# REPORT ON DETAIL SEISMIC ASSESSMENT & RETROFIT DESIGN OF WESTERN REGIONAL HOSPITAL, POKHARA, 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 Western Regional Hospital (WRH), Pokhara – 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 sixteen building blocks from 10 – 34 years old. Of these, nine are unreinforced stone masonry buildings, while the remainder are RCC framed buildings with stone masonry and/or hollow/brick concrete blocks (for details see Chapter 3 of this report). 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.
- There are no expansion or construction joints between. Most of these joints were either connected or filled later to resolve drainage and seepage of water inside the blocks during rainy season
- Most of the buildings are suitable for retrofitting, other than a few minor structures attached to the main blocks. , if these buildings meet their intended functional requirements as per current standards , and also if the buildings meet their hospital's Master Plan requirements. 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

### 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

After the detailed seismic assessment and analysis, it was concluded that existing four RCC Framed buildings – Laboratory Block, Emergency– I, Mortuary, and Abortion Block – and a masonry building - Laboratory block are found to be safe and do not need any retrofitting/strengthening works for exiting condition without further changes to the civil works, although regular repair and maintenance will still be required. It is recommended that the Diabetes Block needs to be demolished and rebuilt. Deficiencies in the remaining building blocks noted during the detailed seismic assessment are summarized below:

Remaining RCC Framed Buildings:

- The remaining RCC buildings did not comply with the codes' requirements for storey drift. The seismic gap required between adjacent blocks, especially Computed Tomography (CT)-scan and Ear Nose Throat (ENT) Blocks, was found to be insufficient.
- 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.

### 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 |
|---|---|---|
| **Unreinforced Masonry Building Blocks** | | |
| 1 | Maternity | Separation of buildings introducing two seismic gaps, reduce opening, develop load path, splint and bandage with wall jacketing, introduce diaphragm at roof level, introduce steel frame at new atrium area and gable wall, brace parapet walls, and anchorage of slate at roof |
| 2 | Medical | Separation of buildings introducing a seismic gap, increase wall density, reduce opening, develop load path, and splint and bandage with wall jacketing |
| 3 | Pediatric | Separation of buildings introducing a seismic gaps, increase wall density, reduce opening, develop load path, and splint and bandage with wall jacketing |
| 4 | OPD | Splint and bandage with wall jacketing and steel bracing of parapet walls |
| 5 | Pharmacy | Splint and bandage with wall jacketing, increasewall density, reduce opening, and steel bracing of parapet walls |
| 6 | Dental | Splint and bandage with wall jacketing, shoe anchorage bracing of parapet walls, and introduce seismic gap |
| 7 | Emergency - II | Splint and bandage with wall jacketing, develop load path, demolish roof structure and walls at first floor and replace with light structures |
| 8 | Link corridor | Introduce seismic gaps, and steel stone column jacketing |

| RCC Framed Building Blocks | | |
|---|---|---|
| I | CT-Scan | RCC shear wall with column jacketing & addition of a columns for load path |
| 2 | ENT | RCC shear wall with column jacketing |
| 3 | Ramp | Introduce new seismic gap, install steel framing up to slab level, replace RCC roof structure with light roofing |
| 4 | Nutrition | Steel column jacketing |
| 5 | Link corridor | Steel column jacketing with cross bracing |
| 6 | Mortuary | Steel column jacketing |
| 7 | Emergency - I | RCC column jacketing |

The retrofitting solutions of the last two blocks - Emergency–I and Mortuary, which were found to be safe during detailed seismic assessment, are proposed for the functional requirements – addition of a floor in these buildings as per Hospital Management requests during last consultation meeting at Pokhara.

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# 1 INTRODUCTION

## 1.1 BACKGROUND

The Nepal Health Sector Support Program III (NHSSP-III) 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, 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 MoHP 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 OBJECTIVES

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 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.

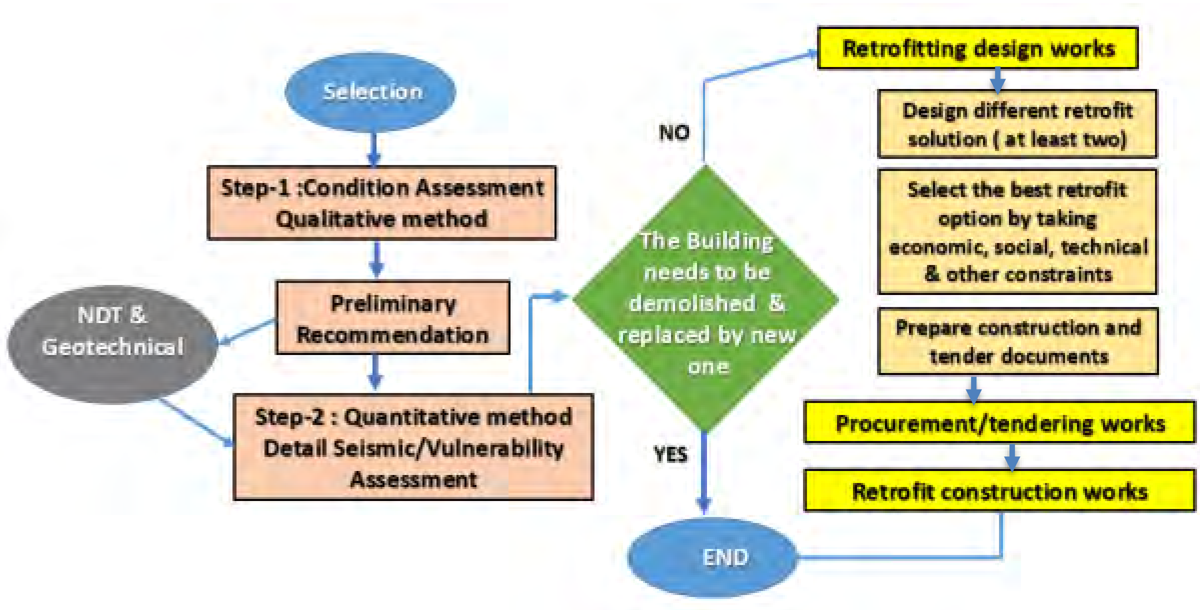



Figure 1: Flowchart of overall process of detail seismic assessment and retrofitting design

The major activities/steps of the procedure are as follows

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

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

# 2 DESCRIPTION OF HOSPITAL

Western Regional Hospital consists of seventeen different blocks of two different building typology. These blocks are constructed using various gravity and lateral force resisting systems and thus, must be treated differently and grouped into the typologies outlined in 2.2. The buildings vary considerably in size, usage requirements and age as well, some buildings being only ten years old while the oldest were constructed 34 years ago. The buildings are clustered together, and most blocks are connected by expansion joints, typically found at the ground floor but sometimes at upper floors as well.

## 2.1 SITE LOCATION

Western Regional Hospital is located in Kaski District, Western Development Region, Nepal. The latitude of the hospital is 28° 12' 44.7156" N and its longitude is 83° 59' 52.4796" E. The location site plan and master plan (blown up) of the hospital are shown in Figure 2 and Figure 3, respectively.

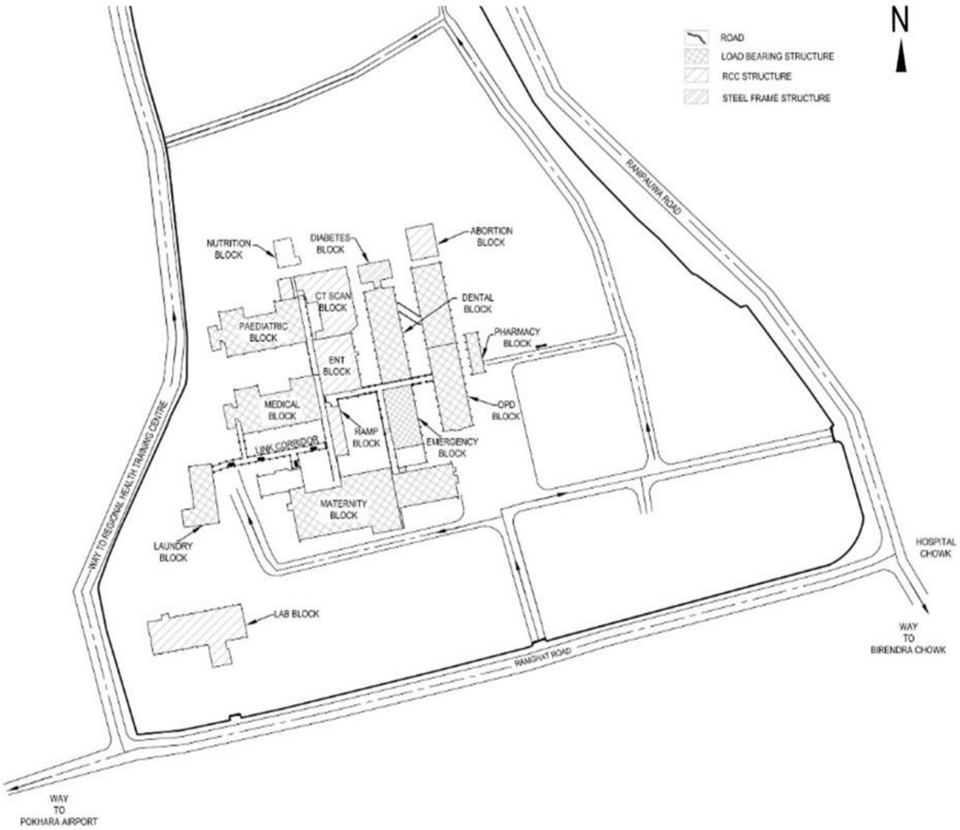



Figure 2: Western Regional Hospital Site Plan

## 2.2 TYPOLOGY OF BLOCKS IN HOSPITAL

After analyzing the building typology, it is identified that there are different types of gravity systems, lateral load carrying systems, floor systems and materials used in the same building. Some buildings have even different gravity systems at different stories. For the sake of the simplification in understanding the building configuration, two different typologies – RC frame and Unreinforced masonry (URM) have been defined.

### 2.2.1 T1-RC FRAMED BUILDING

This type of building includes only reinforced concrete frame as a gravity and lateral system with infill wall of stone, brick and hollow concrete block. The floor system is RC slab

### 2.2.2 T2- UNREINFORCEMNET MASONRY BUILDING

This type of building has unreinforced stone masonry in cement mortar as a gravity and lateral system. The floor system is RC slab. In some buildings, few frame structure (reinforced concrete column) are presented in some location with stone masonry load bearing system

Majority of the hospital building comprises stone as infill walls / load bearing walls.

Table 1 shows building typology within the hospital campus.

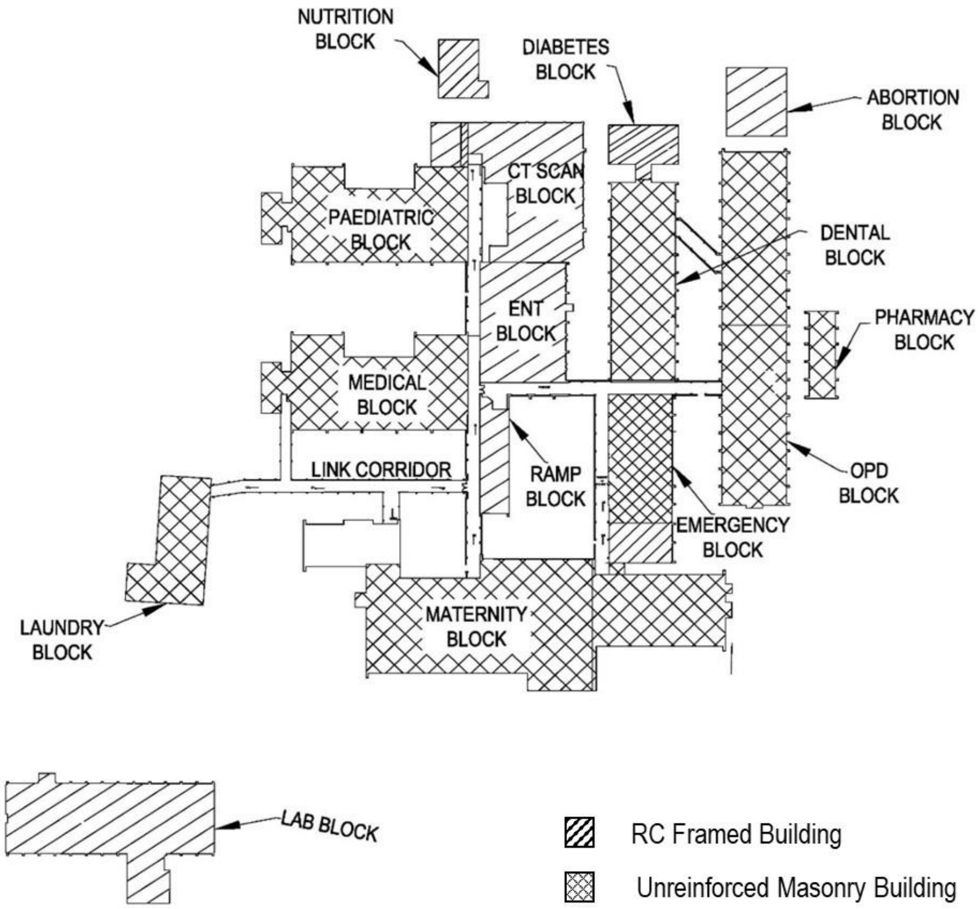



Figure 3: Building Typologies in Western Regional Hospital

Table 1: Building Typology

| S.No | RC Framed with ordinary masonry infill wall Panels | |
|---|---|---|
| | **Block** | **Wall Construction** |
| 1 | Abortion Block | Brick masonry with cement mortar |
| 2 | ENT Block | Stone masonry with cement mortar |
| 3 | CT Scan | Stone masonry with cement mortar |
| 4 | Link Corridor | N/A |
| 5 | Nutrition | Stone masonry with cement mortar |
| 6 | Ramp | Brick masonry with cement mortar |
| 7 | Lab | Stone masonry with cement mortar |

| S.No | Load bearing masonry buildings with reinforced concrete floor slab | |
|---|---|---|
| | **Block** | **Wall Construction** |
| 1 | Diabetes | Stone masonry building with cement mortar and some reinforced concrete members |
| 2 | Emergency | Stone masonry building with cement mortar |
| 3 | Dental | Stone masonry building with cement mortar and steel roof |
| 4 | Maternity Block | Stone masonry building with cement mortar |
| 5 | Laboratory | Dual structural system: stone masonry load bearing system and RC frame system |
| 6 | Medical | Stone masonry building with cement mortar |
| 7 | OPD | Stone masonry building with cement mortar |
| 8 | Pharmacy | Stone masonry building with cement mortar |
| 9 | Pediatric | Stone masonry building with cement mortar |

Further details of majority of the buildings at Western Regional Hospital campus are presented in Table 2 below.

## Table 2: Detail Description of Buildings

| S. No. | Building Name | # of Stories | Gravity System | Lateral System | First Floor Wall System | Second Floor Wall System | 1st Floor System | 2nd Floor System | Year of Construction | Age (Yrs) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Abortion Block | 1 | RC Frame with brick infill | RC Frame with Brick Infill | Stone Masonry wall /Infill & Brick Masonry infill | - | RC Slab | | 2062 BS | 12 |
| 2 | OPD Block | 2 | Stone Masonry in cement mortar & RC (First Floor) , Frame & Steel (2nd Floor) | Stone Masonry & RC (First Floor), Frame & Brick Masonry (2nd Floor) | Stone Masonry wall & Stone Masonry infill | Brick Masonry Infill | RC Slab | Light Steel Structure | 2040BS | 34 |
| 3 | Pharmacy Block | 1 | Stone Masonry | Stone Masonry | Stone Masonry & Stone Masonry infill | - | RC Slab | | 2040BS | 34 |
| 4 | Diabetes Block | 1 | Stone Masonry in cement mortar, Steel Post and Brick Masonry in cement mortar | Stone Masonry /Brick masonry and Steel Post | Stone Masonry /Infill & Brick Masonry infill | - | Light Steel Structure | | 2040BS | 34 |
| 5 | Dental Block | 2 | Stone Masonry in cement mortar | Stone Masonry | Stone Masonry wall | Stone Masonry wall | RC Slab | RC Slab | 2040BS | 34 |
| 6 | Emergency Block | 2 | Stone Masonry in cement mortar (First Floof) RC with brick infill in cement mortar (Second Floor) | Stone Masonry, Frame & Brick Masonry (2nd Floor) | Stone Masonry wall | Brick Masonry Infill | RC Slab | Light Steel + RC Slab | 2040BS | 34 |
| 7 | Maternity Block | 2 | Stone Masonry in cement mortar | Stone Masonry in cement mortar | Stone Masonry wall | Stone Masonry wall | RC Slab | Timber + Slate | 2030BS | 44 |
| 8 | Nutrition Block | 2 | RC Frame with stone masonry infill (outer wall) and RC Frame with brick masonry infill (Internal wall) | RC Frame with stone and brick infill | Stone Infill/ Internal Brick Infill | Stone Infill/ Internal Infill Brick | RC Slab | RC Slab | 2064BS | 10 |
| 9 | CT Scan Block | 2 | RC Frame with Stone Infill | RC Frame with Stone Infill | Stone Masonry Infill | Stone Masonry | RC Slab | RC Slab | 2055BS | 19 |
| 10 | Kidney Stone Block | 2 | RC Frame with Stone Infill | RC Frame with Stone Infill | Stone Masonry Infill | Stone Masonry | RC Slab | RC Slab | 2064BS | 10 |
| 11 | ENT Block | 2 | RC Frame with Stone Infill | RC Frame with Stone Infill | Stone Masonry Infill | Stone Masonry Infill | RC Slab | RC Slab | 2040BS | 34 |
| 12 | Ramp | 2 | RC Frame with Brick and stone Infill | RC Frame with Stone Infill | Brick/Stone Infill | Brick/Stone Masonry Infill | RC Slab (Inclined) | RC Slab (Inclined) | 2040BS | 34 |
| 13 | Pediatric Block | 2 | Stone Masonry in cement mortar | Stone Masonry in cement mortar | Stone Masonry wall | Stone Masonry wall | RC Slab | RC Slab (Inclined) | 2040BS | 34 |
| 14 | Medical Block | 2 | Stone Masonry in cement mortar | Stone Masonry in cement mortar | Stone Masonry wall | Stone Masonry wall | RC Slab | RC Slab (Inclined) | 2040BS | 34 |
| 15 | Link Corridor | 2 | RC Frame without in fill (First Floor) and Steel Frame (Second Floor) | RC Frame without in fill (First Floor) and Steel Frame (Second Floor) | No Infill | No Infill | RC Slab | Steel Truss | 2050/2060 | 24/14 |
| 16 | Laundry Block | 2 | Stone Masonry in cement mortar (First Floor) & RC Frame with stone infill (second Floor) | Stone Masonry in cement mortar (First Floor) & RC Frame with stone infill (second Floor) | Stone Masonry Wall | Stone Masonry Infill Wall | RC Slab | RC Slab | 2040/2055 BS | 34/19 |
| 17 | Lab Block | 2 | RC Frame with Stone Infill | RC Frame with Stone Infill | Stone Infill Wall | Stone Infill wall | RC Slab | Steel Truss | 2050BS | 24 |

# 3 CONDITIONAL ASSESSMENT

## 3.1 BACKGROUND

The condition assessment of the building is a preliminary assessment of existing building of the prioritized hospital. 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 summary the methodology of condition assessment and its findings and recommendations.

## 3.2 METHODOLOGY

The methodology for condition assessment includes the following components

### 3.2.1 COLLECTION AND 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 as-built drawings 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

Different teams 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 Mr Jitendra Bothara from Miyamoto New Zealand was conducted on-site structural condition assessment. The on-site assessment was one of a capacity enhancement activity of the programme for technical staffs of the MoH 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, three different engineer team from NHSSP, PCU and DUDBC were assessed the buildings with addition field verification during NDT/DT and details 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

The details condition assessment of each block is presented in Condition Assessment Report (Annex). 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 4: Serious seepage issues inside Emergency Block & OPD Block

#### 3.3.2 CORROSION

Due to seepage and lack of timely maintenance, there are some corrosion issues in major buildings – OPD, Emergency,  Dental and Maternity blocks

Figure 5: Corrosion cracks in Emergency Block & OPD Block

### 3.3.3 CRACKS

Cracks are observed in participation wall in the CT scan building and ENT building. As per hospital staffs, these cracks are the effects of Gorkha Earthquake.

