on retrofitting.

5.9 CHECK FOR FRAME STRUCTURE

5.9.1 INTER-STOREY DRIFT

The story drift is checked for load combinations of earthquake in each direction. The permissible limit of inter-storey drift as specified by the IS code is 0.4%

5.9.2 TORSIONAL IRREGULARITY

A well-proportioned building should not twist about its vertical axis. The stiffness distribution of the vertical elements resisting lateral loads is checked whether it is balanced in plan according to the distribution of mass in the plan at each storey level.

5.9.3 SOFT STOREY

As per IS 1893:2002 part I, Soft storey is one in which lateral stiffness is less than 70% of that in the storey above or less than 80% of the average lateral stiffness of the three storey above .

5.9.4 WEAK STOREY

As per IS 1893:2002 part I, Weak storey is one in which lateral strength is less than 80% of that in the storey above. The storey lateral strength is the total strength of all seismic force resisting elements sharing the storey shear in the considered direction.

5.9.5 MASS IRREGULARITY

As per IS 15988:2013, there shall be no change in effective mass more than 100 percent from one storey to the next. Light roofs, penthouses, and mezzanine floors need not be considered, in mass irregularity.

5.9.6 COLUMN DCR

The demand to capacity ratio (DCR) of column for flexures (P-M-M) is calculated and checked against the value of 1.

5.10 RESULT AND DISCUSSION

The analysis results are discussed in this chapter. Simple linear elastic analysis is carried out and Static seismic coefficient method and Response spectrum method are used for earthquake loading. The major discussions are focused on the seismic demand, modal mass participation; inter story drift and torsional irregularity along the two orthogonal directions. The structural member capacity is then checked for limit state load combination for earthquake loading are checked with their respective seismic demand.

5.10.1 SEISMIC DEMAND

1. Seismic Coefficient Method:

The seismic demand of the building is calculated as per IS 1893:2002. The seismic demand of building is shown in Table 16 below.

Table 16: Seismic Demand of Building

Load Pattern	Type	Direction	Coeff. Used	Weight Used	Base Shear
				kN	kN
EQX	Seismic	X	0.225	10795.483	2428.984
EQY	Seismic	Y	0.225	10795.483	2428.984

2. Response spectrum Method:

The seismic demand of the building as per response spectrum method is calculated as,

For the initial run following scale factor was used

$$\frac{I}{R} * \frac{g}{2} = \frac{1.5}{3} * \frac{9.81}{2} \approx 2.45$$

Base shear from this scale factor is computed as:

In global X direction, base shear = V_B = 1481.028 kN

In global Y direction, base shear = V_B = 1587.823 kN

Which are less than base shear (V_b) from seismic coefficient method and thus, need to be modified as per IS 1893: 2016, the modification factor being:

In global X direction:

$$\frac{V_b}{V_B} = \frac{2428.984}{1481.028} = 1.64$$

In global Y direction:

$$\frac{V_b}{V_B} = \frac{2428.984}{1587.823} = 1.5298$$

Hence, the modified scale factors to be used are:

RSx = 2.4525 x1.6401 1.3270 = 4.02226

RSy = 2.4525 x 1.5298 1.2538 = 3.75173

Thus, modified base shear from response spectrum method are:

In global X direction = 2428.984 KN

In global Y direction = 2428.984 KN

5.10.2 MODAL TIME PERIOD AND MASS PARTICIPATION

IS 1893: 2002 clause 7.8.4.2 states that number of modes to be used in the analysis should be such that the sum total of modal masses of all modes considered is at least 90 percent of the total seismic mass of the structure. Analysis was carried out for first 8 modes so that the mass participation satisfies this criterion in both orthogonal directions. Table 17 shows time period and mass participation ratio for all modes.

Table 17: Modal time period and mass participation

Case	Mode	Period	UX	UY	Sum UX	Sum UY
Modal	1	0.661	0.5071	0.0944	0.5071	0.0944
Modal	2	0.573	0.275	0.4899	0.7822	0.5842
Modal	3	0.491	0.0788	0.2788	0.8609	0.8631
Modal	4	0.23	0.0598	0.0127	0.9208	0.8758
Modal	5	0.198	0.0391	0.0645	0.9599	0.9403
Modal	6	0.17	0.0112	0.0364	0.9711	0.9767
Modal	7	0.146	0.0082	0.004	0.9793	0.9807
Modal	8	0.128	0.0119	0.0068	0.9911	0.9875
Modal	9	0.109	0.0022	0.0074	0.9933	0.9948
Modal	10	0.096	3.533E-05	3.81E-06	0.9933	0.9948

5.10.3 STOREY DISPLACEMENT AND DRIFT

As per Cl. no. 7.11.1 of IS 1893-2002, the storey drift in any storey due to specified design lateral force with no load factor, shall not exceed 0.004 times the storey height. In this building the storey drift is limited to 12.76 mm. From the analysis the displacements of the mass centre of various floors are obtained and are shown in Table 18 along with storey drift.

Table 18: Storey Drift Calculations

Story	Elevation	X-Dir	Y-Dir	Drift X	Drift Y
	m	mm	mm	%	%
Story3	9.480	51.821	32.675	0.324	0.238
Story2	6.290	41.479	25.071	0.660	0.407
Story1	3.130	20.608	12.201	0.658	0.390
Base	0.000	0.000	0.000	0.000	0.000

It is seen that drift exceed the code prescribed value of 0.004 times story height. Thus the drift check does not comply with the safety value mentioned in the code.

5.10.4 CHECK FOR TORSIONAL IRREGULARITY

As per IS 1893:2002 part I, torsional irregularity to be exit when the maximum storey drift, computed with design eccentricity, at one end of the structures transverse to an axis is more than 1.2 times the average of the storey drift at the two ends of the structure. The torsional irregularity check is presented in Table 19 below which does not comply with the codal provision.

Table 19: Torsional Irregularity Check

Story	Load Case	Direction	Maximum	Average	Ratio
			mm	mm	
Story3	RSX Max	X	51.821	38.757	1.337
Story2	RSX Max	X	40.210	29.704	1.354
Story1	RSX Max	X	19.807	14.353	1.380

Story	Load Case	Direction	Maximum	Average	Ratio
			mm	mm	
Story3	RSY Max	Y	32.675	28.251	1.157
Story2	RSY Max	Y	25.071	21.206	1.182
Story1	RSY Max	Y	12.201	10.291	1.186

5.10.5 SOFT STOREY

As per IS 1893:2002 part I, Soft storey is one in which lateral stiffness is less than 70% of that in the storey above or less than 80% of the average lateral stiffness of the three storey above . The soft storey check is presented in Table 20 and Table 21 below which comply with the codal provision.

Table 20: Soft Storey Check for X-Direction

Story	Load	Storey Shear	Drift	Stiffness	% difference compare to	Check (70% limit)
		KN	mm	KN/m	Above storey	
Story3	RSx	1179.71	10.342	114070	-	N/A
Story2	RSx	1964.00	20.871	94102	82.495	OK
Story1	RSx	2428.98	20.608	117866	125.253	OK

Table 21: Soft Storey Check for Y-Direction

Story	Load	Storey Shear	Drift	Stiffness	% difference compare to	Check (70% limit)
		KN	mm	KN/m	Above storey	
Story3	RSy	1198.00	7.604	157549	-	N/A
Story2	RSy	1971.79	12.870	153208	97.245	OK
Story1	RSy	2428.98	12.201	199081	129.942	OK

5.10.6 MASS IRREGULARITY

As per IS 15988:2013, There shall be no change in effective mass more than 100 percent from one storey to the next. Light roofs, penthouses, and mezzanine floors need not be considered, in mass irregularity. The mass irregularity check is presented in below which comply with the codal provision.

Table 22: Mass irregularity Check

Story	MassX	% difference compare to		Check (50% limit)	
	kg	Above storey	Below storey	X	Y
Story3	212586.260	19.909	16.603	OK	-
Story2	177289.530	9.338	10.3	OK	OK
Story1	195550.950	9.338	-	OK	-

5.10.7 STRENGTH RELATED CHECKS

I. Shear Stress in RC Frame Columns

The average shear stress in concrete columns along X–direction is 0.838 Mpa and along Y-direction is 0.931 Mpa. The computed value in accordance with the following equation, is more than,

a. 0.4Mpa and
b. 0.1√fck, fck is characteristic cube strength of concrete =0.387 Mpa

$$\tau_{col} = \left(\frac{n_c}{n_c - n_f}\right)\left(\frac{V_j}{A_c}\right)$$

Where;

n_c = total number of columns

nf = total number of frames in the direction of loading

V_j = storey shear at level j

A_c = total cross sectional area of columns

II. Axial Stress in Moment Frames

The maximum compressive axial stress in the column of moment frame at base due to overturning force alone (F_0) as calculated using the following equation is 0.283 Mpa along X-direction and 0.137 Mpa along Y-direction. This value is less than 0.25fck (3.75 Mpa).

$$F_0 = \frac{2}{3}\left(\frac{V_B}{n_f}\right)\left(\frac{H}{L}\right)$$

Where;

nf = total number of frames in the direction of loading

V_B = Base shear

H = total height

L = length of the building

III. Columns Capacity Demand Check

The seismic demand of each structural member (Columns) for earthquake loading as explain above under heading seismic load are computed and Structural members capacity are checked for earthquake demand. The demand capacity ratio below one "1" means the structural member is safe and above one "1" means the structural member is unsafe. The demand capacity ratios for structural members are shown in **Error! Reference source not found.** below.