Figure 6: Wall cracks in Emergency Block & OPD Block

Besides, it is also observed a crack in the slab and wall in Maternity building at the location of load path problem - lack of wall in ground floor

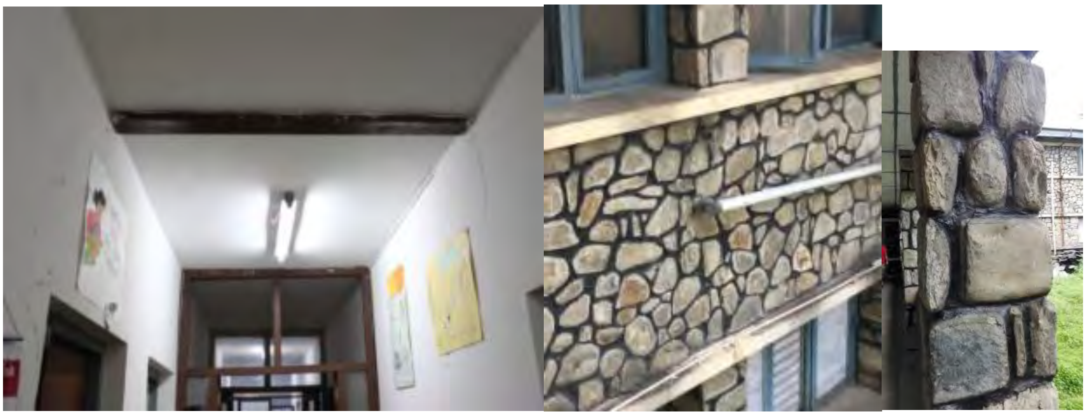


Figure 7: Wall and Floor cracks in Maternity Block

Cracks are observed in most of the construction joints due to lack of proper gaps as well as sealing these gaps

Figure 8: Vertical Cracks on Masonry Wall (Sealed area of Seismic Separation)

### 3.3.4 POUNDING EFFECTS

It is observed a pounding effect between CT Scan building and ENT building during Gorkha Earthquake as shown in the following photos

Figure 9: Pounding Effect at ENT and CT Scan Block Connection

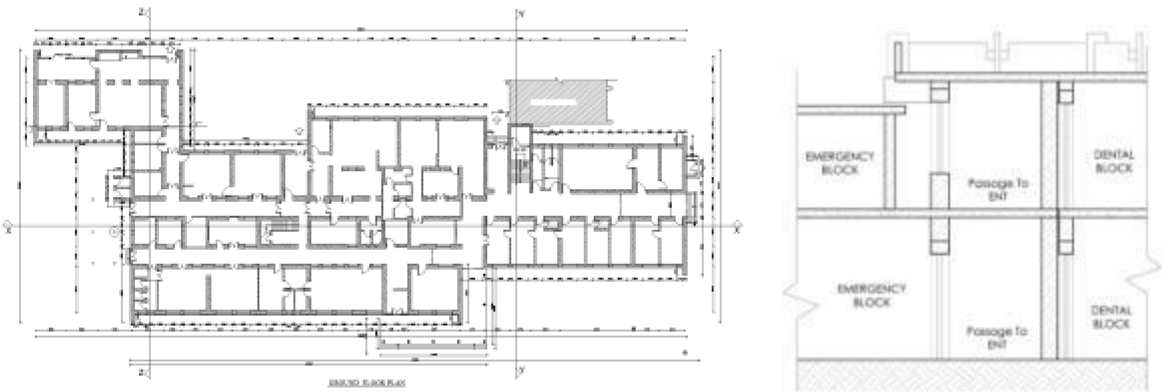
### 3.3.5 POOR MAINTENANCE

Growing plants and leakage of pipe line are clearly indicated the lack and/or poor maintenance in the most of the building. Besides, as mentioned above, it is also observed many seepage, rusting and deterioration of materials in most of the building as a symptoms of poor maintenance of these buildings

Figure 10: Poor Maintenance

### 3.3.6 LOAD PATH & CONFIGURATION

All the buildings except Maternity block are in regular configuration in plan. The plan of Maternity block is presented in the following Figure. However, there are lacks of complete load path in some location in Dental, Emergency and Maternity blocks.

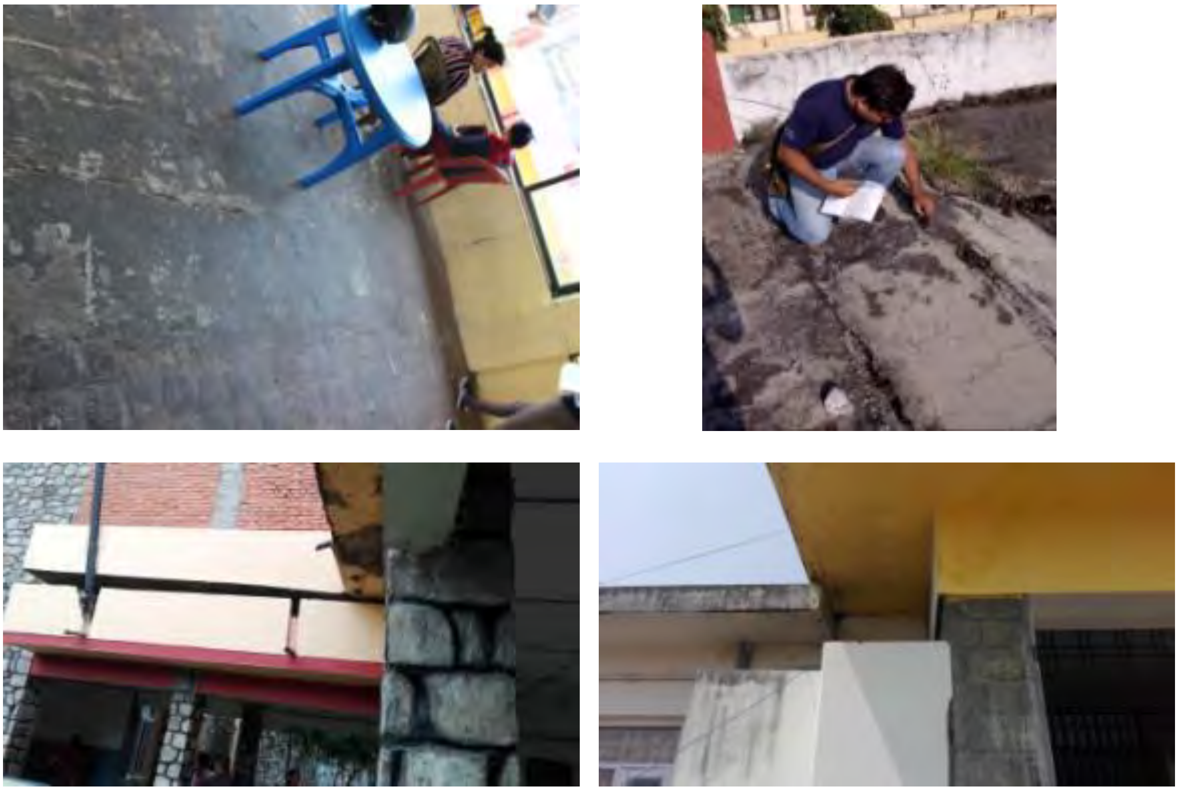



(a) (b)

Figure 11: a) Plan of Maternity Block. b) A disconnect load path in Emergency Block

### 3.3.7 SEISMIC SEPERATION

The hospital buildings are present in a clustered form where the majority of the blocks are connected to each other with seismic /expansion joints. However, there are lacking of proper location and separation in most of the seismic gaps. The most of separation are covered by flooring finishing, and concrete as shown in the following photos. The joints provided are not maintained and rubble has collected in the joints. Along with that, due to pervasive cracking in the joint covers and level differences between buildings, there is commonly a water seepage problem at the expansion joint area. In other cases, the joints are discontinuous at upper levels of the buildings where two beams / floors are attached (see Figure 12). A structural engineer team of DUDBC and NHSSP has investigated in the field while reviewing the design and incorporated in analysis and retrofitting design of each block which is presented in block-wise detail reports.



Slab at two different slab level (Link Corridor between Dental and ENT Block)

Slab at two different level between emergency and corridor at first floor but slab continuous at ground floor

Figure 12: Discontinuity Seismic Separation

### 3.3.8 NON-STRUCTURES COMPONETS

Upon investigation of the buildings within the hospital periphery, following deficiencies among non-structural components were found

- Lack of appropriate anchorage and support of NSC
- Poor drainage and piping system
- Damages of flash ceiling
- Poor electric wiring and HVSC system

Figure 13:  Condition of Non Structural Components (Utility Services)

### 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. Most of the buildings are load bearing type with stone masonry walls in cement mortar where as some are RCC frame with stone or brick masonry infill. 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 CT scan buildings and 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 sewerage drainage, electrical wiring as well as other HVAC 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 most of the buildings located at the Western Regional 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
    - Concrete coring and compression tests
2) Load Bearing Masonry Structures
    - Penetrometer Test
    - Ferro Scan 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. The summary of the test results are as follows:

### 4.1.1 IN-SITU BED JOINT SHEAR TEST

The summary of the bed joint shear test is presented in Table 3 below.

Table 3: Summary of Bed Joint Shear Test

| S.No. | Building | Location | Wall thickness (mm) | Height of Wall above test location (m) | Shear Strength (MPa) | Remarks |
|---|---|---|---|---|---|---|
| 1 | Pediatric | Grid D/E-1 | 457 | 6.0 | 0.3 | |
| 2 | Medical | Grid K-7/8 | 457 | 6.23 | 0.4 | |
| 3 | Maternity | Grid Q-1/2 | 457 | 5.26 | 0.41 | |
| 4 | Dental | Grid L-3/4 | 457 | 5.26 | 0.31 | |
| 5 | Lab | Grid A-1/2 | 457 | 6.17 | 0.42 | |

From the above test results, it shows that shear strength of stone masonry wall varies from 0.3 - 0.42 MPa.

Mean of the test data = μ = 0.368

Standard deviation = $\alpha = 0.058$

Shear Strength as per test result = 0.368±1*0.058 = 0.31/0.426 MPa (ASCE 41-13)

Knowledge factor = $k = 0.7$ (IS 15988- 2013)

Allowable shear strength = 0.217/ 0.298 MPa

According to Public Works and Government Services Canada, 2000 (PWGSC, 2002).“Guidelines for the Seismic Assessment of Stone-masonry Structures” the shear strength of stone masonry needs to be limited to a maximum value of 0.2 MPa for rubble construction (German standard DIN 1053).Thus, the lower bound value of 0.31MPa of on-site test shear strength using knowledge factor as per IS 15988 (2013) is considered for the structural analysis.

Figure 14: Photograph showing Bed Joint Shear Test

### 4.1.2 STONE COMPRESSIVE STRENGTH TEST

For compressive strength of the stone, stones were collected from the three different building and tested in the lab. The test results are presented in Table 4 below.

Table 4: Summary of Compressive Strength Test of Stone

| Sample | A | B | C |
|---|---|---|---|
| Testing dimension (cm) | 7.64 X 7.77 X 7.35 | 7.70 X 7.64 X 7.18 | 7.85 X 7.82 X 6.08 |
| Surface Area ($cm^2$) | 59.3 | 58.77 | 61.38 |
| Volume | 435.57 | 422.00 | 373.06 |
| Density | 2.66 | 2.64 | 2.37 |
| Weight | 1157.5 | 1113.6 | 884.2 |
| Failure load Psi | 3750 | 5250 | 2400 |
| Compression Strength ($N/mm^2$) | 55.24 | 77.96 | 34.16 |


Figure 15: Photograph showing Compressive Strength Test of Stone

### 4.1.3 CORE TEST FOR COMPRESSIVE STRENGTH OF CONCRETE

The summary of the core testing location and test results are presented in Table 5 below.

Table 5: Summary of Core Cutting Test

| S.No. | Building | Element | Location | Measured Compressive Strength kg/cm2 | In-situ Cube Strength (core drilled vertically) kg/cm2 | Remarks |
|---|---|---|---|---|---|---|
| 1 | Nutrition | Slab | Grid B/C-1 | 237.53 | 266.71 | |
| 2 | Pediatric | Slab | Grid A-4/6 | 217.48 | 229.55 | |
| 3 | Ramp | Slab | Grid B/C-6 | 226.57 | 256.84 | |
| 4 | CT Scan | Slab | Grid B/C-9 | 231.8 | 254.08 | |
| 5 | Maternity | Slab | Grid P/Q-1 | 227.83 | 252.85 | |
| 6 | Medical | Slab | Grid A-1/2 | 220.04 | 240.61 | |
| 7 | Pharmacy | Slab | Grid A-1/2 | 227.17 | 247.34 | |
| 8 | Emergency | Slab | Grid I'/J' | 216.15 | 231.05 | |
| 9 | Dental | Slab | Grid E/F-1 | 223.13 | 252.33 | |
| 10 | ENT | Slab | Grid F-3/4 | 222.48 | 247.39 | |

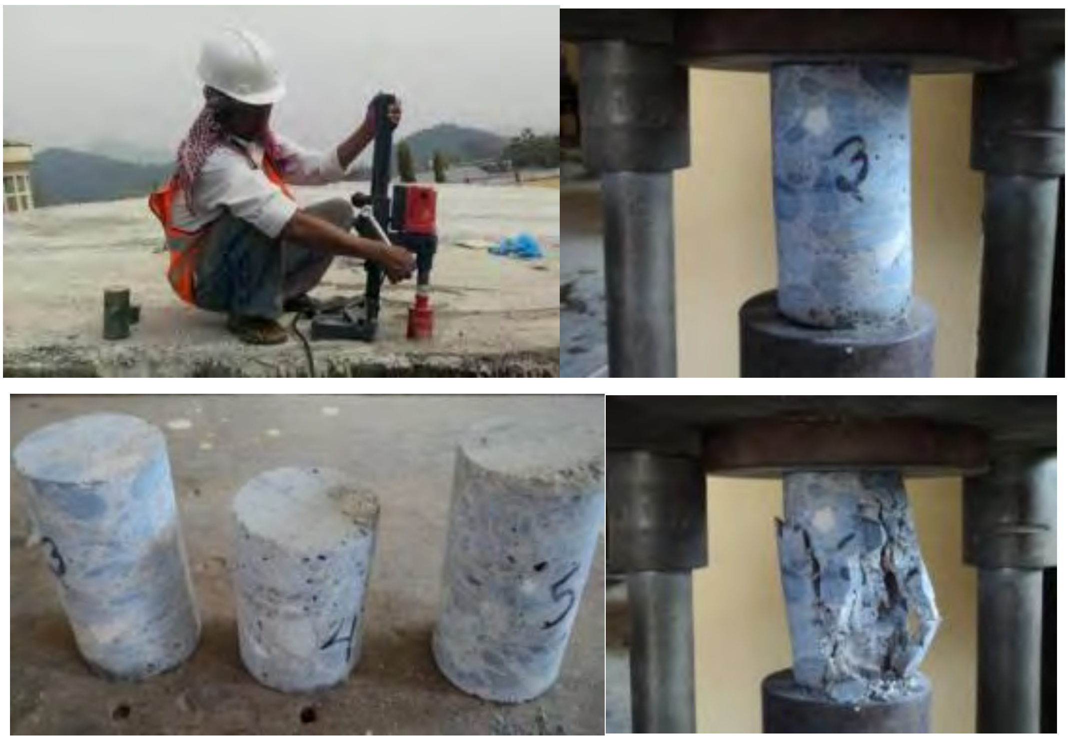



Figure 16: Photograph showing Concrete Core Test

### 4.1.4 PENETROMETER TEST

To find the compressive strength of the mortar of the existing buildings, penetrometer tests were conducted in different location of all the assessed hospital buildings. The test results are presented in the separate report. Sample penetrometer test results performed on dental and emergency blocks are presented in Table 6.

Table 6: Penetrometer Tests of Cement Mortar of Existing Structures

GS

**G.S. Soil & Materials Engineers (P) Ltd.**

*(Soil Investigation & Analysis, Design & Construction of Piling, Anchoring, Slope Stability Analysis, Geo-synthetic Design & Supply, Field Investigation, Soil & Material Lab Testing)*

Surface Hardness Rebound Number Test

Project Western Regional Hospital - Dental Block
Floor : Ground
Structural Element:Wall

| S.No. | Position | Penetrometer Reading Kg/cm2 | Mean Value | Commpressive Strength (MPa) | Remarks |
|---|---|---|---|---|---|
| 1 | Grid A'/A-1/2 | 38 | 37.40 | 3.67 | |
| 2 | | 38 | | | |
| 3 | | 37 | | | |
| 4 | | 38 | | | |
| 5 | | 36 | | | |

Project Western Regional Hospital - Dental Block
Floor : Ground
Structural Element:Wall

| S.No. | Position | Penetrometer Reading Kg/cm2 | Mean Value | Commpressive Strength (MPa) | Remarks |
|---|---|---|---|---|---|
| 1 | Grid A/B-2 | 37 | 37.20 | 3.66 | |
| 2 | | 36 | | | |
| 3 | | 38 | | | |
| 4 | | 38 | | | |
| 5 | | 37 | | | |

Surface Hardness Rebound Number Test

Project Western Regional Hospital - Emergency Block
Floor : Ground
Structural Element:Wall

| S.No. | Position | Penetrometer Reading Kg/cm2 | Mean Value | Commpressive Strength (MPa) | Remarks |
|---|---|---|---|---|---|
| 1 | Grid A-4/5 | 37 | 37.20 | 3.66 | |
| 2 | | 38 | | | |
| 3 | | 37 | | | |
| 4 | | 36 | | | |
| 5 | | 38 | | | |

Project Western Regional Hospital - Emergency Block
Floor : Ground
Structural Element:Wall

| S.No. | Position | Penetrometer Reading Kg/cm2 | Mean Value | Commpressive Strength (MPa) | Remarks |
|---|---|---|---|---|---|
| 1 | Grid D/E-6 | 37 | 37.40 | 3.67 | |
| 2 | | 39 | | | |
| 3 | | 38 | | | |
| 4 | | 37 | | | |
| 5 | | 36 | | | |

From the pocket penetrometer test, the average compressive strength of mortar was found to be 3.622 MPa

## 4.2 GEOTECHNICAL INVESTIGATION

The aims of geotechnical investigation are to understand the geology and engineering properties of existing soil at the Western Regional Hospital. Five bore holes of 20m depth were investigated during this investigation. The locations of the bore holes are as shown in Figure 17.. 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 17: 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 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 | Allowable bearing capacity in $KN/m^2$ | Modulus of Sub Grade Reaction in $KN/m^3$ |
|---|---|---|---|---|---|
| 2.0 x 2.0 | 1.0 | 169.2 | 20.4 | 169.2 | 13536.0 |
| 2.0 x 2.0 | 1.5 | 204.4 | 23.4 | 204.4 | 16352.0 |

### 4.3 FOUNDATION EXPLORATION

A structure engineer team of DUDBC and NHSSP has conducted foundation exploration work in Western Regional Hospitals.

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

- Lack of tie beam in the masonry building at plinth level.
- Step wall footings of stone masonry in cement sand mortar as shown in the figures
- Water seepage in foundation of medical block.

The depth, size and thickness of the foundation as per excavation are presented in figure below

Foundation Excavation

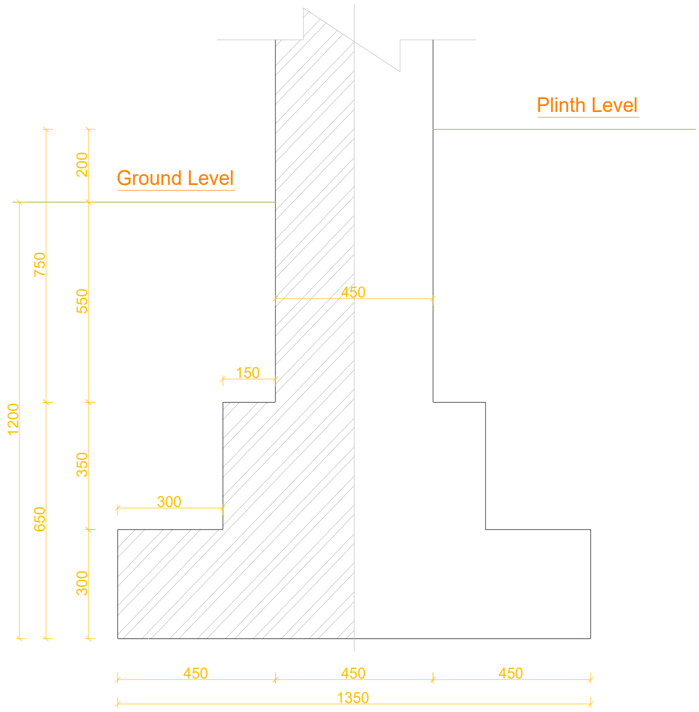
Foundation Measurement

Figure 18: Foundation Exploration of Masonry Block

Table 8: Findings of Foundation Excavation

| S.N. | Description | Finding (Maternity Block) |
|---|---|---|
| 1 | Soil Type | Gravel mixed Clay |
| 2 | Foundation Depth | 1200mm |
| 3 | Foundation Size | 1250 mm |
| 4 | Footing thickness | 350+300=650 mm |

Note: There is water seepage found during foundation exploration in Medical Blocks. Thus, foundation exploration cannot complete. In case of RC framed buildings, there exist sanitary and water supply pipe lines running and sanitary manholes. Thus, no proper location found for foundation exploration.




Foundation Measured During Excavation
Maternity Block

## 4.4 FOUNDATION CHECK

The following are the foundation check calculation

Table : Joint Reaction from Analysis (Maternity Block I)

| Location | Joint Label | Unique Name | Load Case/Combo | FX | FY | FZ |
|---|---|---|---|---|---|---|
| | | | | kN | kN | kN |
| GL | 1 | 5 | DL+LL+EQY | 6.0291 | -393.2136 | 11.6124 |
| GL | 2 | 57 | DL+LL+EQY | 17.146 | -370.4394 | 686.5512 |
| | | | | | Total = | 698.1636 |
| GL | 1 | 5 | DL+LL-EQY | 4.7157 | 459.0548 | 677.7964 |
| GL | 2 | 57 | DL+LL-EQY | 46.9313 | 399.4613 | 291.4342 |
| | | | | | Total = | 969.2306 |

| | | | |
|---|---|---|---|
| Total Load = | 969.231 | kN | |
| Length of wall = | 5.515 | m | |
| Load per meter = | 175.744 | kN/m | |
| ABC = | 169.200 | $kN/m^2$ | |
| Width of footing required = | 1.039 | m | |
| Width of footing = | 1.35 | m | safe |
| Unit wt of soil = | 21.000 | $kN/m^3$ | |
| Angle of repose = | 31 | degree | |
| | 0.541 | rad | |
| Depth of footing required = | 0.826 | m | |
| Depth of footing = | 1.2 | | safe |

From the above calculation, it shows that the existing foundation is found to be safe

# RC Frame Buildings

# 5 DETAILED SEISMIC ASSESSMENT FOR RC FRAME BUILDING

## 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 mortar | 3.5 | 3.5 | Mpa | As per IS Code, M2 Mortar Grade |
| 2 | Shear Strength of Stone masonry Wall | 0.31 | 0.217 | Mpa | Applying knowledge factor as per IS Code 15988 |
| 3 | Compressive strength of concrete | 27 | 15 | 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 CODES AND STANDARDS

The following Nepal Building Codes, Indian Standard Codes of Practices, 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 15988 : 2013 Seismic Evaluation and Strengthening of Existing Reinforced Concrete Buildings – Guidelines
- Nepal Building Codes

## 5.5 LOADING

Loads in the building are as per Indian standard code of practices. The calculation process of load and load cases are as follows

### 5.5.1 DEAD LOAD

The dead load is derived from the unit weight of different structural and non-structural elements in from IS 875 Part I and presented in Table 11. The load calculations are based on actual measured drawings.

- The weight of infill walls is calculated based on measured drawings considering reducing opening present in wall 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& ANALYSIS METHOD

There are two methods for the seismic analysis of the building; one is Seismic Coefficient Method and another is Response spectrum method (dynamic analysis).Both methods are considered for the calculation of seismic demand as per IS 1893:2002/2016 for RCC buildings.

I. SEISMIC COEFFICIENT METHOD

To determine the seismic load, it is considered that the country (Nepal) lies in the seismic zone V according to IS 1893:2000. The soil type is considered as medium with 5% damping to determine average response acceleration. The building is analyzed as ordinary moment resisting frame without 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 6, Cl6.4.2, IS 1893 -2002]

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

Detail sample calculation is presented in Table 14below.

## II. 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, storey forces, and storey 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 ($\varphi_{ik}$) 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 ($\varphi_{ik}$) 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 7.8.4.5c and 7.8.4.5d.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 7.8.2.

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(CT scan Block)

| | | | | |
|---|---|---|---|---|
| Seismic zone | | | V (Very Sever)-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 | | 3.77 | m |
| Dimension of the building Along X | $D_x$ | | 36.60 | m |
| Dimension of the building Along Y | $D_y$ | | 12.24 | m |
| Time period of the building | $T=0.075h^{0.75}$ | Cl. 7.6.2 | 0.056 | 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 | |

Thus, the seismic demand as per IS 1893: 2002 is <u>0.225</u> percentage of seismic weight.

Table 15: Design Horizontal Seismic Coefficient as per NBC 105 (CT scan Block)

| | | | | |
|---|---|---|---|---|
| Seismic zone | | | Pokhara | |
| 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 | | | Moment Resisting Frame | |
| Structural performance factor | K | Cl. 8.1.8, table 8.2 | 2 | |
| Height of the building | h | | 7.00 | m |
| Dimension of the building along X | $D_X$ | | 23.56 | m |
| Dimension of the building along Y | $D_Y$ | | 27.750 | m |
| Time period of the building along X | $T=\frac{0.09h}{\sqrt{D_X}}$ | Cl. 7.3 (b) | 0.130 | sec |
| Time period of the building along Y | $T=\frac{0.09h}{\sqrt{D_Y}}$ | Cl. 7.3 (b) | 0.120 | sec |
| Soil type | | | Type II (Medium Soil) | |
| Basic seismic coefficient along X | $C_X$ | Cl. 8.1.4, fig 8.1 | 0.08 | |
| Basic seismic coefficient along X | $C_Y$ | Cl. 8.1.4, fig 8.1 | 0.08 | |
| Design Horizontal Seismic Coefficient along X | $C_{dX}$ = CZIK | Cl. 8.1.1 | 0.24 | |
| Design Horizontal Seismic Coefficient along X | $C_{dY}$ = CZIK | Cl. 8.1.1 | 0.24 | |

The seismic demand as per NBC is 0.24 and as per IS code 0.225. NBC 105 gives higher seismic demand. Hence, 0.24Horizontal Seismic Coefficient as per NBC 105 is taken for analysis of masonry structure

## 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 NBC 105: 1994and IS 456: 2000 & IS 1893: 2002. The design load combinations are the various combinations of the load cases for which the structure needs to be checked. Although the structure is subjected to dead load (DL), live load (LL), wind load (WL), Snow load (SL) and earthquake induced load (E), Wind load and snow load are not considered in the structural analysis of the WRH's buildings. The following load combinations have been defined.

1. For the analysis as per NBC 105:1994:

   Static Load Combination:

   DL + LL

   Seismic Load Combination:

   DL + 1.3 LL + 1.25 E;

   0.9 DL + 1.25 E;

   DL + 1.3 SL + 1.25E

2. For the analysis as per IS 1893:2002:

   Static Load Combination:

   1.5 (DL + LL)

   Seismic Load Combination:

   1.2 (DL +LL ± EQ)

   0.9 DL ±1.5EQ

   1.5 (DL ± EQ)

## 5.7 STRUCTURAL MODELLING

The building is modeled using finite element modeling software, ETABS 2016 V 16.2.1. 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 RC wall and floor Slab.

For structural modeling, analysis and design, the following assumptions are considered

- 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 assumed 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 sections.

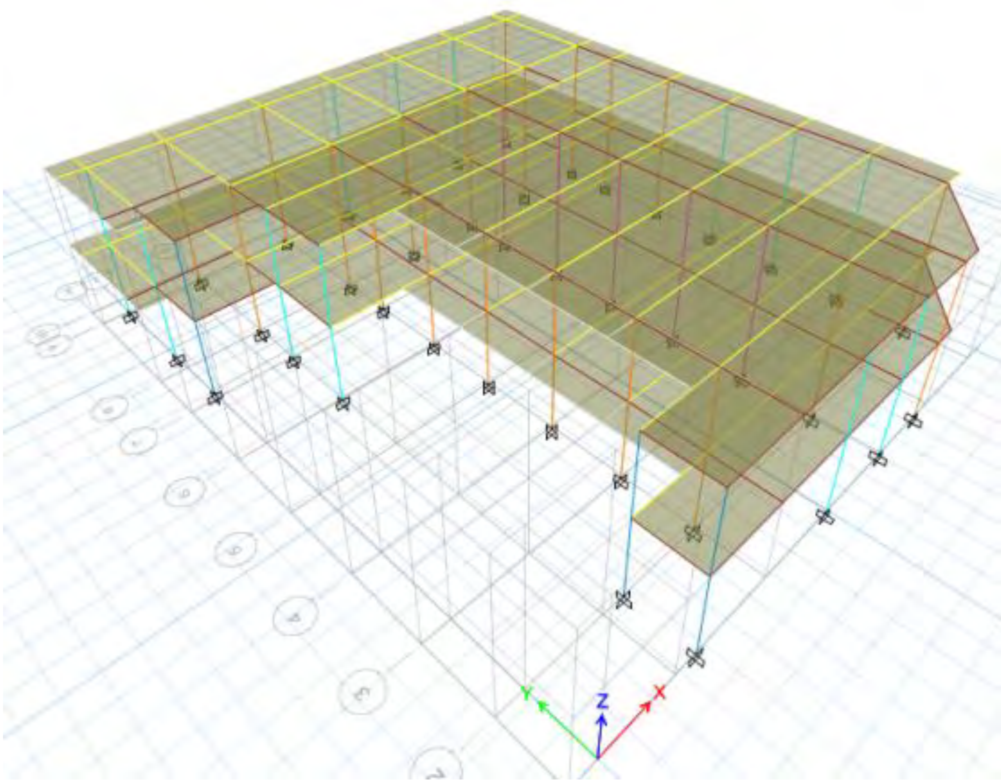



Figure 19: 3D Model of Building

## 5.8 ANALYSIS METHOD

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 probable strength calculated from conventional methods is modified with the factor k, known as the knowledge factor (for Western Regional Hospital, k is taken 0.7). The seismic demand is calculated based on NBC 105:1994 for lateral forces considering useable life factor U=1 for the Hospital buildings, as per IS 15988: 2013 for building with critical safety. Under this process a building analysis is performed, the evaluation requirements are based on linear response spectrum analysis.

Two configurations are analyzed: 1) the bare frame and 2) the infilled frame, in order to examine the variation of storey stiffness and strength. For the modeling of the infill panels, Equivalent Diagonal Strut Method is used as per IS 1893: 2016.

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 RESULTS AND DISCUSSION

The analysis results are discussed in this section. In this assessment, seismic demand is based on NBC 105 (1994) while the configuration and strengthen related checks for seismic assessment are based on IS 15988 (2013) because of lack of seismic evaluation standards in Nepal codes.

It focuses on the seismic demand, modal mass participation, inter storey drift, pounding, soft storey, torsional and mass irregularity and other configuration and strength related checks specified in IS 15988 (2013).The structural member capacity is checked for limit state load combination for earthquake loading with their respective seismic demand. The results of the CT Scan building are presented and discussed in the following section as a sample example. The results and discussion of other building are presented in Annex

### 5.9.1 SEISMIC DEMAND

**A) Seismic Coefficient Method:**

The seismic demand of the building is calculated as per NBC 105:1994. 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 kN | Base Shear kN |
|---|---|---|---|---|---|
| EQX | Seismic | X | 0.24 | 13122.496 | 3149.398 |
| EQY | Seismic | Y | 0.24 | 13122.496 | 3149.398 |

**B) Response spectrum Method:**

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

For the initial run following scale factor was used

$$ZIK = 1.5 * 2 * 1 \approx 3.0$$

Base shear from this scale factor is computed as:

In global X direction, base shear = $V_B$ = 296.83 kN

In global Y direction, base shear = $V_B$ = 271.90 kN

Which are less than base shear ($V_b$) from seismic coefficient method and thus, need to be modified as per NBC 105:1994, clause 11.3, the modification factor being:

In global X direction:

$$\frac{V_b}{V_B} = \frac{3149.398}{296.83} = 9.5491$$

In global Y direction:

$$\frac{V_b}{V_B} = \frac{3149.398}{271.90} = 10.4246$$

Hence, the modified scale factors to be used are:

RSx = 3.00 x9.5491= 28.647

RSy = 3.00 x 10.4246= 31.273

Thus, modified base shear from response spectrum method are:

In global X direction = 2833.740 KN

In global Y direction = 2834.180 KN

### 5.9.2 MODAL TIME PERIOD AND MASS PARTICIPATION

NBC 105:1994 Clause 11.2 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 10 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 sec | $U_X$ | $U_Y$ | Sum $U_X$ | Sum $U_Y$ |
|---|---|---|---|---|---|---|
| Modal | 1 | 0.553 | 0.00000699 | 0.9329 | 7E-06 | 0.9329 |
| Modal | 2 | 0.47 | 0.0283 | 0.0009 | 0.0283 | 0.9338 |
| Modal | 3 | 0.458 | 0.8943 | 0.000006575 | 0.9226 | 0.9338 |
| Modal | 4 | 0.212 | 1.027E-06 | 0.066 | 0.9226 | 0.9998 |
| Modal | 5 | 0.181 | 0.0129 | 0.00001369 | 0.9355 | 0.9998 |
| Modal | 6 | 0.169 | 0.0637 | 0.000004024 | 0.9992 | 0.9998 |
| Modal | 7 | 0.118 | 0.0001 | 0 | 0.9993 | 0.9998 |
| Modal | 8 | 0.113 | 0 | 0.000003852 | 0.9993 | 0.9998 |
| Modal | 9 | 0.106 | 0.00002913 | 0 | 0.9994 | 0.9998 |
| Modal | 10 | 0.104 | 6.102E-07 | 0.000005136 | 0.9994 | 0.9998 |

### 5.9.3 STOREY DISPLACEMENT AND DRIFT

From the analysis the displacements of the mass centre of various floors are obtained and are shown in Table 18: Storey Drift CalculationsTable 18 along with storey drift.

Table 18: Storey Drift Calculations

| Storey | Elevation m | Storey Displacement (mm) | | Storey drift (%) | |
|---|---|---|---|---|---|
| | | X Dir'n | Y Dir'n | X Dir'n | Y Dir'n |
| Storey2 | 7.0 | 15.600 | 22.544 | 0.185 | 0.265 |
| Storey1 | 3.5 | 9.118 | 13.275 | 0.261 | 0.379 |

| Storey | Elevation m | Storey Displacement (mm) | | Storey drift (%) | |
|---|---|---|---|---|---|
| | | X Dir'n | Y Dir'n | X Dir'n | Y Dir'n |
| Storey2 | 7.0 | 15.600 | 22.544 | 0.185 | 0.265 |
| Base | 0.0 | 0.000 | 0.000 | 0.000 | 0.000 |

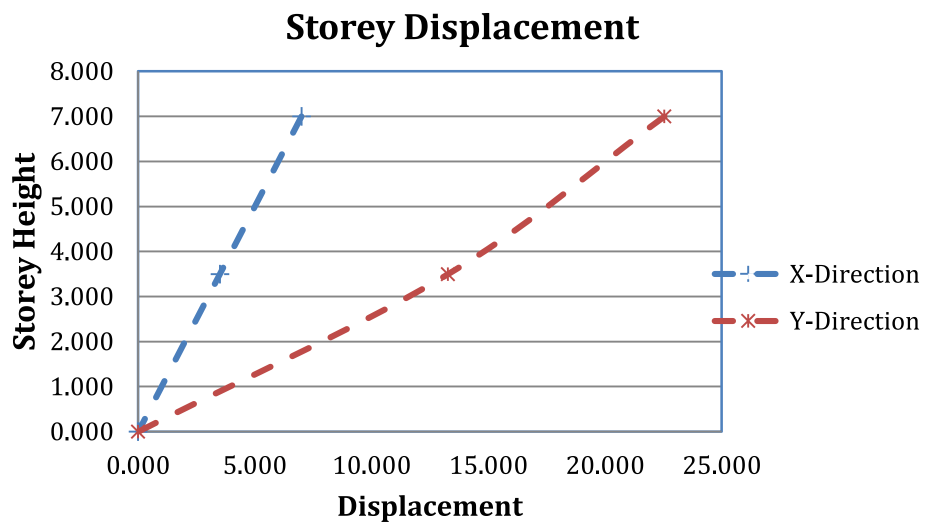



Figure 20: Storey Displacement Check

From the above results, it shows that storey drift does not exceed the code prescribed value of 0.01 times story height. Thus the drift check comply with the safety value mentioned in the code. (Cl. no. 9.3 of NBC 105:1994),

The ultimate deflections of building for lateral load are calculated as per NBC 105 by multiplying elastic deflection by factor 5/ K = 2.5

Where, K = structural performance factor = 2

The ultimate deflections for different blocks are presented in Table 19 below.

Table 19: Ultimate Deflection

| Story | Elevation (m) | Displacement (mm) | |
|---|---|---|---|
| | | X-Dir | Y-Dir |
| Storey2 | 7.0 | 39.00 | 56.35 |
| Storey1 | 3.5 | 22.795 | 33.1875 |
| Base | 0.0 | 0.000 | 0.000 |

### 5.9.4 CHECK FOR ADJACENT BUILDINGS

The seismic gap required between CT scan and ENT blocks is shown in Table 20 below.

Table 20: Requirement of Seismic Gap

| Storey | Elevation (m) | Displacement (mm) | | Check Criteria | |
|---|---|---|---|---|---|
| | | CT Scan | ENT | 0.004hi | |
| Storey2 | 7.24 | 56.35 | 135.105 | 0.004*7240 =28.96 mm | 50mm |
| Gap Required = | | 56.35+135.105 = 191.455 mm | | | |

As per Cl. no. 9.2.2 of NBC 105:1994, parts of the buildings or buildings on the same site which are not designed to act as an integral unit shall be separated from each other by a distance of not less than the sum of the design lateral deformations or 0.004hi or 50mm whichever is the greater.

The seismic gap required between CT scan and ENT blocks is 191.455mm and existing gap between two blocks is less than 25mm.Thus the building separation check does not comply with the safety value mentioned in the code.

Table 21: Requirement of Seismic Gap

| Story | Elevation hi (mm) | Displacement (mm) | | Check Criteria | |
|---|---|---|---|---|---|
| | | CT Scan | Pediatric | 0.004hi | |
| Storey2 | 7240 | 56.35 | 8.54 | 0.004*7240 =28.96 mm | 50mm |
| Gap Required = | | 56.35+8.54 = 64.89 mm | | | |

The seismic gap required between CT scan and Pediatric blocks is 64.89 mm and existing gap between two blocks is 100mm.Thus the building separation check seems to comply with the safety value mentioned in the code.

### 5.9.5 CHECK FOR TORSIONAL IRREGULARITY

The torsional irregularity check is presented in Table 22 below which complies with the codal provision.

Table 22: Torsional Irregularity Check

| Storey | Load Case | Direction | Computed Storey drift | | Ratio |
|---|---|---|---|---|---|
| | | | Maximum | Average | |
| Storey 2 | EQX | X | 16.25 | 16.13 | 1.01 |
| Storey 1 | EQX | X | 9.47 | 9.11 | 1.04 |
| Storey 2 | EQY | Y | 23.46 | 22.91 | 1.02 |
| Storey 1 | EQY | Y | 13.82 | 13.58 | 1.02 |

From the above table, it shows that the maximum storey displacement, 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. Thus the building does not exist torsional irregularity as per IS 1893 (part I):2002.

### 5.9.6 SOFT STOREY

The soft storey check is presented in Table 23 and Table 24 below.