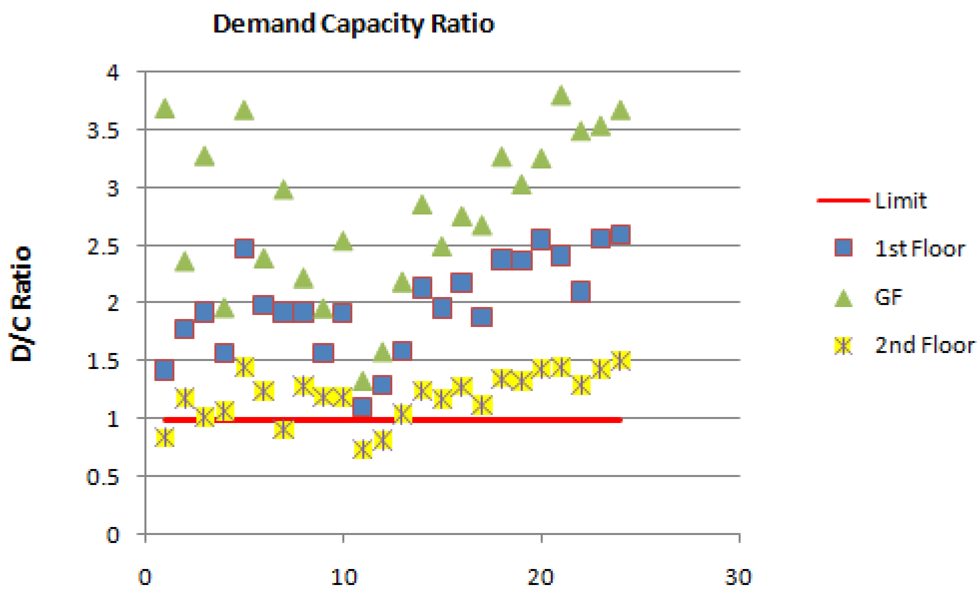


Figure 23: Demand Capacity Ratio of Structural Member (Column)

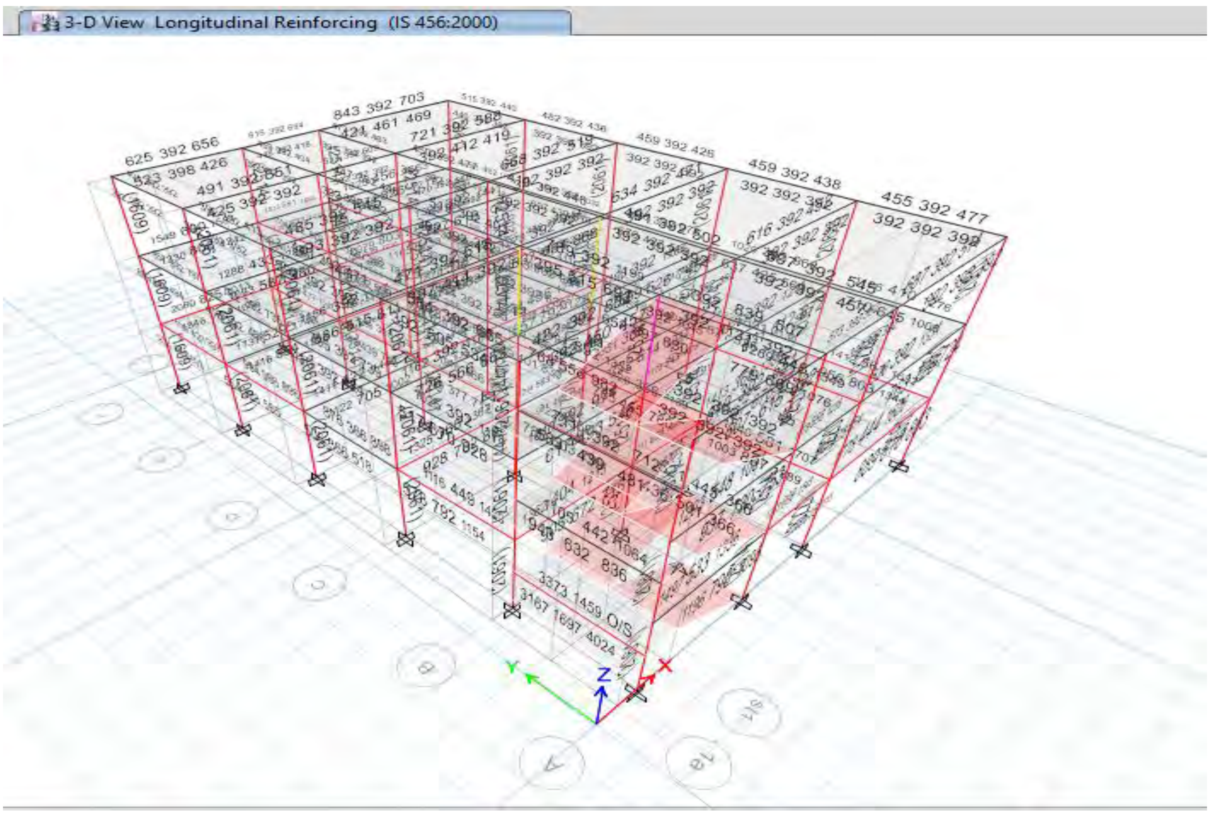


Figure 2: Demand Capacity Ratio of Structural Member (Column)

5.11 FINDINGS AND RECOMMENDATIONS

Base on the above structural analysis results, the following findings are observed:

- The buildings does not comply with codal requirement for story drift check. Hence the building is not safe in drift.
- The building has torsional irregularity (IS 1893:2002)
- But the building does not have soft storey, mass irregularity, and eccentricity check. (IS1893:2002)
- The shear areas of column are found exceeding the safety limit for seismic demand as per relevant Indian Standard Codes. (IS 1893:2002)
- The structural column members' capacities are found insufficient for seismic demand as per relevant Indian Standard Codes. (IS 1893:2002)

6 RETROFIT DESIGN

This chapter summarizes retrofitting strategies adopted and retrofitting design.