Table 23: Soft Storey Check for X-Direction

| Storey | Load | Storey Force (kN) | Displacement (mm) | Stiffness kN/m | % difference compare to | Check (70% limit) |
|---|---|---|---|---|---|---|
| Storey 2 | RSx | 1520.70 | 16.254 | 93558 | - | OK |
| Storey 1 | RSx | 1431.86 | 9.501 | 150707 | 161.084 | OK |

Table 24: Soft Storey Check for Y-Direction

| Storey | Load | Storey Force (kN) | Displacement (mm) | Stiffness kN/m | % difference compare to above storey | Check (70% limit) |
|---|---|---|---|---|---|---|
| Storey 2 | RSy | 1493.05 | 23.512 | 63502 | - | OK |
| Storey 1 | RSy | 1459.51 | 13.842 | 105441 | 166.044 | OK |

From the above tables, it shows that is the lateral stiffness is less than 70% of that in the storey above. Thus, as per IS 1893:2002 part I, the building does not have soft storey.

### 5.9.7 MASS IRREGULARITY

The mass irregularity check is presented in below.

Table 25: Mass irregularity Check

| Storey | Mass kg | % difference compare to | |
|---|---|---|---|
| | | Above storey | Below storey |
| Storey 1 | 843968.76 | 70.791 | - |
| Storey 2 | 494153.39 | - | 41.449 |

From the above table, it shows that there is no change in effective mass more than 100 percent from one storey to the next. Thus the building does not have any mass irregularity as per IS 15988:2013.

### 5.9.8 STRENGTH RELATED CHECKS

As per IS 15988:2013, the following strength related checks are computed

**I. Shear Stress in RC Frame Columns:**

The average shear stress in concrete columns

along X–direction = 0.568 Mpa, and

along Y-direction = 0.503 Mpa.

Thus, the computed value shear stresses are more than, a) 0.4Mpa and b) 0.1√fck, fck =0.387 Mpa

**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 are

0.010 Mpa along X-direction, and

0.015 Mpa along Y-direction.

These values are less than 0.25fck as specified in IS 15988:2013.

### 5.9.9 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 member 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 Figure 21 and Figure 22 below.

Table 26: Column PMM Envelope Check

| GRID | Floor | Location | | Size | Reinforcement | PMM ratio | Check |
|---|---|---|---|---|---|---|---|
| A8 | Ground | Bottom | | 350X450 | 4-20+4-16 | 1.96 | FAIL |
| | First | Bottom | | | | 1.627 | FAIL |
| A9 | Ground | Bottom | | 350X450 | | 1.944 | FAIL |
| | First | Bottom | | | | 1.295 | FAIL |
| B6 | Ground | Bottom | | 350X450 | | 1.803 | FAIL |
| | First | Bottom | | | | **0.999** | **PASS** |
| B7 | Ground | Bottom | | 350X450 | | 1.927 | FAIL |
| | First | Bottom | | | | 1.463 | FAIL |
| D1 | Ground | Bottom | | 350X450 | | 1.641 | FAIL |
| | First | Bottom | | | | **0.805** | **PASS** |
| D9 | Ground | Bottom | | 350X450 | | 1.821 | FAIL |
| | First | Bottom | | | | 1.397 | FAIL |
| E1 | Ground | Bottom | | 350X450 | | 1.983 | FAIL |
| | First | Bottom | | | | **0.921** | **PASS** |
| E9 | Ground | Bottom | | 350X450 | | 1.821 | FAIL |
| | First | Bottom | | | | 1.391 | FAIL |
| F9 | Ground | Bottom | | 350X450 | | 1.82 | FAIL |
| | First | Bottom | | | | 1.388 | FAIL |
| G3 | Ground | Bottom | | 350X450 | | 1.922 | FAIL |
| | First | Bottom | | | | 1.545 | FAIL |
| G4 | Ground | Bottom | | 350X450 | | 1.89 | FAIL |
| | First | Bottom | | | | 1.484 | FAIL |
| G5 | Ground | Bottom | | 350X450 | | 1.894 | FAIL |
| | First | Bottom | | | | 1.575 | FAIL |

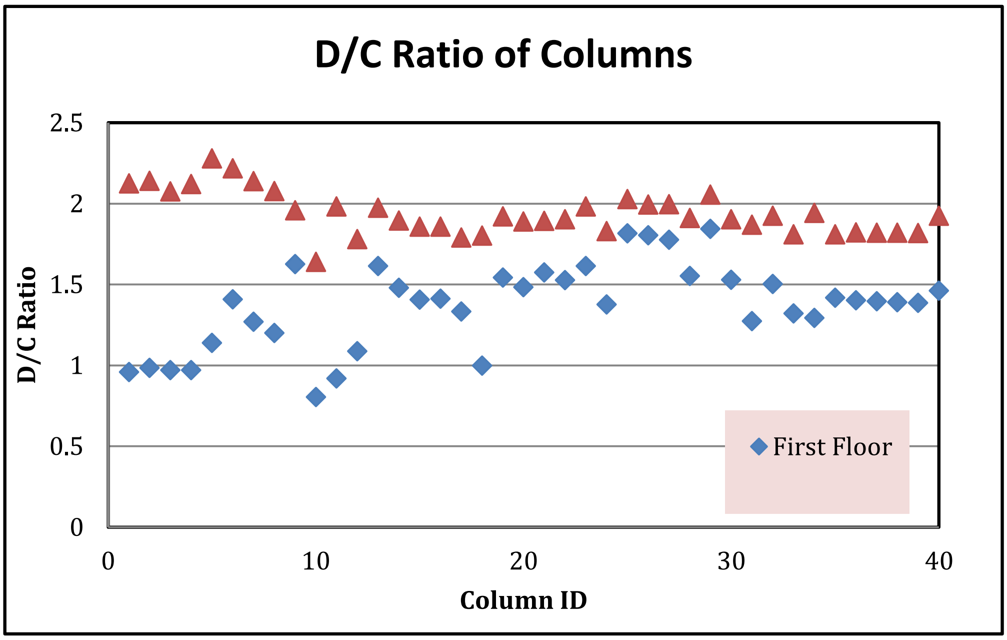



Figure 21: Demand Capacity Ratio of Structural Member (Column)

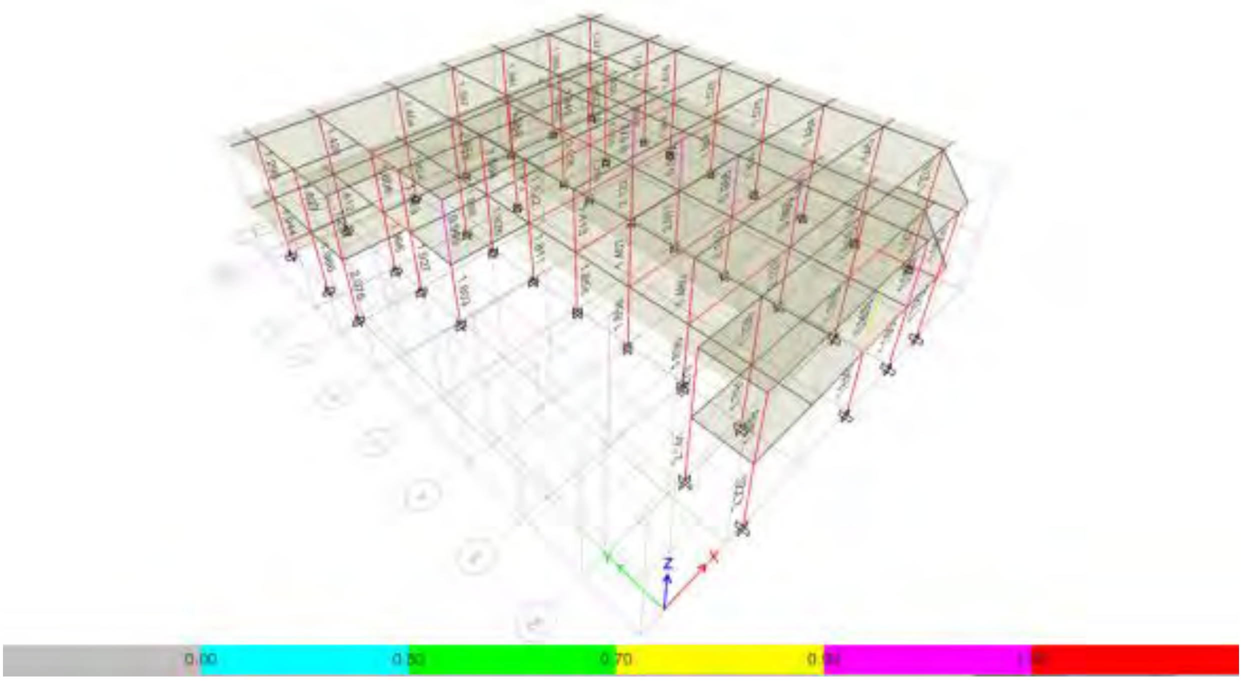


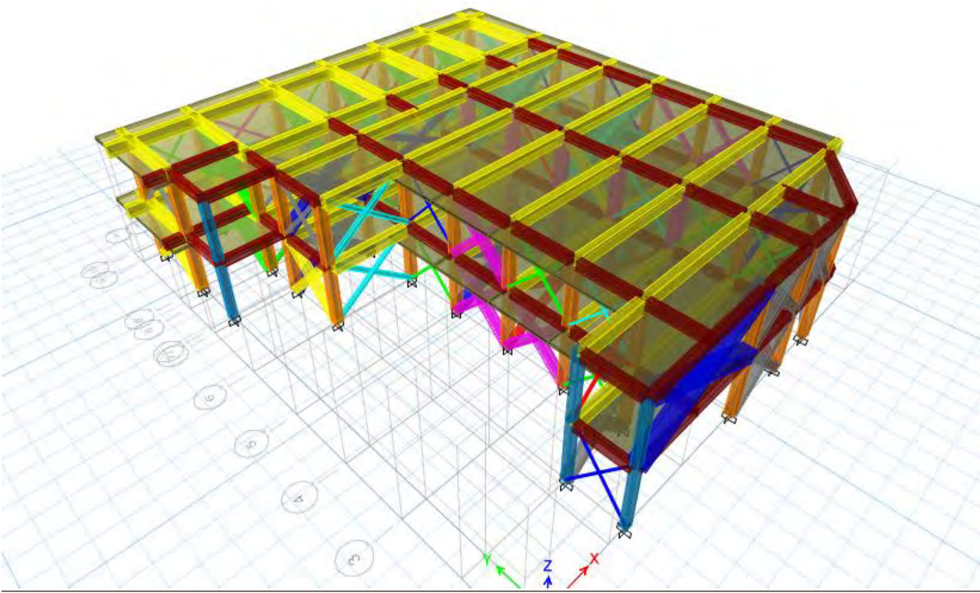
Figure 22: Demand Capacity Ratio of Structural Member (Column)

## 5.10 EQUIVALENT DIAGONAL STRUT METHOD:

The Equivalent Diagonal Strut Method is the most accepted method for the analysis of in-filled frame structure. In this method, beams and column are designed as frame members which are having six DOF at every node and the entire infill is replaced by a pin joined equivalent diagonal compressive strut. The tensile strength of the equivalent strut is neglected.

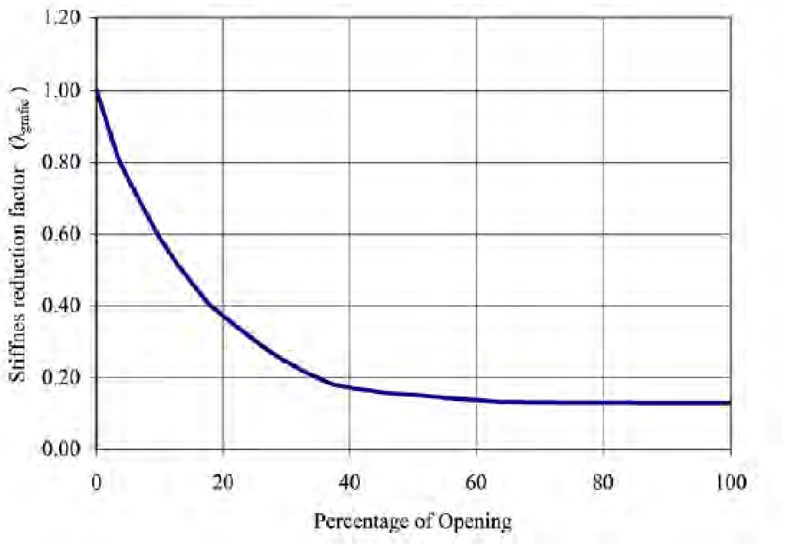
The stiffness and strength of the equivalent diagonal compressive strut is determined using the recommendation given in FEMA 306. The thickness of the struts is considered to be same as actual infill wall and its length is equal to the length of the diagonal between the two compressive corners. Width of the strut is calculated by the equation specified in IS 1893 (part 1) 2016.

$$w_{ds} = 0 \cdot 175(\alpha_h)^{-0.4} L_{ds}$$




Under lateral in-plane loading, lateral stiffness of the infilled frame with opening depends on the size and position of the openings. The equivalent width of the diagonal compressive struts is reduced by a coefficient in the modeling of the infilled wall with opening. This stiffness reduction coefficient depends on the percentage of the opening. The coefficient is determined from the following Graph recommended by Asteris PG (2003). Thus the effective width of the equivalent diagonal strut for infill wall with opening is calculated by

$$w_{ds} = 0 \cdot 175\lambda_{graphic}(\alpha_h)^{-0.4} L_{ds}$$



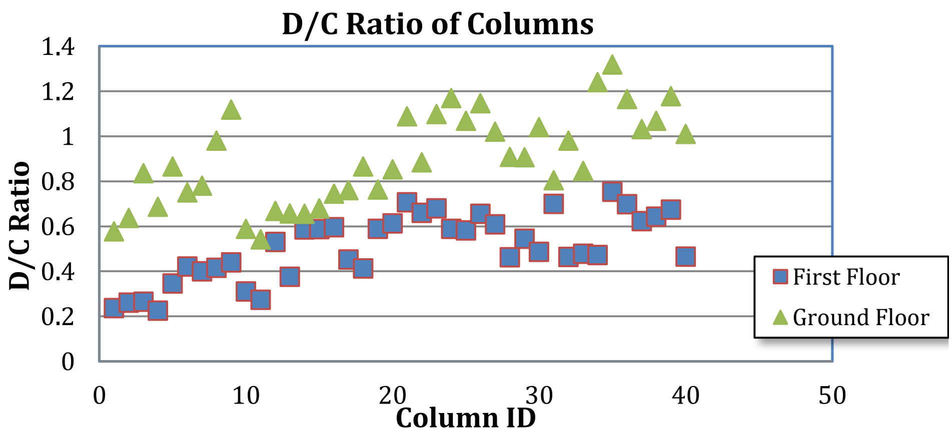

### 5.10.1 RESULT AND DISCUSSION:

#### 1) Drift Check

| Storey | Elevation m | Storey Displacement (mm) | | Storey drift (%) | |
|---|---|---|---|---|---|
| | | X Dir'n | Y Dir'n | X Dir'n | Y Dir'n |
| Storey2 | 7.000 | 9.946 | 4.923 | 0.103 | 0.063 |
| Storey1 | 3.500 | 6.338 | 2.716 | 0.181 | 0.078 |
| Base | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

From the above results, it shows that storey drift does not exceed the code prescribed value of 0.01 times story height. Thus the drift check comply with the safety value mentioned in the code. (Cl. no. 9.3 of NBC 105:1994),

#### 2) Capacity Demand Ratio Check



| GRID | Floor | Location | Size | Reinforcement | PMM ratio | Check |
|---|---|---|---|---|---|---|
| E3 | Ground | Bottom | 600X450 | 4-25+4-20 | 0.652 | Pass |
| | First | Bottom | | | 0.248 | Pass |
| E4 | Ground | Bottom | 600X450 | 4-25+4-20 | 0.677 | Pass |
| | First | Bottom | | | 0.26 | Pass |
| E5 | Ground | Bottom | 600X450 | 4-25+4-20 | 0.801 | Pass |
| | First | Bottom | | | 0.256 | Pass |
| E6 | Ground | Bottom | 600X450 | 4-25+4-20 | 0.758 | Pass |
| | First | Bottom | | | 0.236 | Pass |
| E7 | Ground | Bottom | 600X450 | 4-25+4-20 | 0.882 | Pass |
| | First | Bottom | | | 0.341 | Pass |
| B'1 | Ground | Bottom | 350X300 | 4-16+4-12 | 0.693 | Pass |
| | First | Bottom | | | 0.473 | Pass |
| B'2 | Ground | Bottom | 350X300 | 4-16+4-12 | 0.79 | Pass |
| | First | Bottom | | | 0.434 | Pass |
| A7 | Ground | Bottom | 350X300 | 4-16+4-12 | 1.003 | **Fail** |
| | First | Bottom | | | 0.422 | Pass |
| A8 | Ground | Bottom | 350X450 | 4-20+4-16 | 1.103 | **Fail** |
| | First | Bottom | | | 0.493 | Pass |
| D1 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.577 | Pass |
| | First | Bottom | | | 0.319 | Pass |
| E1 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.558 | Pass |
| | First | Bottom | | | 0.297 | Pass |
| F1 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.647 | Pass |
| | First | Bottom | | | 0.514 | Pass |
| E2 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.745 | Pass |
| | First | Bottom | | | 0.417 | Pass |
| C3 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.71 | Pass |
| | First | Bottom | | | 0.621 | Pass |
| C4 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.747 | Pass |
| | First | Bottom | | | 0.589 | Pass |
| C5 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.795 | Pass |
| | First | Bottom | | | 0.597 | Pass |
| C2 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.786 | Pass |
| | First | Bottom | | | 0.483 | Pass |

| | | | | | | |
|---|---|---|---|---|---|---|
| B6 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.929 | Pass |
| | First | Bottom | | | 0.456 | Pass |
| G3 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.792 | Pass |
| | First | Bottom | | | 0.606 | Pass |
| G4 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.854 | Pass |
| | First | Bottom | | | 0.633 | Pass |
| G5 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.999 | Pass |
| | First | Bottom | | | 0.747 | Pass |
| G6 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.921 | Pass |
| | First | Bottom | | | 0.673 | Pass |
| G7 | Ground | Bottom | 350X450 | 4-20+4-16 | 1.032 | **Fail** |
| | First | Bottom | | | 0.679 | Pass |
| G9 | Ground | Bottom | 350X450 | 4-20+4-16 | 1.15 | **Fail** |
| | First | Bottom | | | 0.603 | Pass |
| G8 | Ground | Bottom | 350X450 | 4-20+4-16 | 1.062 | **Fail** |
| | First | Bottom | | | 0.598 | Pass |
| B8 | Ground | Bottom | 350X450 | 4-20+4-16 | 1.119 | **Fail** |
| | First | Bottom | | | 0.694 | Pass |
| C8 | Ground | Bottom | 350X450 | 4-20+4-16 | 1.019 | **Fail** |
| | First | Bottom | | | 0.65 | Pass |
| D8 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.934 | Pass |
| | First | Bottom | | | 0.485 | Pass |
| E8 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.922 | Pass |
| | First | Bottom | | | 0.583 | Pass |
| F8 | Ground | Bottom | 350X450 | 4-20+4-16 | 1.03 | **Fail** |
| | First | Bottom | | | 0.53 | Pass |
| G2 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.835 | Pass |
| | First | Bottom | | | 0.696 | Pass |
| C7 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.971 | Pass |
| | First | Bottom | | | 0.512 | Pass |
| C6 | Ground | Bottom | 350X450 | 4-20+4-16 | 0.932 | Pass |
| | First | Bottom | | | 0.532 | Pass |
| A9 | Ground | Bottom | 350X450 | 4-20+4-16 | 1.224 | **Fail** |
| | First | Bottom | | | 0.498 | Pass |
| B9 | Ground | Bottom | 350X450 | 4-20+4-16 | 1.251 | **Fail** |
| | First | Bottom | | | 0.801 | Pass |

| | | | | | | |
|---|---|---|---|---|---|---|
| C9 | Ground | Bottom | 350X450 | 4-20+4-16 | 1.136 | **Fail** |
| | First | Bottom | | | 0.731 | Pass |
| D9 | Ground | Bottom | 350X450 | 4-20+4-16 | 1.04 | **Fail** |
| | First | Bottom | | | 0.66 | Pass |
| E9 | Ground | Bottom | 350X450 | 4-20+4-16 | 1.055 | **Fail** |
| | First | Bottom | | | 0.667 | Pass |
| F9 | Ground | Bottom | 350X450 | 4-20+4-16 | 1.134 | **Fail** |
| | First | Bottom | | | 0.7 | Pass |
| B7 | Ground | Bottom | 350X450 | 4-20+4-16 | 1.016 | **Fail** |
| | First | Bottom | | | 0.5 | Pass |

**Check for Seismic Gap between ENT Block and CT Scan Block**

The calculation of seismic gap required between CT scan and ENT blocks is presented in the following table. The calculations of displacement of ENT block are presented in the Annex.

| Description | CT Scan | ENT |
|---|---|---|
| Total linear Displacement | 4.923 mm | 7.971 mm |
| K | 2 | |
| Gap required (ultimate displacement ) : | (4.923+7.971)*5/2= 32.235 mm | |

The seismic gap required between CT scan and ENT blocks is 32.235 mm as per NBC 105 and existing gap between two blocks is about 25mm.Thus, the seismic gap required between adjacent block is found insufficient.

## 5.11 FINDINGS AND RECOMMENDATIONS

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

- The building complies with codal requirement for storey drift. But the seismic gap required between adjacent block is found insufficient. So, there is possibility of seismic pounding.
- The buildings do not have torsional irregularity, soft storey, mass irregularity, and eccentricity.
- The structural column members are not found safe for earthquake loading as per present relevant NBC and Indian Standard Codes.
- It is recommended that retrofitting solutions are required to strengthen the building addressing the above mentioned deficiencies as well as to upgrade the performance of the buildings reducing seismic risk

# 6 RETROFIT DESIGN FOR RC FRAME BUILDING

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 building.

- Addition of shear wall to improve lateral stiffness of building.
- Steel bracing to improve stability of free standing parapet wall.
- Providing sufficient gap between two adjacent buildings to avoid seismic pounding.

## 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 OPTIONS

The following retrofitting options are applied in the RCC frame buildings

### 6.4.1 ADDITION OF SHEAR WALL:

Concrete RC all 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 storey 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

I. 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 27 below.

Table 27: Seismic Demand of Building after retrofit

| Load Pattern | Type | Direction | Coeff. Used | Weight Used | Base Shear |
|---|---|---|---|---|---|
| | | | | kN | kN |
| EQX | Seismic | X | 0.225 | 13920.082 | 3132.018 |
| EQY | Seismic | Y | 0.225 | 13920.082 | 3132.018 |

II. 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

$$\frac{I}{R} * \frac{g}{2} = \frac{1}{3} * \frac{9.81}{2} = 2.4525$$

Base shear from this scale factor is computed as:

In global X direction, base shear = $V_B$ = 2685.95kN

In global Y direction, base shear = $V_B$ = 2556.96kN

Which are less than base shear ($V_b$) from seismic coefficient method and thus, need to be modified as per IS 1893: 2002, clause 7.8.2, the modification factor being:

In global X direction:

$$\frac{V_b}{V_B} = \frac{3132.018}{2685.95} = 1.1661$$

In global Y direction:

$$\frac{V_b}{V_B} = \frac{3132.018}{2556.96} = 1.2249$$

Hence, the modified scale factors to be used are:

For RSx = 2.4525 x1.1661= 2.8599

For RSy = 2.4525 x 1.2249= 3.0041

Thus, modified base shear from response spectrum method are:

In global X direction = 3132.018 KN

In global Y direction = 3132.018KN

### 6.5.2 MODAL TIME PERIOD AND MASS PARTICIPATION

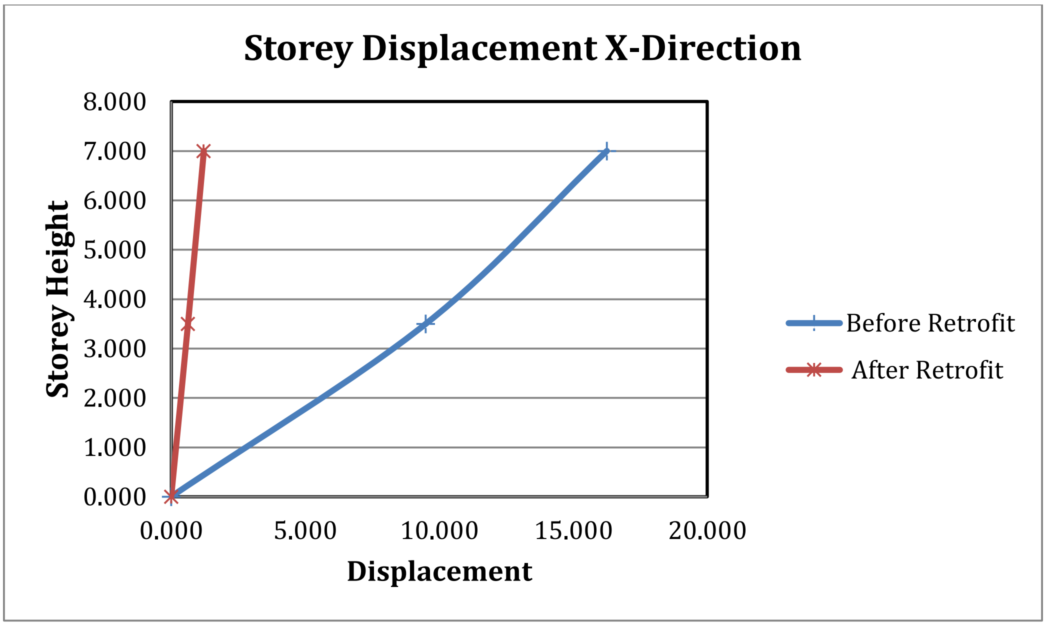
IS 1893: 2002 clause 7.8.4.2 states that number of modes to be used in the analysis should be such that the sum total of modal masses of all modes considered is at least 90 percent of the total seismic mass of the structure. Analysis was carried out for first 90 modes so that the mass participation satisfies this criterion in both orthogonal directions. Table 28 shows time period and mass participation ratio for all modes.

Table 28: Modal time period and mass participation after retrofit

| Case | Mode | Period | UX | UY | Sum UX | Sum UY |
|---|---|---|---|---|---|---|
| | | sec | | | | |
| Modal | 1 | 0.125 | 0.8561 | 0.0001 | 0.8561 | 0.0001 |
| Modal | 2 | 0.116 | 0.0015 | 7E-06 | 0.8576 | 0.0001 |
| Modal | 3 | 0.11 | 0.0001 | 0.0001 | 0.8577 | 0.0001 |
| Modal | 4 | 0.105 | 0.0006 | 0.0004 | 0.8582 | 0.0005 |
| Modal | 5 | 0.102 | 4.7E-05 | 0.0024 | 0.8583 | 0.0029 |
| Modal | 6 | 0.098 | 0.0001 | 0.8157 | 0.8584 | 0.8186 |
| Modal | 7 | 0.098 | 0.0001 | 0.0009 | 0.8585 | 0.8195 |
| Modal | 8 | 0.094 | 0.0001 | 0.0015 | 0.8586 | 0.821 |
| Modal | 9 | 0.092 | 0 | 0.0042 | 0.8586 | 0.8252 |
| Modal | 10 | 0.087 | 0.0001 | 0.0011 | 0.8587 | 0.8263 |
| ….. | …. | ….. | | | | |
| Modal | 87 | 0.035 | 4.3E-05 | 0.0017 | 0.9879 | 0.979 |
| Modal | 88 | 0.035 | 1.3E-05 | 0.0023 | 0.9879 | 0.9813 |
| Modal | 89 | 0.035 | 4.2E-05 | 0.0001 | 0.9879 | 0.9814 |
| Modal | 90 | 0.034 | 3.9E-06 | 7.3E-06 | 0.988 | 0.9814 |

### 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 partial load factor of 1.0, shall not exceed 0.004 times the storey height. In this building the storey drift is limited to 14.0 mm. From the analysis the displacements of the mass centre of various floors are obtained and are shown in Table 29 along with storey drift.



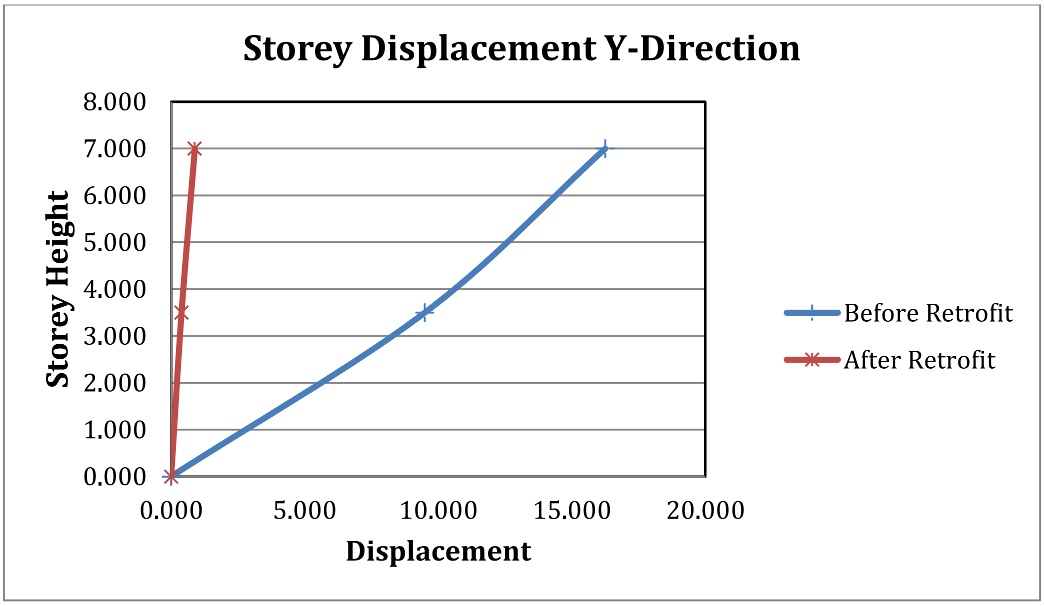




Figure 23: Storey Displacement Comparison

Table 29: Storey Drift Calculations after retrofit

| Storey | Elevation | Storey Displacement (mm) | | Storey drift (%) | |
|---|---|---|---|---|---|
| | m | X Dir'n | Y Dir'n | X Dir'n | Y Dir'n |
| Storey2 | 7.000 | 1.212 | 0.881 | 0.017 | 0.014 |
| Storey1 | 3.500 | 0.624 | 0.387 | 0.018 | 0.011 |
| 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 storey height (i.e. permissible storey displacement is 14.00 mm). Thus the drift check seems to comply with the safety value mentioned in the code.

### 6.5.4 CHECK FOR ADJACENT BUILDINGS

As per IS 1893:2002 part I, Cl, 7.11.3, torsional two adjacent buildings or two adjacent units of the same building with separation joint in between shall be separated by a distance equal to the amount R times the sum of the calculated storey displacements as per IS 1893:2002(Part I) cl.7.11.1 of each of them, to avoid damaging contact when the two units deflect towards each other. When floor levels of two similar adjacent units or buildings are at the same elevation levels, factor R in this requirement may be replaced by R/2.

The seismic gap required between CT scan and ENT blocks is shown in Table 30below.

Table 30: Requirement of Seismic Gap after retrofit

| | CT Scan | ENT |
|---|---|---|
| Total Displacement | 0.88mm | 1.00mm |
| Response reduction Factor (R) | 3 | |
| Gap required: | (0.880+1.00)*3/2 = 2.82 mm | |

The seismic gap required between CT scan and ENT blocks is 50mm and existing gap between two blocks is less than 25mm.Thus the building separation check seems to comply with the safety value mentioned in the code.

### 6.5.5 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 31 below which complies with the codal provision.

Table 31: Torsional Irregularity Check after retrofit

| Storey | Load Case | Direction | Maximum mm | Average mm | Ratio |
|---|---|---|---|---|---|
| Storey 2 | EQX | X | 0.806 | 0.694 | 1.161 |
| Storey 1 | EQX | X | 0.675 | 0.649 | 1.039 |
| Storey 2 | EQY | Y | 0.497 | 0.481 | 1.034 |
| Storey 1 | EQY | Y | 0.387 | 0.382 | 1.011 |

### 6.5.6 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 Figure 24 and Figure 25 below.

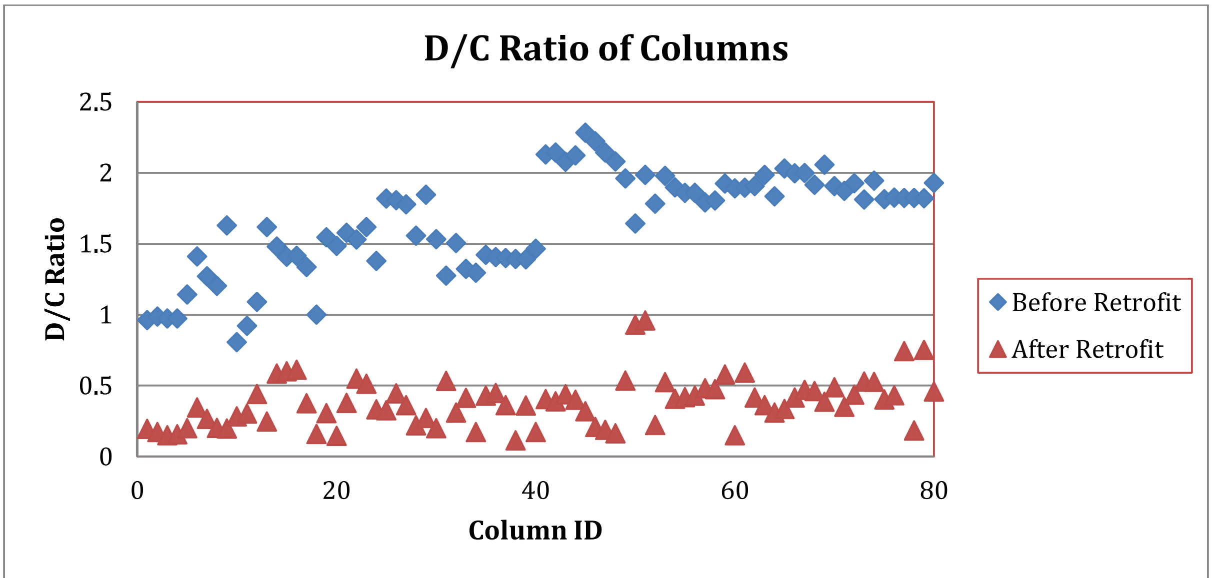



Figure 24: Demand Capacity Ratio of Structural Member (Column) after Retrofit

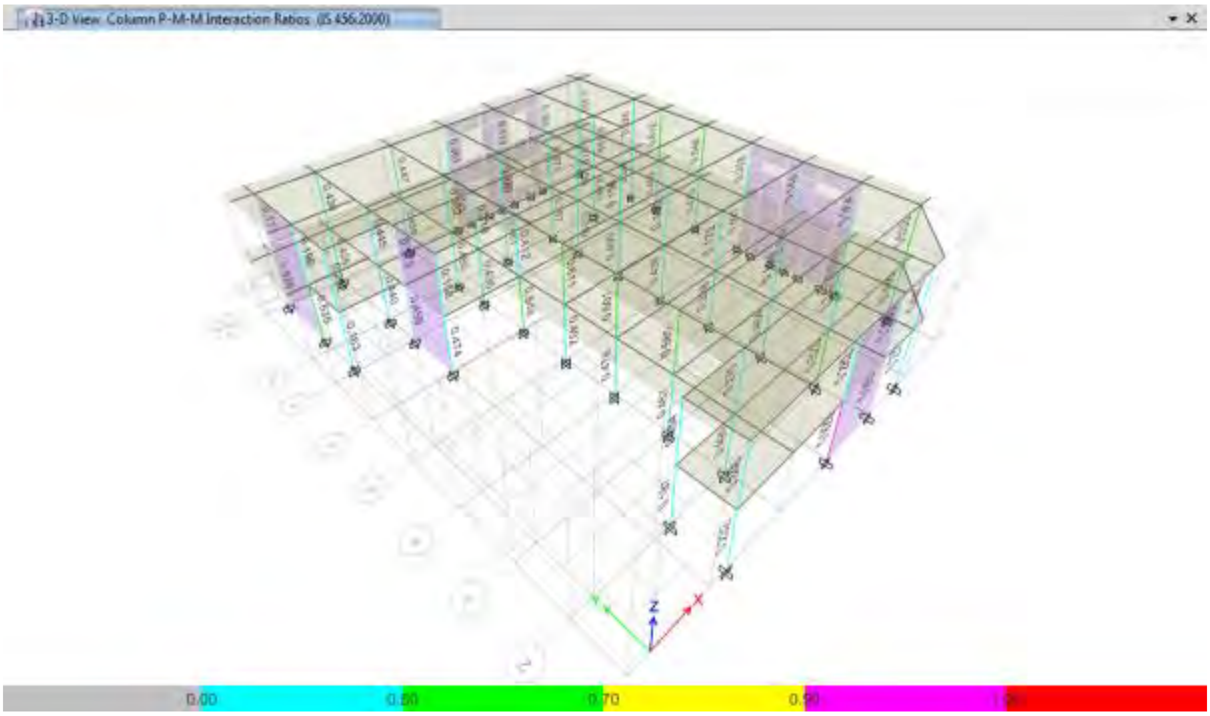



Figure 25: Demand Capacity Ratio of Structural Member (Column) after retrofit

## 6.6 DESIGN OF SHEAR WALL

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

1.0 Given Data:

| | | | |
|---|---|---|---|
| Axial Force | ($P_u$) | 955.440 | kN |
| Shear Force | ($V_u$) | 110.860 | kN |
| Moment | ($M_u$) | 789.170 | kN-m |

2.0 Material Constant:

| | | | |
|---|---|---|---|
| Grade of Concrete | (M) | 25 | Mpa |
| Grade of Steel | (Fe) | 415 | Mpa |
| Elastic Modulus of Steel | ($E_s$) | 200000 | Mpa |

3.0 Preliminary Dimension

| | | | |
|---|---|---|---|
| Length of Wall | ($l_w$) | 3370 | mm |
| Thickness of Wall | ($t_w$) | 300 | mm |
| Height of Wall | ($h_w$) | 3500 | mm |

Check for thickness as Per IS 13920:1993 Cl 9.1.2

| | | |
|---|---|---|
| > | 150 | mm |

Ok

Effective Depth of Wall Section ($d_w$) $0.8*l_w$

2696 mm

4.0 Vertical Reinforcement:

Axial Force ($P_u$) 955.44 kN

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

Area of Reinforcement Required ($A_{st}$) 785 mm²/m

Provided ($A_{st}$) 12 mm ϕ @ 150 c/c spacing

no of layers (n) 2

Provided ($A_{st}$) 1508 mm²/m

Ok

($P_t$) 0.503 %

Minimum reinforcement ratio As per IS13920 Cl. 9.1.4

$(P_t)$min 0.25 %

Ok

5.0 Horizontal Reinforcement:

Factored Shear Force ($V_u$) 110.860 kN

As per IS 13920:1993 Cl. 9.2.1

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

($\tau_v$) 0.138 N/mm²

($P_t$) 0.503 %

From IS 456 Table 19

($\beta$) 5.775

Maximum Shear Strength of Concrete ($\tau_{c,max}$) 3.1 N/mm²

($\tau_v$) < ($\tau_{c,max}$)

Section Ok

Design Shear Strength of Concrete ($\tau_c$) 0.49 N/mm²

($\tau_v$) < ($\tau_c$)

Design for Shear Reinforcement

Excess Shear Force ($V_{us}$) 0.000 kN

Shear Reinforcement Required ($A_{us}$) 0 mm²/m

Horizontal Reinforcement Required ($A_{st}$) 750 mm²/m

Provide ($A_{st}$) 10 mm ϕ @ 150 c/c spacing

No of layers (n) 2

Provided ($A_{st}$) 1047 mm²/m

Ok

6.0 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 0.005

$$\Phi = \frac{0.87 f_y \rho}{f_{ck}}$$ ϕ 0.073

$$\beta = \frac{0.87 f_y}{0.0035 E_s}$$ β 0.516

$$\lambda = \frac{P_u}{f_{ck} t_w l_w}$$ λ 0.0378

$$\frac{x_u}{l_w} = \frac{\phi + \lambda}{2\phi + 0.36}$$ $x_u / l_w =$ 0.219

$$\frac{x_u^*}{l_w} = \frac{1}{(1+\beta)}$$ $x_u^* / l_w =$ 0.660

$x_u / l_w$ < $x_u^* / l_w$

Case I : When $(x_u / l_w) < (x_u^* / l_w)$

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

$M_{uv}$ 2413 kN-m

$M_u$ < $M_{uv}$

Section Safe in Flexure

7.0 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 provid along the vertical boundaries of the walls.

| | | | |
|---|---|---|---|
| Area of Cross section | $A_g$ | 1011000 | $mm^2$ |
| Moment of Inertia of the section | $I_y$ | 9.57E+11 | $mm^4$ |
| Extreme fiber compressive stress | $f_c$ | 2.335 | $N/mm^2$ |
| | $0.2f_{ck}$ | 5.000 | $N/mm^2$ |

No Boundary Element Required

## 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.

- Addition of 300 mm thick Concrete shear wall at grid location 1 (D-E), 9 (D-F) A (8'-9), B (6-7) and G (3-5) (Refer drawing for location of shear walls)
- Concrete jacketing of existing columns at ends of newly added shear walls.
- Protection of nonstructural elements by proper connection and anchoring

# Masonry Buildings

# 7 DETAILED SEISMIC ASSESSMENT FOR MASONRY BUILDING

## 7.1 BACKGROUND

The detail seismic assessment is performed to determine the probable strength of the lateral load resisting system and compare with expected seismic demand on the members. To understand the geology and engineering properties of existing soil at the specific locations of the buildings located at WRH, geotechnical investigation is carried out. Likewise, with an evaluation for material strength and condition for building material, material testing is conducted at desired locations. Also numerical modeling is done to estimate the probable flexure and shear demand capacity ratio of the structural elements calculated as per IS 1905 – 1987, IS 15988-2013. The demands to capacity ratio for critical elements like wall piers, columns, diaphragms etc. are calculated in this assessment. The process is further outlined in following sections.