6.1 RETROFITTING STRATEGY

The goal of retrofitting is to improve the seismic behavior of structures. Different retrofit strategies have adopted for seismic retrofitting. A good retrofit scheme is the combination of three distinctive features of a structure, these are: Stiffness, ultimate resistance and deformation capacity. The three retrofit strategies are adopted for the retrofit of the hospital buildings. They are:

- Improving Regularity
- Strengthening
- Increasing Ductility

6.1.1 IMPROVING REGULARITY

Improvement of geometry, stiffness, resistance and mass distribution in plan and elevation is carried out for the structure such that regularity in the overall structure is created. This includes breakdown of complex configurations like C-type, U-type into simple configurations; addition of walls, slabs to increase stiffness and resistance; and relocation of walls for correcting load paths and uniformity of mass distribution.

6.1.2 STRENGTHENING

Strengthening of the existing structural system through introduction of new building elements, improvement in strength of the existing structural elements increases the resistance and stiffness of the structure. With this strategy, however, deformation capacity is practically unchanged.

6.1.3 INCREASING DUCTILITY

Brittle structural elements have made more ductile by reinforced strips or reinforcement jacketing or addition of ductile bracing and frame. With this strategy, the entire deformation capacity is increased while the ultimate resistance and stiffness is only slightly increased.

6.2 SELECTION OF RETROFIT STRATEGIES

In order to ensure building safety, the global and local response of the buildings need to be studied with the use of various seismic strengthening option like RC and Steel jacketing, steel bracing, addition of RC shear wall. Among the different options, the best options are applied. The different retrofit strategies adopted are as follows:

- RC jacketing of column to improve strength, ductility and stability of structural members.
- Addition of shear wall to improve lateral stiffness of building.

- Steel bracing to improve stability of free standing parapet wall.
- Providing anchorages for non structural elements.

6.3 RETROFIT DESIGN

Based on the retrofitting strategies as in section 6.1, retrofitting of RC frame building is designed. In this section retrofitting design of masonry structure are summarized.

The building is remodeled on ETABS software including applying retrofit options and analyze again. The Indian code IS 1893:2002 and IS 15988:2013 are used during analysis. Both linear static and Response spectrum analysis are performed for retrofitted structure.

6.4 RETROFIT OPTION

6.4.1 ADDITION OF SHEAR WALL:

Concrete RC wall of thickness 300mm are added at four different locations. Addition of shear wall will increase lateral stiffness, decreases lateral deflection and increase global performance of building.

6.4.2 CONCRETE COLUMN JACKETING:

Concrete jacketing of 100mm thick around concrete column are added for selected column. It will increase lateral stiffness of column and increase local performance of individual columns.

6.5 ANALYSIS RESULT AND DISCUSSION

The analysis results are discussed in this chapter. Simple linear elastic analysis is carried out and Static seismic coefficient method and Response spectrum method are used for earthquake loading. The major discussions are focused on the seismic demand, modal mass participation; inter story drift and torsional irregularity along the two orthogonal directions. The structural member capacity is then checked for limit state load combination for earthquake loading with their respective seismic demand.

6.5.1 SEISMIC DEMAND

1. Seismic Coefficient Method:

The seismic demand of the building is calculated as per IS 1893:2002. The seismic demand of building is shown in Table 23 below.

Table 23: Seismic Demand of Building after retrofit

Load Pattern	Type	Direction	Coeff. Used	Weight Used	Base Shear
				kN	kN
RSX	Seismic	X	0.225	10972.9535	2468.9145
RSY	Seismic	Y	0.225	10972.9535	2468.9145

2. Response spectrum Method:

The seismic demand of the building as per response spectrum method is calculated as,

For the initial run following scale factor was used

$$\frac{I}{R} * \frac{g}{2} = \frac{1.5}{3} * \frac{9.81}{2} \approx 2.45$$

Base shear from this scale factor is computed as:

In global X direction, base shear = V_B = 1907.744 kN

In global Y direction, base shear = V_B = 2042.655 kN

Which are less than base shear (V_b) from seismic coefficient method and thus, need to be modified as per IS 1893: 2002, the modification factor being:

In global X direction:

$$\frac{V_b}{V_B} = \frac{2468.915}{1907.744} = 1.2942$$

In global Y direction:

$$\frac{V_b}{V_B} = \frac{2468.915}{2042.655} = 1.2087$$

Hence, the modified scale factors to be used are:

RSx = 2.45 x1.2942 1.3270 = 3.17391

RSy = 2.45 x 1.2087 1.2538 = 2.96429

Thus, modified base shear from response spectrum method are:

In global X direction = 2468.915 KN

In global Y direction = 2468.915 KN

6.5.2 MODAL TIME PERIOD AND MASS PARTICIPATION

IS 1893: 2002 clause 7.8.4.2 states that number of modes to be used in the analysis should be such that the sum total of modal masses of all modes considered is at least 90 percent of the total seismic mass of the structure. Analysis was carried out for first 60 modes so that the mass participation satisfies this criterion in both orthogonal directions. Table 24 shows time period and mass participation ratio for all modes.