The detail seismic assessment 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).

## 7.2 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 masonry buildings are 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

## 7.3 MATERIAL PARAMETER

The typologies of building structure found in hospital are load bearing stone masonry in cement mortar and reinforce concrete frame building. Some none 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. The test results adopted for further analysis are tabulated below.

Table 32: Parameter Adopted from NDT/DT Test

| S.N. | Parameter | Test Result | Adopted Value | Units | Remark |
|---|---|---|---|---|---|
| 1 | Compressive strength of cement sand mortar | 3.5 | 3.5 | Mpa | As per IS Code, M2 Mortar Grade |
| 2 | Shear Strength of Stone masonry Wall | 0.31 | 0.217 | Mpa | From test data applying knowledge factor of 0.7 as per IS Code 15988 |
| 3 | Compressive strength of concrete | 27 | 15 | Mpa | Applying knowledge factor as per IS Code 15988 |

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

Table 33: Mechanical Properties of Stone Masonry

| | | |
|---|---|---|
| Compressive Strength: | 2.5 | $N/mm^2$ |
| Permissible Tensile strength: | 0.12 | $N/mm^2$ |
| Shear Strength: | 0.31 | $N/mm^2$ |
| Knowledge Factor (K): | 0.7 | |
| Permissible shear strength: | 0.21 | $N/mm^2$ |
| Modulus of elasticity of stone masonry: | 1740 | $N/mm^2$ |
| Unit Weight: | 25 | $KN/m^3$ |
| Poisson's ratio for stone masonry: | 0.2 | |

Since, there are lacks of codes and standard for mechanical parameters of stone masonry, the mechanical parameters adopted are as per international guideline and research paper. (Reference: Guidelines for The Seismic Assessment of Stone-masonry Structures, July 2000, and Michele Betti and Luciano Galano; Seismic Analysis of Historic Masonry Buildings: The Vicarious Palace in Pescia (Italy))

Table 34: 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 | $N/mm^2$ |

## 7.4 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 13935 : 2009 Seismic Evaluation, Repair and Strengthening of Masonry Buildings – Guidelines
- Nepal Building Codes
- Guidelines for The Seismic Assessment of Stone-masonry Structures

## 7.5 LOAD AND LOAD CASES

### 7.5.1 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 $kN/m^2$.

- 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 35: Unit Weight of Materials Used

| Type | Value |
|---|---|
| Reinforced Concrete | 25 $KN/m^3$ |
| Stone Masonry | 25 $KN/m^3$ |
| Screed | 20.4 $KN/m^3$ |
| Plaster | 20.4 $KN/m^3$ |
| Mosaic Tile | 20.4 $KN/m^3$ |

### 7.5.2 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 36below.

Table 36: 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 | $KN/m^2$ |

## 7.6 SEISMIC LOAD

Static coefficient method is considered for the calculation of seismic demand for masonry structure. Seismic demand is calculated as per NBC 105 and IS 1893. The higher seismic demand between NBC and IS code is taken for further analysis.

### 7.6.1 AS PER NBC 105

To determine the seismic load, it is considered that the site lies in the seismic zone Pokhara according to NBC 105. The soil type is considered as medium with 5% damping to determine average response acceleration. The building is analyzed load bearing masonry wall. Therefore, the fundamental time period $T_a$ is obtained by using the following formula:

$$Ta = \frac{0.09h}{\sqrt{D}}$$ [Cl.7.3.b, NBC 105:1994]

Other factors considered for seismic load calculations are as follows

Zone factor, $Z$ = 1.0 for Pokhara [Fig. 8.2, C l 8.1.6, NBC 105:1994]

Importance factor, $I$ = 1.5 [Table 8.1, Cl. 8.1.7, NBC 105:1994]

Structural Performance Factor, K = 4 for Load bearing masonry [Table 8.1, Cl. 8.1.8, NBC 105:1994]

Detailed calculation is presented in Table 38 below.

### 7.6.2 AS PER IS1893:2002

To determine the seismic load, it is considered that the country lies in the seismic zone V according to IS 1893:2000. The soil type is considered as medium with 5% damping to determine average response acceleration. The building is analyzed as ordinary moment resisting frame without consideration of infill wall. Therefore the fundamental time period $T_a$is obtained by using the following formula:

$$Ta = \frac{0.09h}{\sqrt{D}}$$ [Cl.7.6.2, 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 6, Cl6.4.2, IS 1893 -2002]

Response Reduction Factor = 1.5for load bearing masonry [Table 6, Cl6.4.2, IS 1893 -2002]

Detail Calculation is presented in Table 39 below.

The seismic weight is determined based on the following load factors. [Table 6.1, Cl.6.0.0, NBC 105:1994 and/or Table 8, Cl.7.9.2, IS 1893 (Part 1):2002]

Table 37: 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 38: Design Horizontal Seismic Coefficient as per NBC-105-1994 (OPD Block II)

| | | | | |
|---|---|---|---|---|
| Seismic zone | | | Pokhara | |
| 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 | | | Load Bearing Masonry | |
| Structural performance factor | K | Cl. 8.1.8, table 8.2 | 4 | |
| Height of the building | h | | 3.77 | m |
| Dimension of the building Along X | $D_x$ | | 36.60 | m |
| Dimension of the building Along Y | $D_y$ | | 12.24 | m |
| Time period of the building along X | $T=0.09h/\sqrt{D_x}$ | Cl. 7.3 | 0.056 | sec |
| Time period of the building along Y | $T=0.09h/\sqrt{D_y}$ | Cl. 7.3 | 0.097 | sec |
| Soil type | | | Type II (Medium Soil) | |
| Basic seismic coefficient | C | Cl. 8.1.4, fig 8.1 | 0.080 | |
| Design Horizontal Seismic Coefficient along X | Cd = CZIK | Cl. 8.1.1 | 0.480 | |
| Design Horizontal Seismic Coefficient along Y | Cd = CZIK | Cl. 8.1.1 | 0.480 | |

Table 39: Design Horizontal Seismic Coefficient as per IS 1893:2002 (OPD Block II)

| | | | | |
|---|---|---|---|---|
| Seismic zone | | | V (Very Sever)-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 | | | Load Bearing Masonry | |
| Response Reduction factor | R | Cl. 6.4.2, Table 7 | 1.5 | |
| Height of the building | h | | 3.77 | m |
| Dimension of the building Along X | $D_x$ | | 36.60 | m |
| Dimension of the building Along Y | $D_y$ | | 12.24 | m |
| Time period of the building Along X | $T=0.09h/\sqrt{D_x}$ | Cl. 7.6.2 | 0.056 | sec |
| Time period of the building Along Y | $T=0.09h/\sqrt{D_y}$ | Cl. 7.6.2 | 0.097 | sec |
| Soil type | | | Type II (Medium Soil) | |
| Average response accl'n coefficient Along X | Sa/g | Cl. 6.4.2, fig 2 | 1.858 | |
| Average response accl'n coefficient Along Y | Sa/g | Cl. 6.4.2, fig 2 | 2.455 | |
| Design Horizontal Seismic Coefficient Along X | $A_{hx}= \frac{Z}{2}\frac{S_a}{g}\frac{I}{R}$ | Cl. 6.4.2 | 0.3345 | |
| Design Horizontal Seismic Coefficient Along Y | $A_{hx}= \frac{Z}{2}\frac{S_a}{g}\frac{I}{R}$ | Cl. 6.4.2 | 0.4419 | |

The seismic demand as per NBC is 0.48 and as per IS code 0.44. NBC 105 gives higher seismic demand. Hence, 0.480 Horizontal Seismic Coefficient as per NBC 105 is taken for analysis of masonry structure.

## 7.7 LOAD COMBINATIONS

Working stress method of analysis and design is adopted for the masonry buildings i.e. for T1 Typology. Load combinations for the analysis are adopted as per NBC 105: 1994.

A) Static Load Combination:

(DL + LL)

B) Seismic Load Combination:

DL +LL + EQ

0.7 DL +EQ

DL + SL + EQ

## 7.8 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 wall and RC floor 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.
- 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 hinge at plinth level. 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.

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

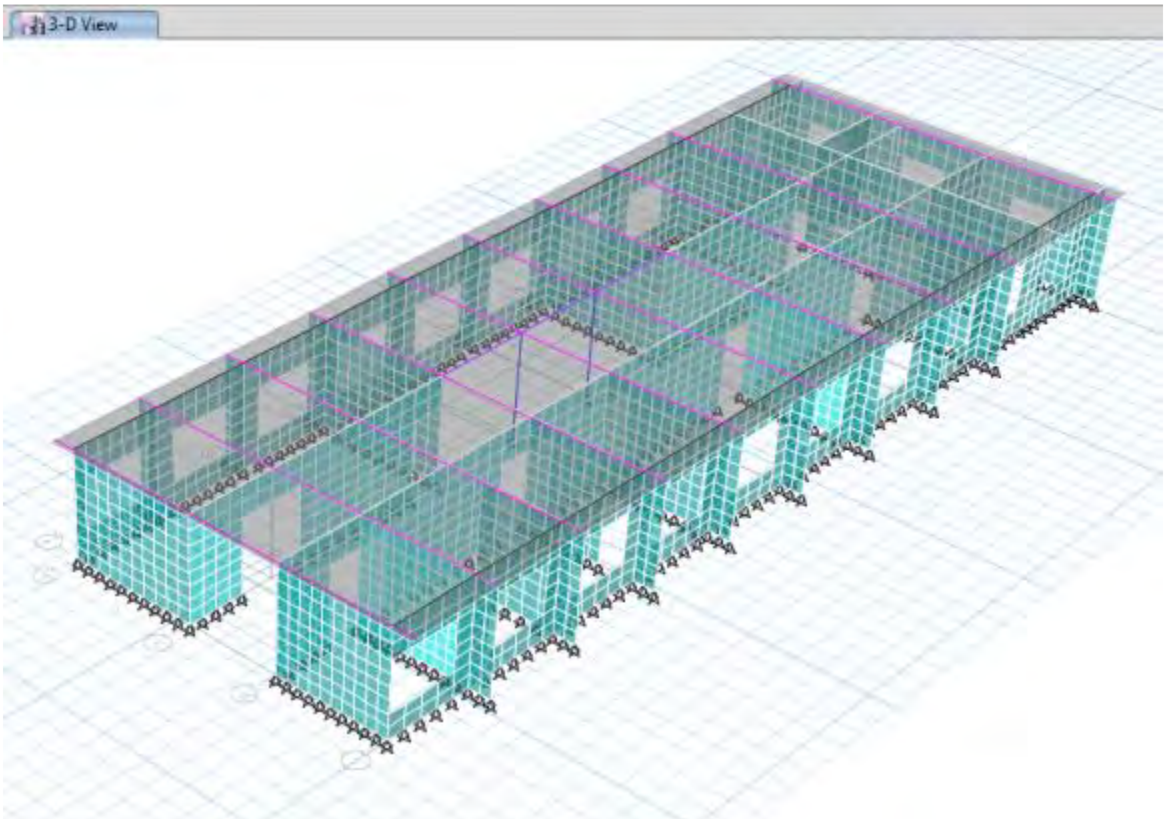



Figure 26: 3D Model of Building

## 7.9 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 probable strength calculated from conventional methods is modified with the factor k, known as the knowledge factor (for Western Regional Hospital, k is taken 0.7). The seismic demand is calculated based on IS1893 (Part 1) and NBC 105 for lateral forces utilizing the factors for reducible seismic demands. (U=1 for Western Regional 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 static analysis described on the subsequent section as per Indian standards and Nepal Building Code.

## 7.10 CHECKFOR MASONRY STRUCTURE

I. CHECK FOR SHEAR (INPLANE LOADING)

The shear wall strength shall be calculated as follows:

$$V_a = \tau_a Dt$$

Where: D = In-plane length of masonry wall (mm) t = thickness of wall (mm)

$\tau_a$ = permissible masonry shear strength (MPa)

II. IN-PLANE AND OUT OF PLANE STRESS CHECK

Efforts have been made to check the stress of existing masonry walls in both in plane and out of plane directions. The structures have been analyzed in ETABS for all the loadings and the in-plane vertical and horizontal stresses (S11 and S22) and out of plane horizontal and vertical bending stress (M11 and M22) due to the load combinations have been observed in all the critical locations against the permissible limits.

III. INTER-STOREY DRIFT

The storey 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%

## 7.11 RESULT AND DISCUSSION

The analysis results are discussed in this chapter. Simple linear elastic analysis is carried out and Static seismic coefficient method is used for earthquake loading. The major discussions are focused on the seismic demand and inter storey drift along the two orthogonal directions. The In-plane direct stresses as well as out plane bending stresses for working stress load combination for earthquake loading are checked with their respective permissible stress.

### 7.11.1 SEISMIC DEMAND

The seismic demand of the building is calculated as per NBC 105. The seismic demand of building is shown in Table 40 below.

Table 40: Seismic Demand of Building

| Load Pattern | Type | Direction | C | K | Weight Used | Base Shear |
|---|---|---|---|---|---|---|
| | | | | | kN | kN |
| EQX | Seismic | X | 0.48 | 1 | 9432.40 | 4527.55 |
| EQY | Seismic | Y | 0.48 | 1 | 9432.40 | 4527.55 |

### 7.11.2 STOREY DISPLACEMENT AND DRIFT

As per cl. no. 9.3 of NBC 105:1994, the ratio of the inter storey deflection to the corresponding storey height shall not exceed 0.010 nor shall the inter storey deflection exceed 60mm. In this building the storey drift is limited to 37.70 mm. From the analysis the displacements of the mass centre of various floors are obtained and are shown in Table 41 along with storey drift.

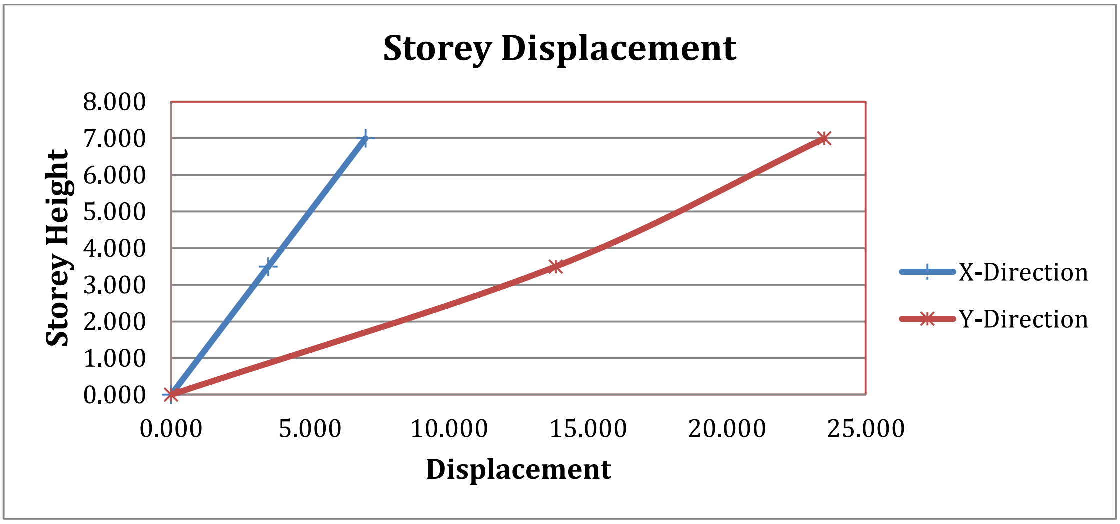



Figure 27 : Storey Displacement Check

Table 41: Storey Drift Calculations

| Storey | Elevation | Storey Displacement (mm) | | Storey drift (%) | |
|---|---|---|---|---|---|
| | m | X Dir'n | Y Dir'n | X Dir'n | Y Dir'n |
| FF | 3.77 | 1.62 | 1.65 | 0.043 | 0.044 |
| GL | 0.000 | 0.00 | 0.00 | 0.000 | 0.000 |

It is seen that drift does not exceed the code prescribed value of 0.010 times storey height (i.e. permissible storey displacement is 37.70 mm). Thus the drift check seems to comply with the safety value mentioned in the code.

The ultimate deflections of building for lateral load are calculated as per NBC 105 by multiplying elastic deflection by factor 5/ K

Where, K = structural performance factor = 4

The ultimate deflections for different blocks are presented in Table 42 below.

Table 42: Ultimate Deflection

| Storey | Elevation (m) | Displacement (mm) | |
|---|---|---|---|
| | | X-Dir | Y-Dir |
| FF | 3.770 | 2.030 | 2.060 |
| GL | 0.000 | 0.000 | 0.000 |

As per cl. no. 9.2.2 of NBC 105:1994, two different buildings shall be separated from each other by a distance of not less than the sum of the design lateral deformations or 0.004hi or 50mm whichever is the greater. The seismic gap required between two OPD blocks is shown in Table 43 below.

Table 43: Requirement of Seismic Gap

| Storey | Elevation (m) | Displacement (mm) | | 0.004hi | |
|---|---|---|---|---|---|
| | | Block I | Block II | | |
| FF | 3.770 | 3.610 | 2.030 | 0.004*3770 | |
| Gap Required = | | 3.610+2.030 = 5.640 mm | | 15.080 mm | 50mm |

The seismic gap required between two OPD blocks is 50mm and existing gap between two blocks is 100mm. Thus the building separation check seems to comply with the safety value mentioned in the code.

### 7.11.3 STRESS CHECKS

Even though, the primary function of masonry elements is to sustain vertical gravity load, structural masonry elements are required to withstand combined shear, flexure and compressive stresses under earthquake or wind load combinations consisting of lateral as well as vertical loads. In this study, the shear stress, tensile stress and compression stress for working stress load combination for earthquake loading are checked with their respective permissible stress.

Even stone masonry structures are commonly practiced in Nepal especially hilly regions, there are lack of experimental mechanical properties of stone masonry and guidelines and codes for stone masonry structures. For this assessment the permissible strength for stone masonry are taken from above mentioned international guidelines and journal papers which are based on experimental data and resemble our conditions and type of stone masonry.

A. In Plane Shear Strength Check

| | A.Shear Stress induced in wall | | | | | | B. Shear strength of wall | Check |
|---|---|---|---|---|---|---|---|---|
| Grid | Length of Wall<br><br>(L) | Thk.<br>(t) | Length of opening<br>(lo) | Area of wall<br>(A) | Shear force in wall<br>(from Analysis)<br><br>(Fv) | Average shear stress in wall<br>(fvi) | Allowable shear strength value<br>(as per test value) | |
| | m | mm | m | $m^2$ | kN | $N/mm^2$ | $N/mm^2$ | |
| Grid, 1-1 | 35.17 | 400 | 20.11 | 6.02 | 1036.16 | 0.172 | 0.217 | Safe |
| Grid, 2-2 | 32.33 | 250 | 8.85 | 5.87 | 1324.43 | 0.226 | 0.217 | **Unsafe** |
| Grid, 3-3 | 17.95 | 250 | 5.05 | 3.23 | 725.16 | 0.225 | 0.217 | **Unsafe** |
| Grid, 4-4 | 35.17 | 400 | 17.70 | 6.99 | 1243.69 | 0.178 | 0.217 | Safe |
| Grid, K-K | 8.85 | 400 | 0.00 | 3.54 | 698.76 | 0.198 | 0.217 | Safe |
| Grid, L-L | 6.55 | 250 | 0.00 | 1.64 | 272.22 | 0.166 | 0.217 | Safe |
| Grid, M-M | 5.32 | 400 | 0.00 | 2.13 | 237.39 | 0.112 | 0.217 | Safe |
| Grid, N-N | 9.23 | 400 | 0.00 | 3.69 | 626.88 | 0.170 | 0.217 | Safe |
| Grid, O-O | 5.75 | 400 | 0.00 | 2.30 | 395.52 | 0.172 | 0.217 | Safe |
| Grid, P-P | 5.75 | 400 | 0.00 | 2.30 | 49.21 | 0.021 | 0.217 | Safe |
| Grid, Q-Q | 4.15 | 250 | 0.00 | 1.04 | 174.69 | 0.169 | 0.217 | Safe |
| | 6.30 | 400 | 0.00 | 2.52 | 438.61 | 0.174 | 0.217 | Safe |
| Grid, R-R | 1.60 | 400 | 0.00 | 0.64 | 38.84 | 0.061 | 0.217 | Safe |
| Grid, S-S | 10.45 | 400 | 0.00 | 4.18 | 694.85 | 0.166 | 0.217 | Safe |
| Grid, T-T | 12.24 | 400 | 5.08 | 2.87 | 438.55 | 0.153 | 0.217 | Safe |
| Grid, U-U | 13.84 | 400 | 4.99 | 3.54 | 515.14 | 0.146 | 0.217 | Safe |

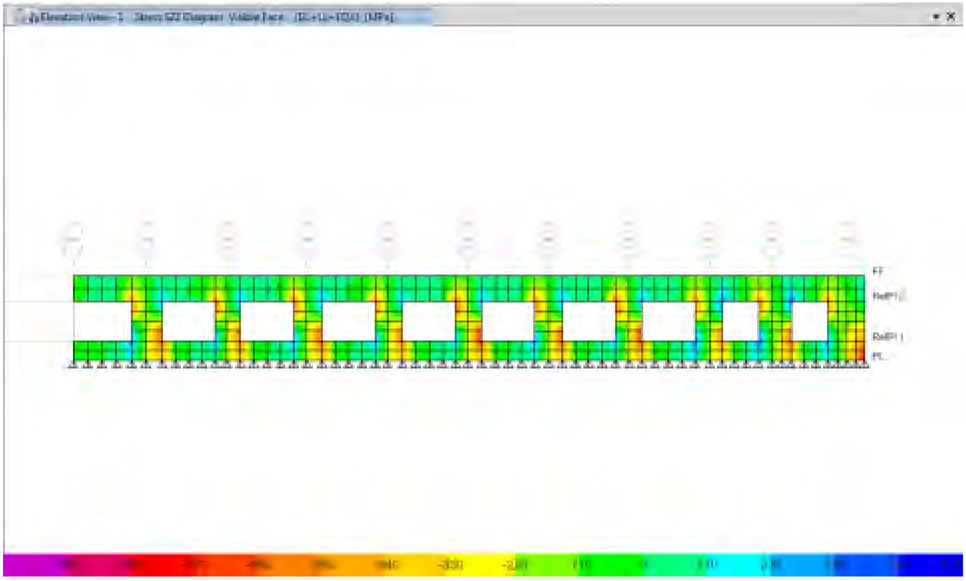
The shear forces induced in each structural wall are calculated using computer software and checked with shear capacity of wall (as per in-site shear strength test result). Most of the walls are found safe in average shear strength check except grid 2 and 3.

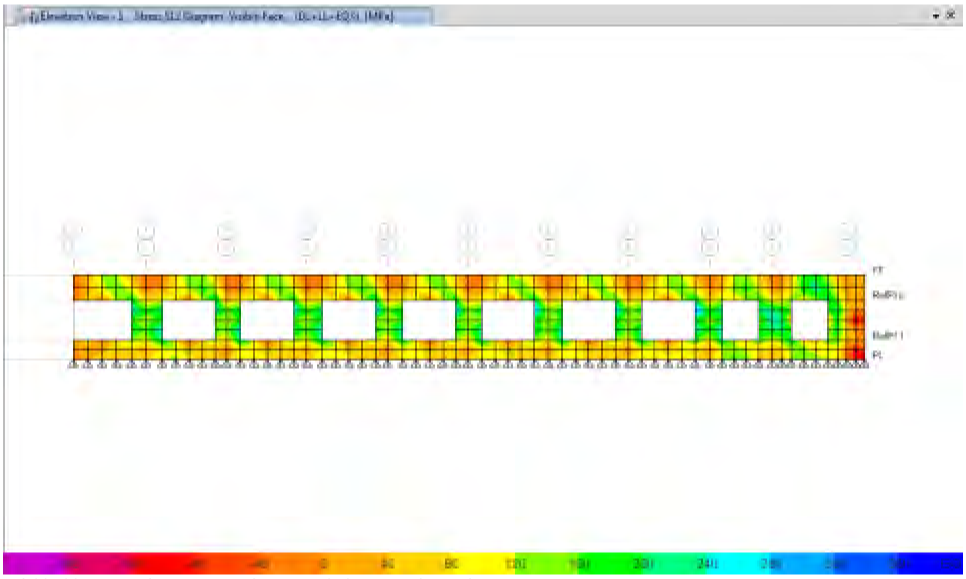
B. In Plane Strength Check

The stresses induced due to the application of in plane earthquake loading are checked with permissible stress. The maximum stresses induced in some of critical wall are presented below.

Grid 1-1

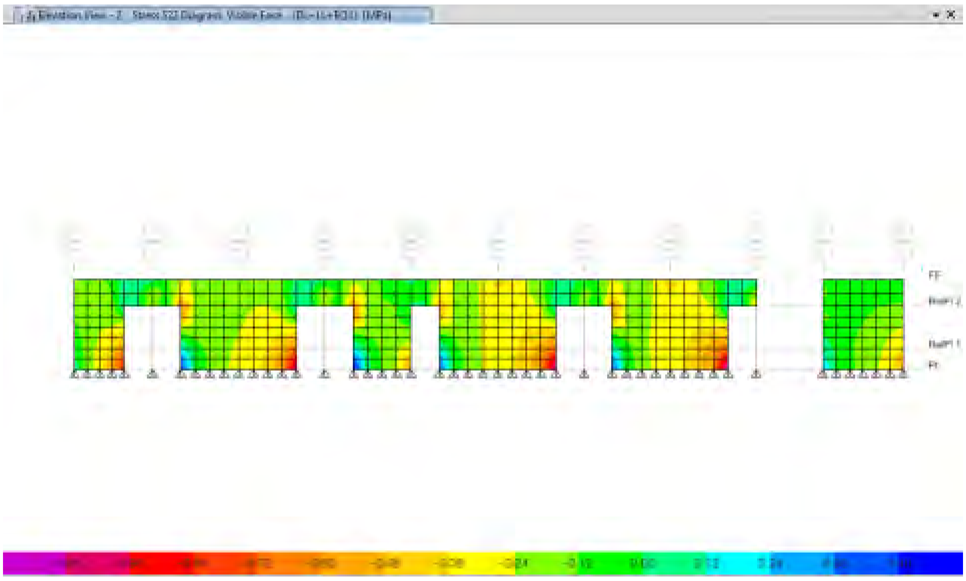
| Load Case | DL+LL+EQ X | DL+LL-EQX | 0.7DL +EQX | 0.7DL -EQX | Max | Check |
|---|---|---|---|---|---|---|
| Compressive Stress: (S22) | 1.07 | 1.04 | 0.89 | 0.9 | 1.07 | ok |
| Tensile Stress: (S22) | 0.49 | 0.46 | 0.58 | 0.53 | 0.58 | Not ok |
| Shear Stress: (S12) | 0.38 | 0.38 | 0.35 | 0.35 | 0.38 | Not ok |

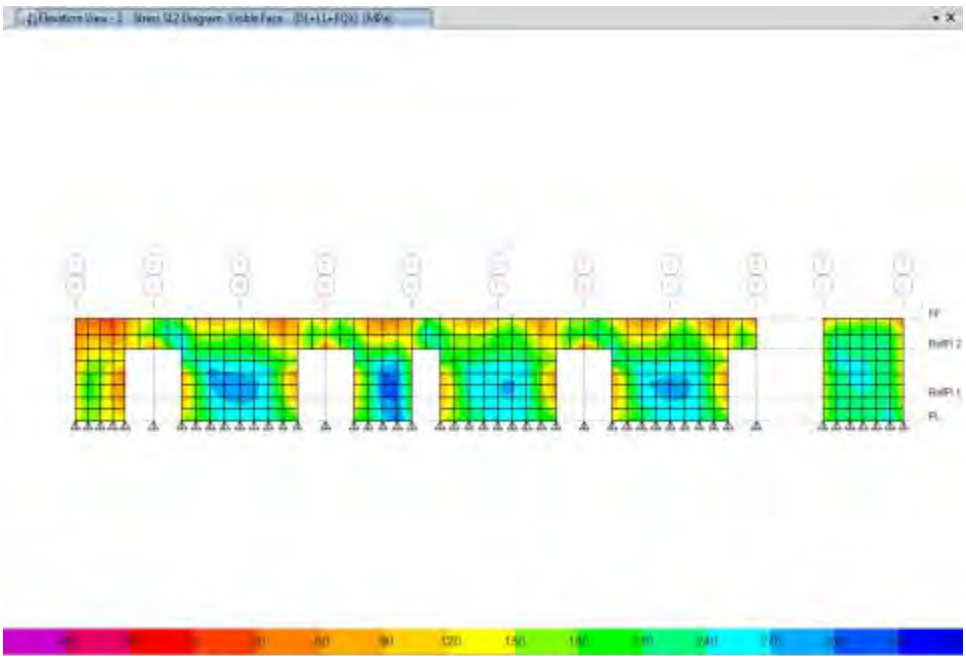




Grid 2-2

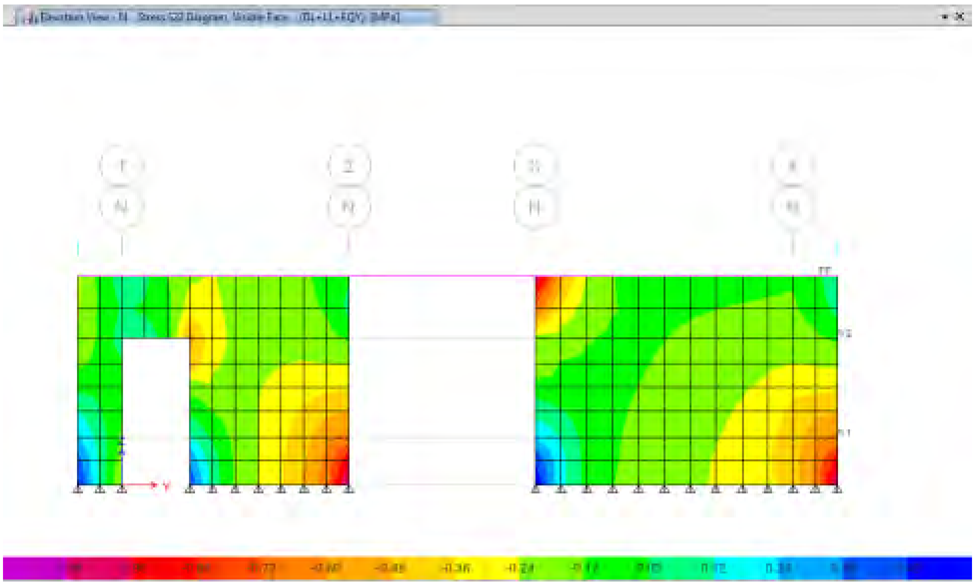
| Load Case | DL+LL+EQ X | DL+LL-EQX | 0.7DL +EQX | 0.7DL -EQX | Max | Check |
|---|---|---|---|---|---|---|
| Compressive Stress: (S22) | 1.16 | 1.14 | 1.01 | 0.99 | 1.16 | ok |
| Tensile Stress: (S22) | 0.58 | 0.54 | 0.68 | 0.62 | 0.68 | Not ok |
| Shear Stress: (S12) | 0.35 | 0.33 | 0.33 | 0.38 | 0.38 | Not ok |

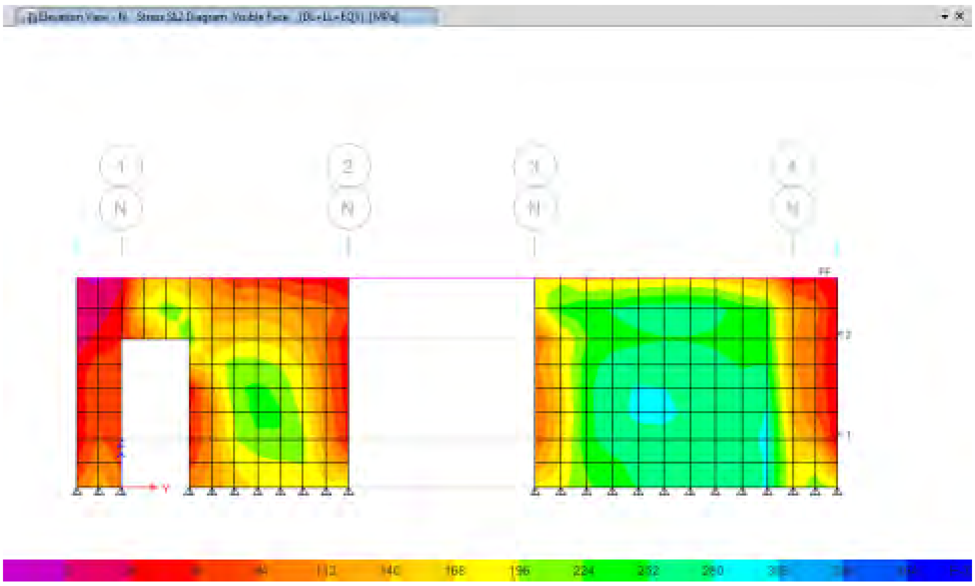




Grid N-N

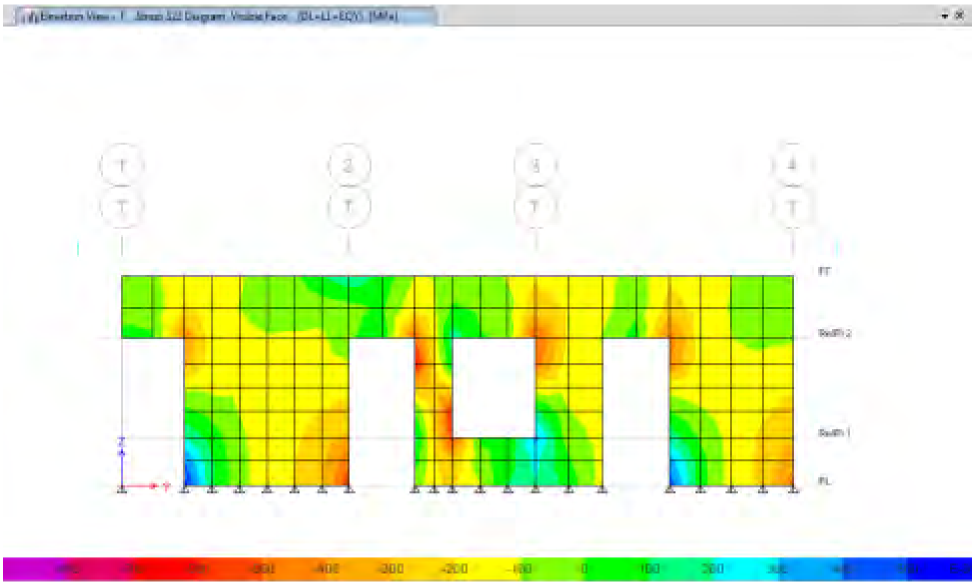
| Load Case | DL+LL+EQY | DL+LL-EQY | 0.7DL +EQY | 0.7DL -EQY | Max | Check |
|---|---|---|---|---|---|---|
| Compressive Stress: (S22) | 1.14 | 1.24 | 1.03 | 1.12 | 1.24 | ok |
| Tensile Stress: (S22) | 0.6 | 0.58 | 0.71 | 0.69 | 0.71 | Not ok |
| Shear Stress: (S12) | 0.38 | 0.32 | 0.33 | 0.3 | 0.38 | Not ok |

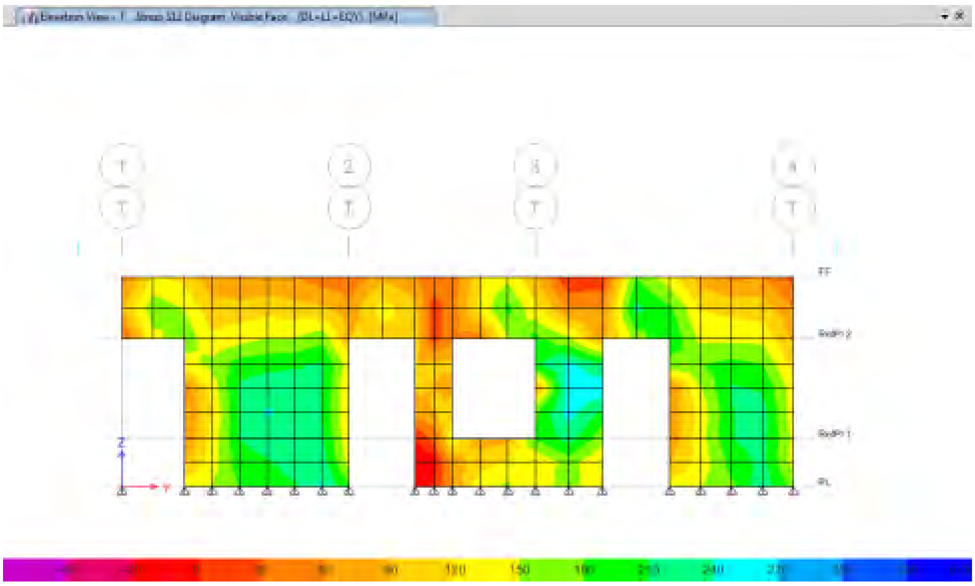




Grid T-T

| Load Case | DL+LL+EQY | DL+LL-EQY | 0.7DL +EQY | 0.7DL -EQY | Max | Check |
|---|---|---|---|---|---|---|
| Compressive Stress: (S22) | 0.88 | 0.98 | 0.76 | 0.89 | 0.98 | ok |
| Tensile Stress: (S22) | 0.53 | 0.42 | 0.63 | 0.53 | 0.63 | Not ok |
| Shear Stress: (S12) | 0.35 | 0.35 | 0.33 | 0.33 | 0.35 | Not ok |