Table 24: Modal time period and mass participation after retrofit

Case	Mode	Period	UX	UY	Sum UX	Sum UX
		sec				
Modal	1	0.227	0.000	0.816	0.000	0.816
Modal	2	0.143	0.761	0.000	0.761	0.816
Modal	3	0.102	0.018	0.003	0.780	0.819
Modal	4	0.085	0.000	0.000	0.780	0.819
Modal	5	0.08	0.000	0.000	0.780	0.819
Modal	57	0.036	0.000	0.000	0.967	0.991
Modal	58	0.035	0.001	0.000	0.967	0.991
Modal	59	0.035	0.000	0.000	0.967	0.991
Modal	60	0.035	0.001	0.000	0.968	0.991

6.5.3 STOREY DISPLACEMENT AND DRIFT

As per Cl. no. 7.11.1 of IS 1893-2002, the storey drift in any storey due to specified design lateral force with no load factor, shall not exceed 0.004 times the storey height. In this building the storey drift is limited to 12.76 mm. From the analysis the displacements of the mass centre of various floors are obtained and are shown in Table 25 along with storey drift.

Table 25: Storey Drift Calculations after retrofit

Story	Elevation	X-Dir	Y-Dir	Drift X	Drift Y
	m	mm	mm	%	%
Story3	9.480	2.151	4.495	0.026	0.047
Story2	6.290	1.329	3.005	0.025	0.053
Story1	3.130	0.532	1.327	0.017	0.042
Base	0.000	0.000	0.000	0.000	0.000

It is seen that drift does not exceed the code prescribed value of 0.004 times story height .Thus the drift check seems to comply with the safety value mentioned in the code.

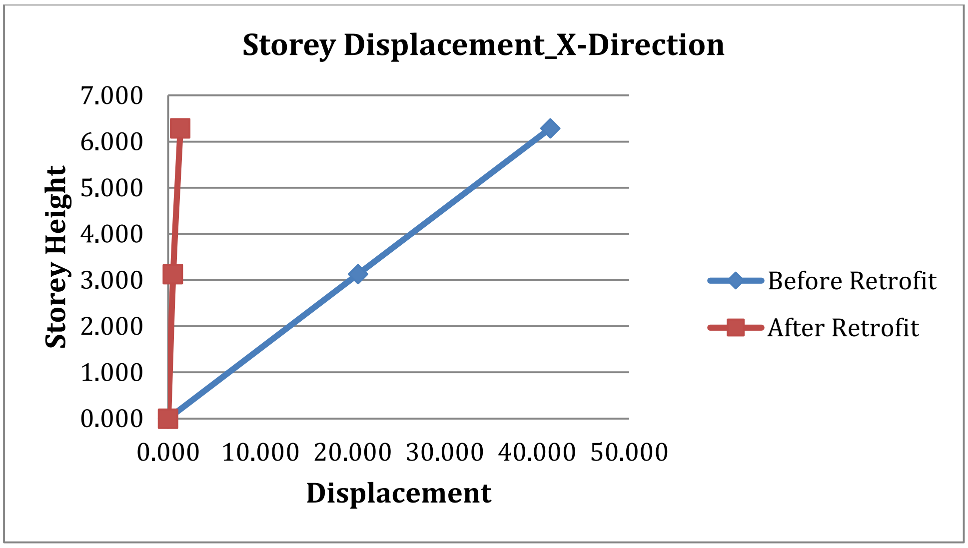


Figure 25 : Drift comparison before and after retrofit along X direction

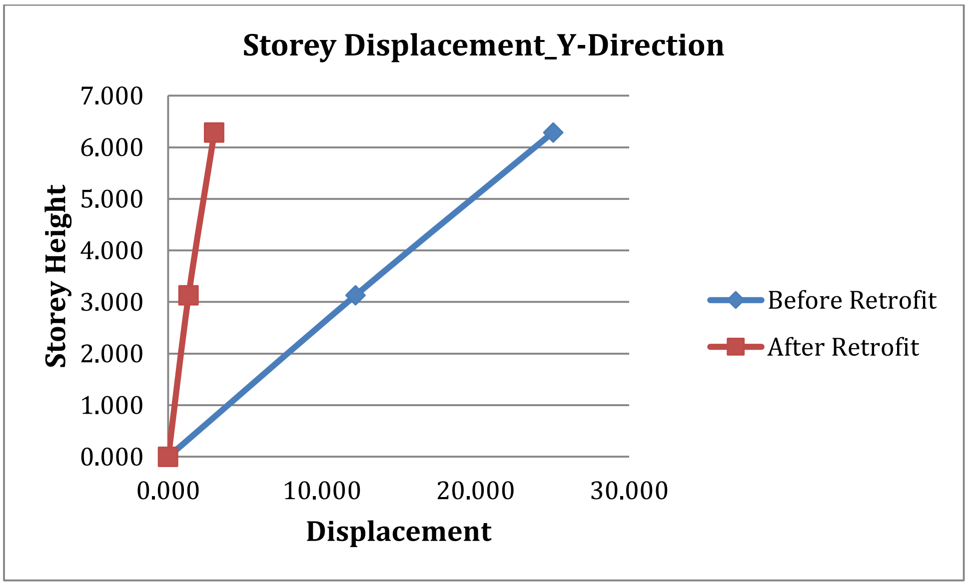


Figure 36 : Drift comparison before and after retrofit along Y direction

6.5.4 CHECK FOR TORSIONAL IRREGULARITY

As per IS 1893:2002 part I, torsional irregularity to be exit when the maximum storey drift, computed with design eccentricity, at one end of the structures transverse to an axis is more than 1.2 times the average of the storey drift at the two ends of the structure. The torsional irregularity check is presented in Table 26 below which complies with the codal provision.

Table 26: Torsional Irregularity Check after retrofit

Story	Load Case	Maximum	Average	Ratio	Check (1.2 limit)
		mm	mm		
Story3	RSX Max	2.151	1.849	1.164	OK
Story2	RSX Max	1.329	1.144	1.161	OK
Story1	RSX Max	0.532	0.459	1.157	OK

Story	Load Case	Maximum	Average	Ratio	Check (1.2 limit)
		mm	mm		
Story3	RSY Max	4.495	4.424	1.016	OK
Story2	RSY Max	3.005	2.963	1.014	OK
Story1	RSY Max	1.327	1.309	1.014	OK

6.5.5 COLUMNS CAPACITY DEMAND CHECK

The seismic demand of each structural member (Columns) for earthquake loading as explain above under heading seismic load are computed and Structural members capacity are checked for earthquake demand. The demand capacity ratio below one "1" means the structural member is safe and above one "1" means the structural member is unsafe. The demand capacity ratios for structural members are shown in **Error! Reference source not found.** below.

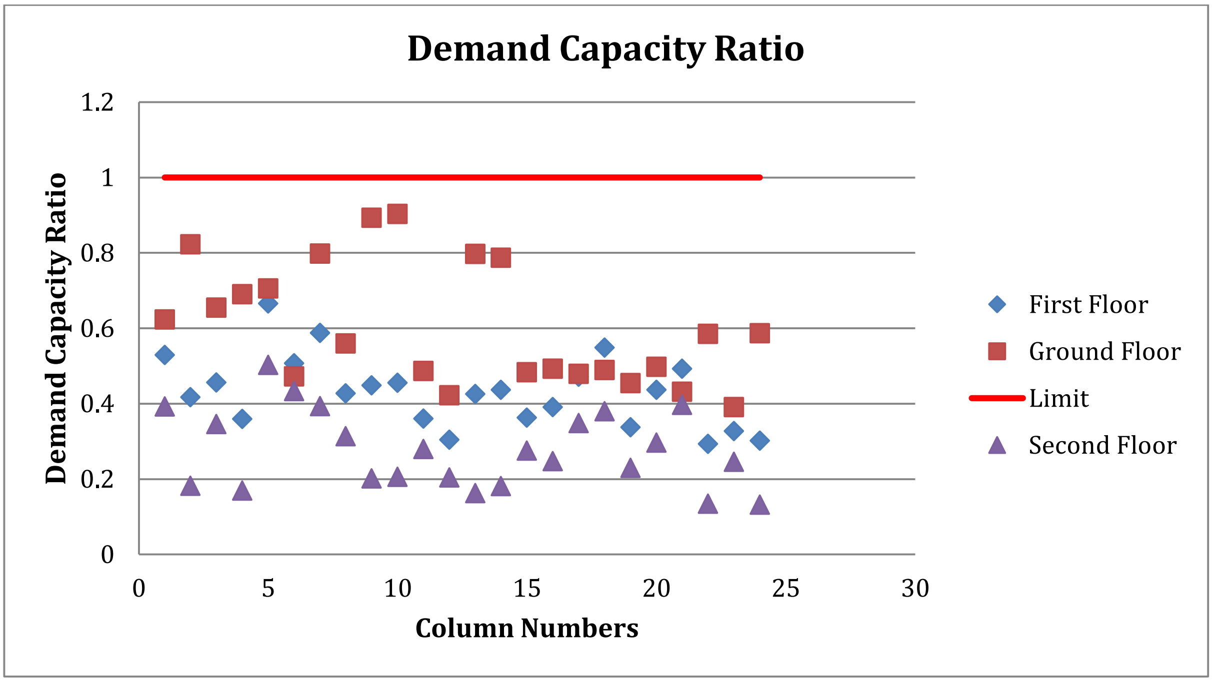


Figure 4: Demand Capacity Ratio of Structural Member (Column) after Retrofit

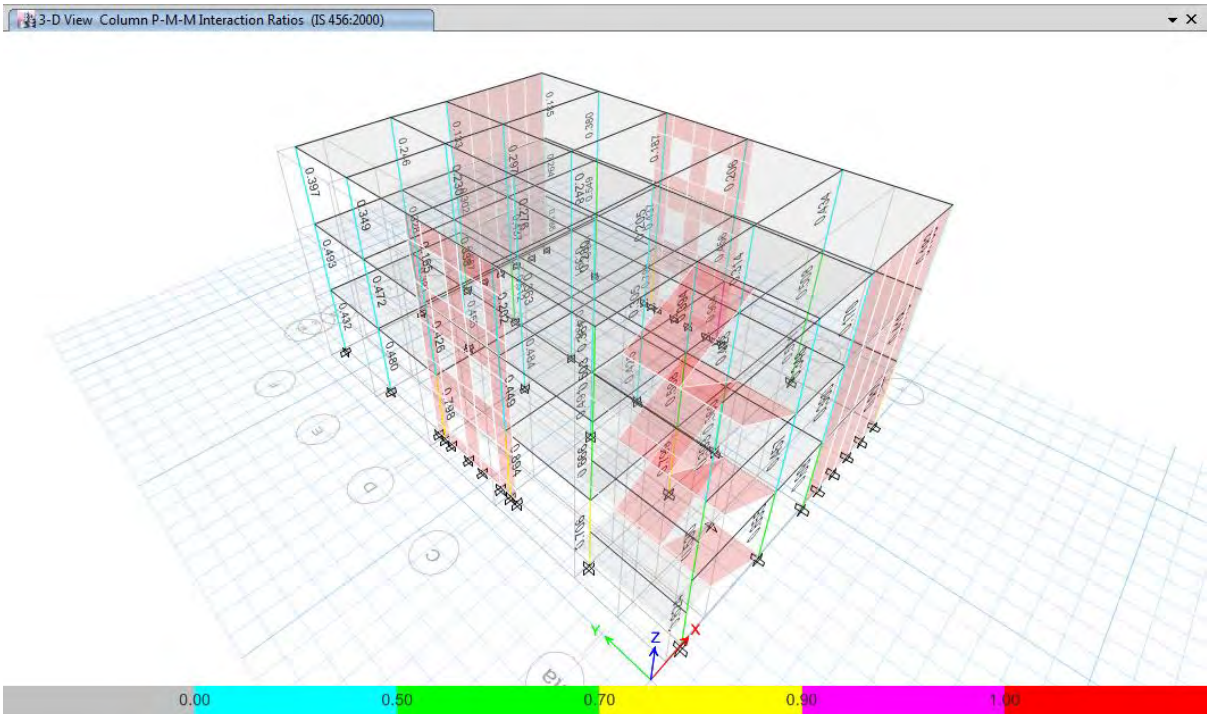


Figure 5 : Demand Capacity Ratio of Structural Member (Column) after retrofit

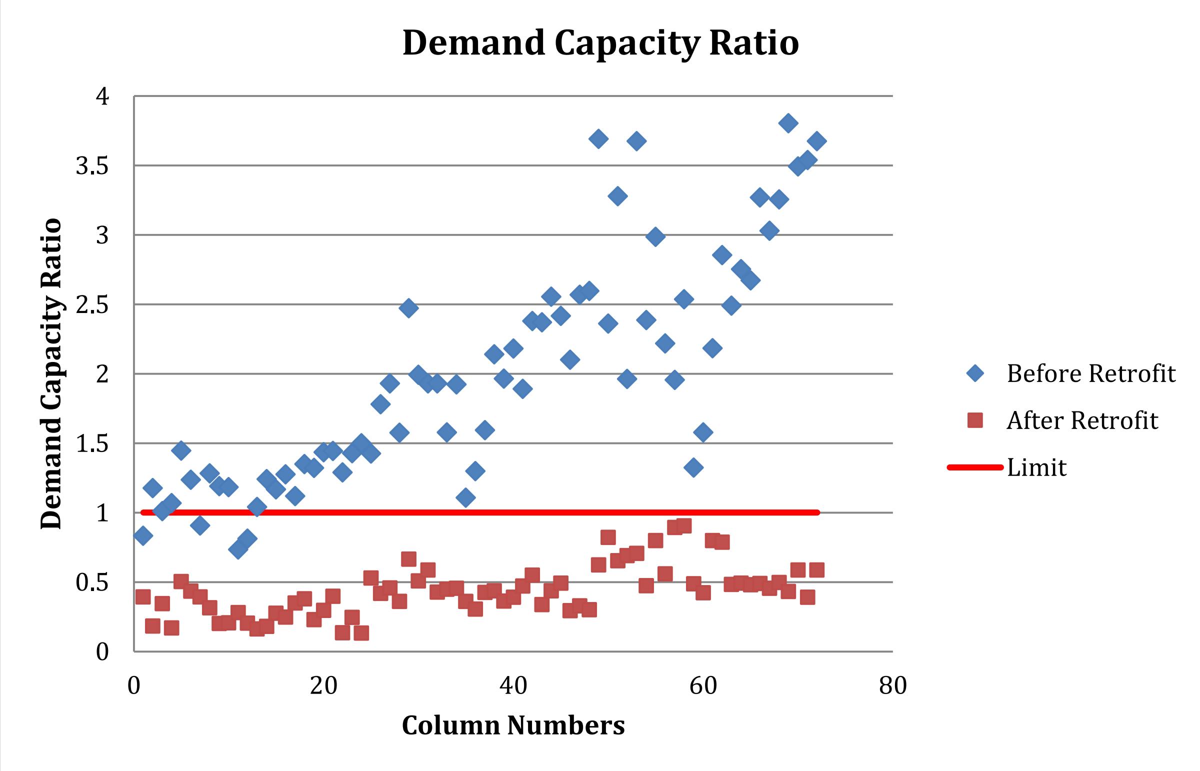


Figure 29: Demand Capacity ratio comparison before and after retrofit

6.6 DESIGN OF SHEAR WALL

The shear wall is designed in ETABS. The sample design output of shear wall is presented below.

Given Data:

Axial Force	(Pu)	1342.002	kN
Shear Force	(Vu)	128.490	kN
Moment	(Mu)	265.270	kN-m

Material Constant:

Grade of Concrete	(M)	25	Mpa
Grade of Steel	(Fe)	500	Mpa
Elastic Modulus of Steel	(Es)	200000	Mpa

Preliminary Dimension

Length of Wall	(lw)	830	mm
Thickness of Wall	(tw)	230	mm
Height of Wall	(hw)	3160	mm

Check for thickness as Per IS 13920:1993 Cl 9.1.2

	>	150	mm
		Ok	
Effective Depth of Wall Section	(dw)	0.8*lw	
		664	mm

Vertical Reinforcement:

Aial Force	(Pu)	1342.002	kN

$$P_u = 0.87\ f_y A_{st}$$

Area of Reinforcement Required	(Ast)	3717	mm2/m		
			mm ϕ		
Provided	(Ast)	20	@	150	c/c spacing
no of layers	(n)	2			
Provided	(Ast)	4189	mm2/m		
		Ok			
	(Pt)	1.821	%		

Minimum reinforcement ratio

(Pt)min	0.25	%	As per IS13920 Cl. 9.1.4
	Ok		

Horizontal Reinforcement:

Factored Shear Force	128.490	kN

$$\tau_v = \frac{V_u}{t_w d_w}$$

	(Vu)				
As per IS 13920:1993 Cl. 9.2.1					
	(τ v)		0.842	N/mm2	
	(Pt)		1.821	%	
From IS 456 Table 19					
	(β)		1.594		
Maximum Shear Strength of Concrete	(τ c,max)		3.1	N/mm2	
	(τ v)	<		(τ c,max)	
		Section Ok			
Design Shear Strength of Concrete	(τ c)		0.793	N/mm2	As per IS 456, Cl. 40.2
	(τ v)	>		(τ c)	
		Design for Shear Reinforcement			
Excess Shear Force	(Vus)		7.483	kN	
Shear Reinforcement Required	(Aus)		26	mm2/m	
Horizontal Reinforcement Required	(Ast)		575	mm2/m	
Provide	(Ast)		12	mm ϕ @	150 c/c spacing
No of layers	(n)		2		
Provided	(Ast)		1508	mm2/m	
		Ok			

Flexural Strength:

Moment of Resistance of Shear wall as per IS 13920:1993 Annex A

Vertical reinforcement ratio

$\rho = \frac{A_{st}}{t_w l_w}$	ρ	0.018
$\Phi = \frac{0.87 f_y \rho}{f_{ck}}$	ϕ	0.317
$\beta = \frac{0.87 f_y}{0.0035 E_s}$	β	0.621
$\lambda = \frac{P_u}{f_{ck} t_w l_w}$	λ	0.2812

$$\frac{x_u}{l_w} = \frac{\phi + \lambda}{2\phi + 0.36}$$ xu / lw = 0.602

$$\frac{x_u^*}{l_w} = \frac{1}{(1+\beta)}$$ xu* / lw = 0.617

xu / lw < xu* / lw

Case I : When (xu / lw) < (xu* / lw)

$$\frac{M_{uv}}{f_{ck}\, t_w\, l_w^2} = \phi\left[\left(1+\frac{\lambda}{\phi}\right)\left(\frac{1}{2} - 0.416\,\frac{x_u}{l_w}\right) - \left(\frac{x_u}{l_w}\right)^2\left(0.168 + \frac{\beta^2}{3}\right)\right]$$

Muv		292	kN-m
Mu	<		Muv
	Section Safe in Flexure		

Boundary Element Check:

As per IS 13920:1993, Cl. 9.4.1, where the extreme compressive stress in the wall due to factored gravity loads plus factored earthquake force exceeds 0.2 fck, boundary elements shall provided along the vertical boundaries of the walls.

Area of Cross section	Ag	190900	mm2
Moment of Inertia of the section	Iy	1.1E+10	mm4
Extreme fibre compressive stress	fc	17.075	N/mm2
	0.2fck	5.000	N/mm2
		Boundary Element Required	

Design of Boundary Elements (cl.9.4)

Size of boundary elements		746	mm
C/C distance bet'n boundary elements	Cw	84	

Axial force due to earthquake moments on the boundary elements (cl.9.4.2 13920:1993)

$$\frac{M_u - M_{uv}}{C_w}$$

0 kN

Ratio of axial compression carried by each boundary elements 0.2

Maximum Compression	268.400	kN
Maximum Tension	268.400	kN
Area of steel for Tension	617	mm2
Diameter of main bar	20	mm
No of main bar	6	
Steel provided, Asc	1885	mm2

% steel provided		0.339	%	

Assuming short column action axial load carrying capacity of the boundary elements,

Axial capacity	Pu	6197	kN	Ok

Special Confining Reinforcement (Cl. 7.4)

Assume spacing of bar	Sv	100	mm	
Area of shear reinforecement	Ash	250	mm2/m	
Provide		10	mm	dia shear bar
Area of shear reinforecement provided		785	mm2/m	Ok

6.7 CONCLUSION AND RECOMMENDATION

Seismic analysis and retrofit design of the building has performed through computer simulations, review of existing documents site visit and material testing. Special Reinforced Concrete Shear wall is found to be more viable, economical and easy to use for constructability. The reinforced concrete shear wall element is added only at the exterior faces that will make minimum service interruption on operation of hospital buildings. Deficiencies noted during detail seismic assessment are corrected to satisfy the building code requirements.

The followings retrofit options are recommended.

I. Addition of 230 mm thick Concrete shear wall at four location (Refer drawing for location of shear walls)
II. Concrete jacketing of existing columns at ends of newly added shear walls.
III. Protection of non structural elements by proper connection and anchoring.

7 ANNEXES

- Annex A: Non Destructive Test Report
- Annex B: Geo technical Investigation Report
- Annex C: Load Calculations
- Annex D: Calculation of Retrofit Design
- Annex E: Non Structural Components
- Annex F: Design Drawing