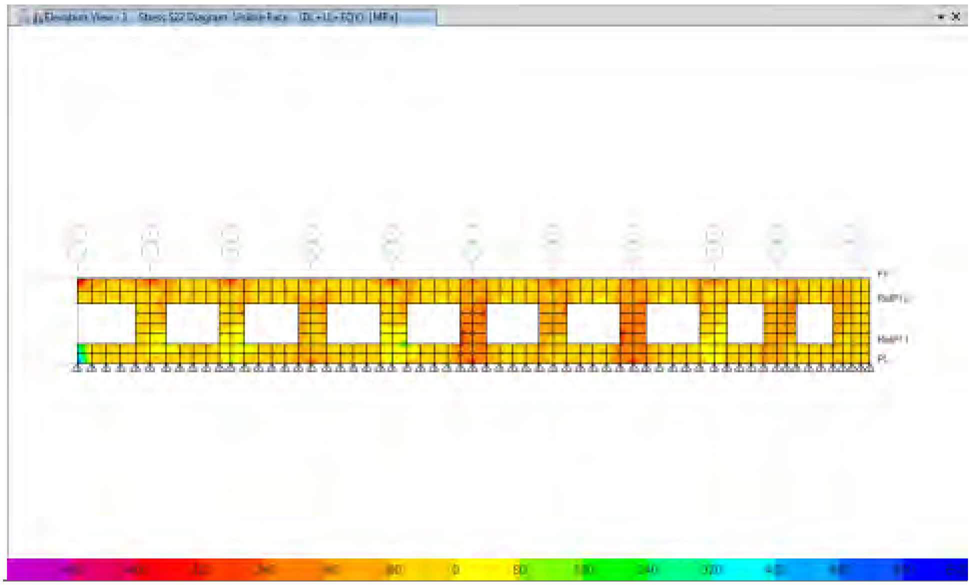
C. Out of Plane Strength Check

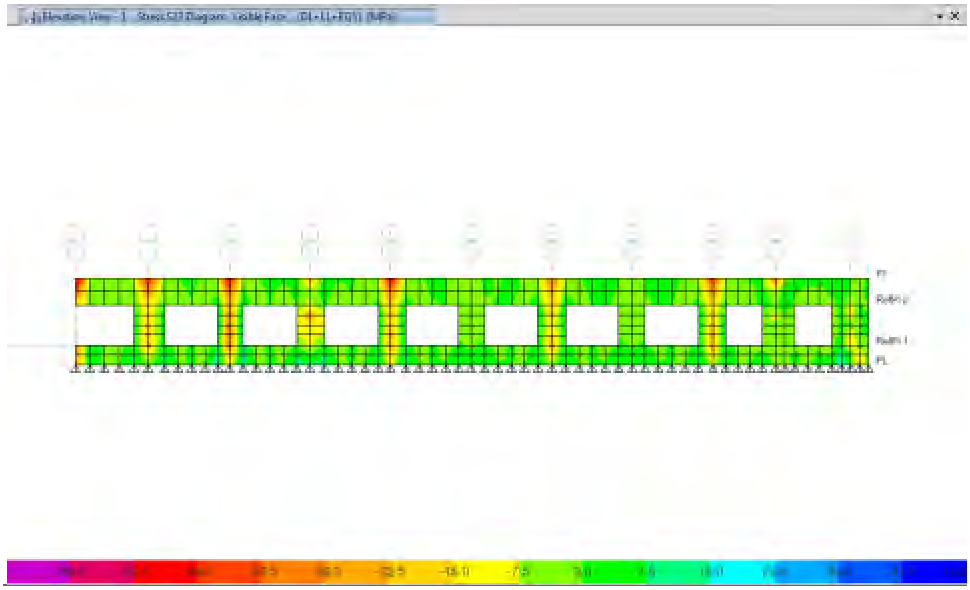
The stresses induced due to the application of out of plane earthquake loading are checked with permissible stress. The stresses are checked for bending stresses due to out of plane vertical and horizontal bending and shear stress. The maximum stresses induced in some of critical wall are presented below.

Grid 1-1

Out of plane Stress Analysis (Vertical Direction)

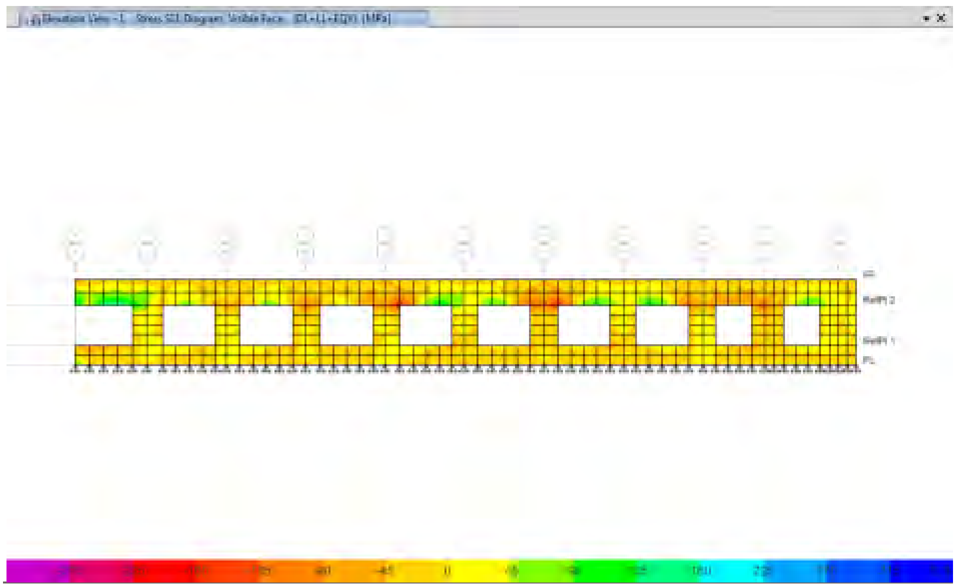
| Load Case | DL+LL+EQY | DL+LL-EQY | 0.7DL +EQY | 0.7DL -EQY | Max | Check |
|---|---|---|---|---|---|---|
| Compressive Stress: (S22) | 0.54 | 0.9 | 0.47 | 0.85 | 0.85 | ok |
| Tensile Stress: (S22) | 0.49 | 0.18 | 0.43 | 0.2 | 0.49 | Not ok |
| Shear Stress: (S23) | 0.06 | 0.05 | 0.06 | 0.05 | 0.06 | ok |

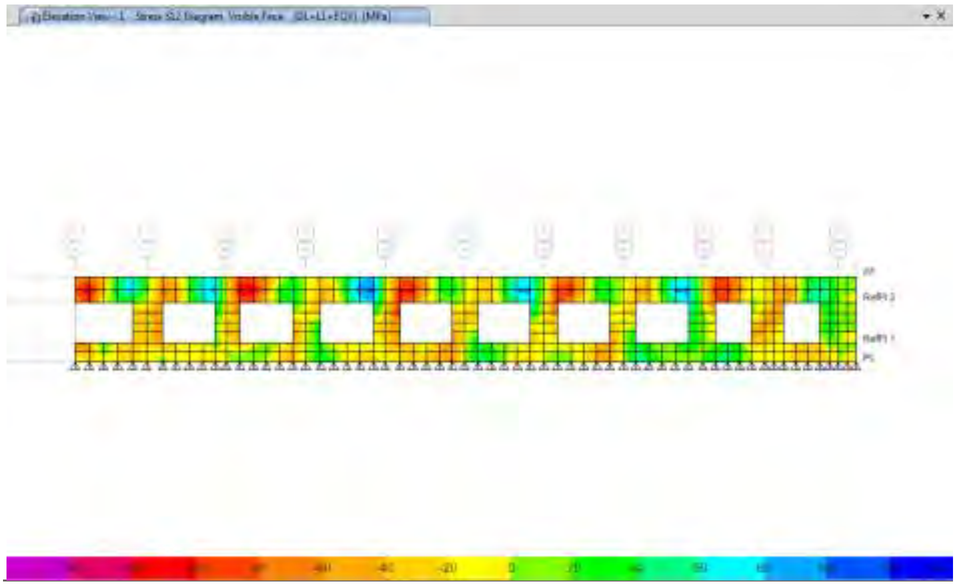




## Out of plane Stress Analysis (Horizontal Direction)

| Load Case | DL+LL+EQY | DL+LL-EQY | 0.7DL +EQY | 0.7DL -EQY | Max | Check |
|---|---|---|---|---|---|---|
| Compressive Stress: (S11) | 0.28 | 0.31 | 0.31 | 0.29 | 0.31 | ok |
| Tensile Stress: (S11) | 0.31 | 0.36 | 0.29 | 0.34 | 0.36 | Not ok |
| Shear Stress: (S12) | 0.16 | 0.21 | 0.17 | 0.2 | 0.21 | Not ok |

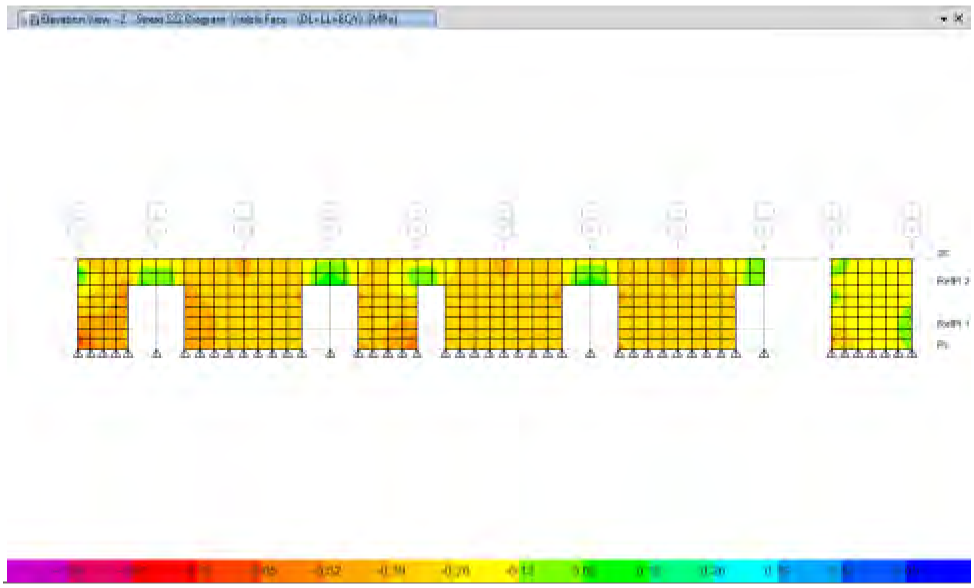


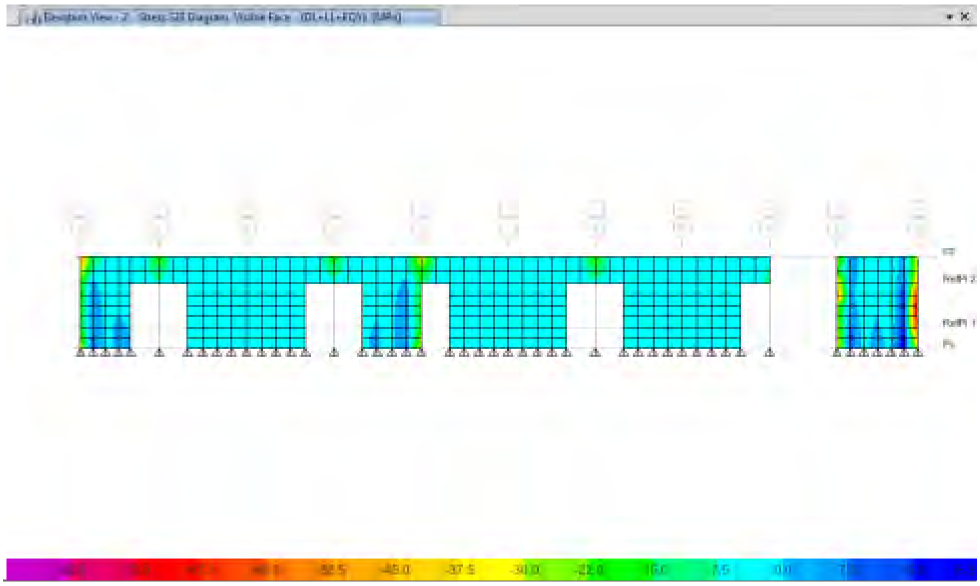


Grid 2-2

Out of plane Stress Analysis (Vertical Direction)

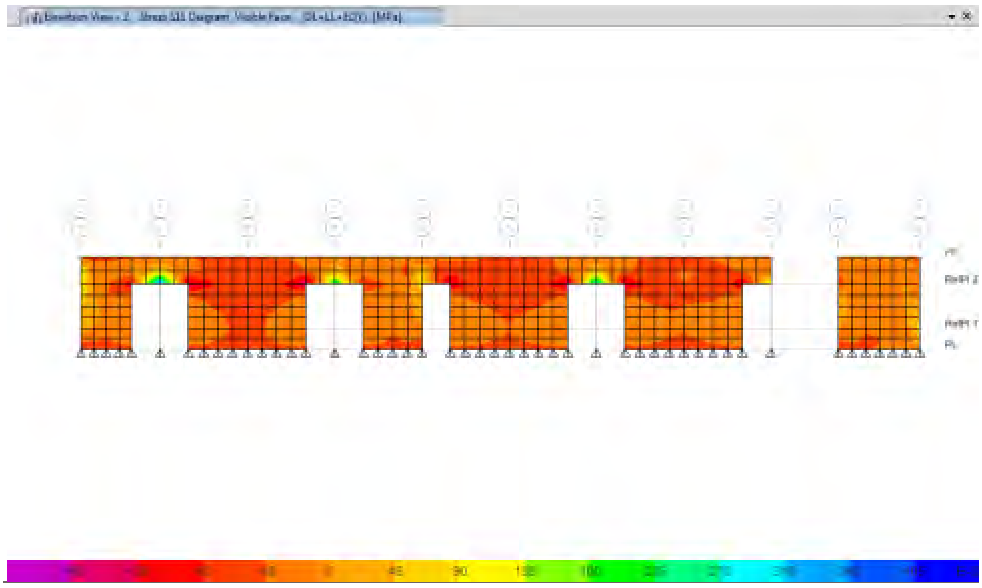
| Load Case | DL+LL+EQY | DL+LL-EQY | 0.7DL +EQY | 0.7DL -EQY | Max | Check |
|---|---|---|---|---|---|---|
| Compressive Stress: (S22) | 1.09 | 1.28 | 1.00 | 1.17 | 1.28 | ok |
| Tensile Stress: (S22) | 0.14 | 0.59 | 0.84 | 0.69 | 0.84 | Not ok |
| Shear Stress: (S23) | 0.09 | 0.13 | 0.09 | 0.12 | 0.13 | ok |

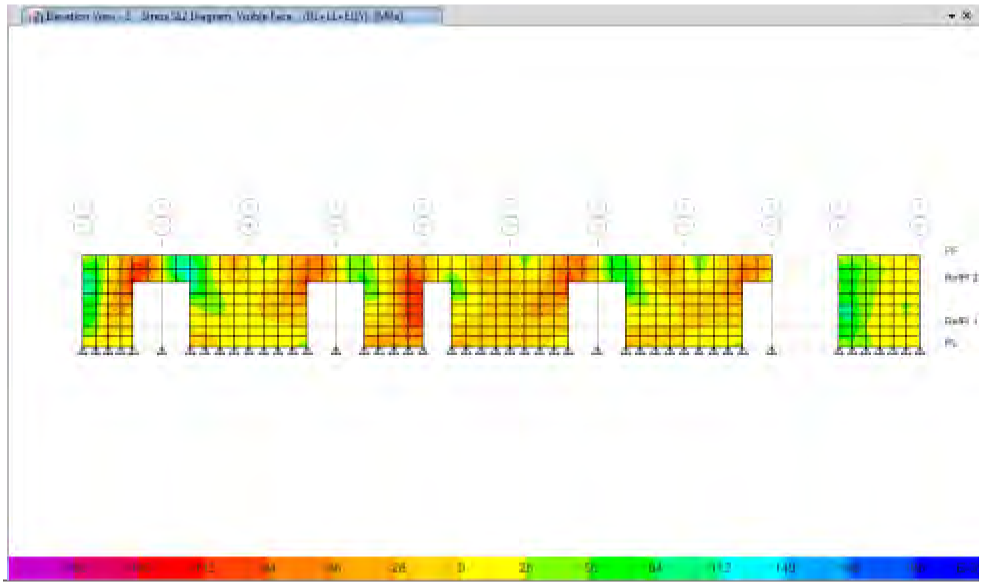




<u>Out of plane Stress Analysis (Horizontal Direction)</u>

| Load Case | DL+LL+EQY | DL+LL-EQY | 0.7DL +EQY | 0.7DL -EQY | Max | Check |
|---|---|---|---|---|---|---|
| Compressive Stress: (S11) | 0.21 | 0.44 | 0.21 | 0.44 | 0.44 | ok |
| Tensile Stress: (S11) | 0.38 | 0.23 | 0.39 | 0.22 | 0.39 | Not ok |
| Shear Stress: (S12) | 0.22 | 0.28 | 0.21 | 0.26 | 0.28 | Not ok |

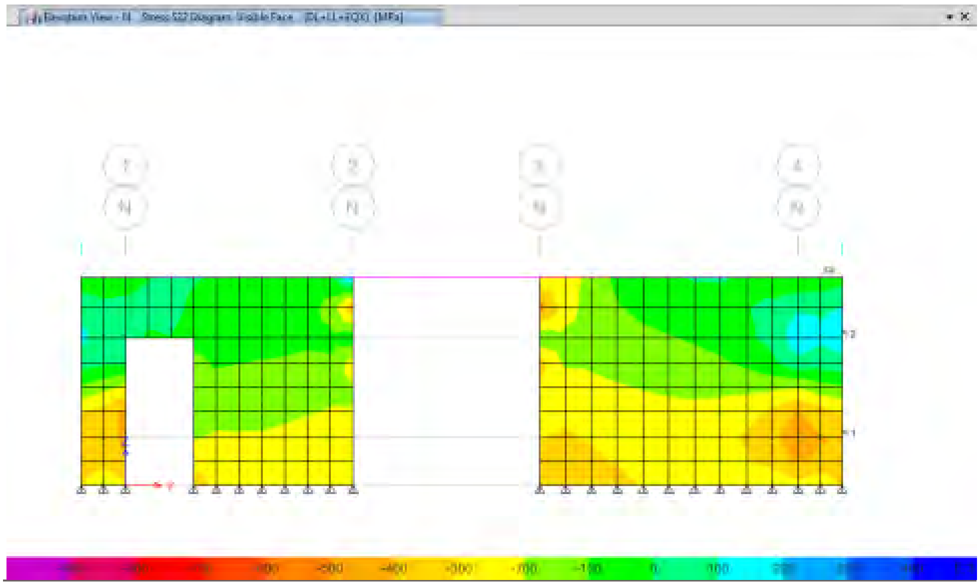


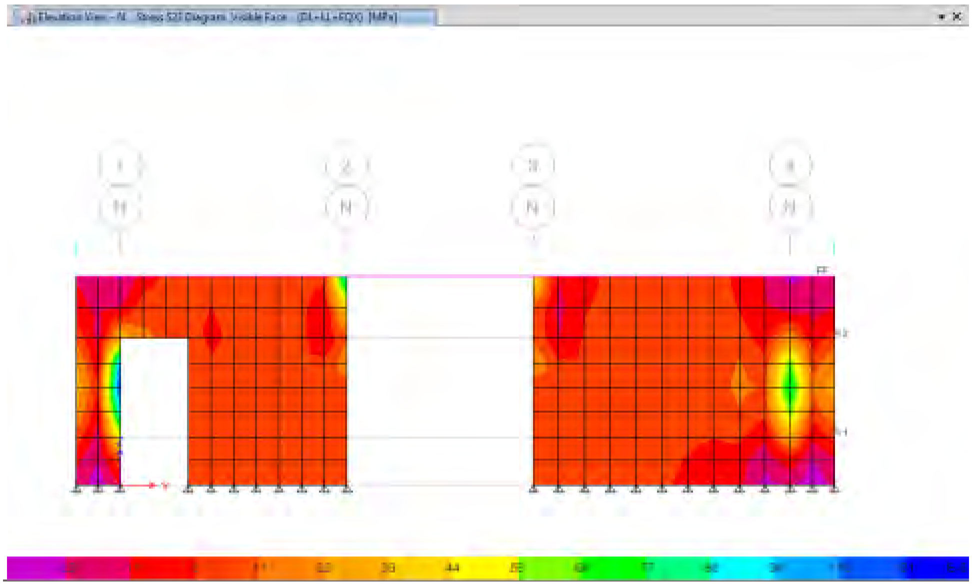


## Grid N-N

### Out of plane Stress Analysis (Vertical Direction)

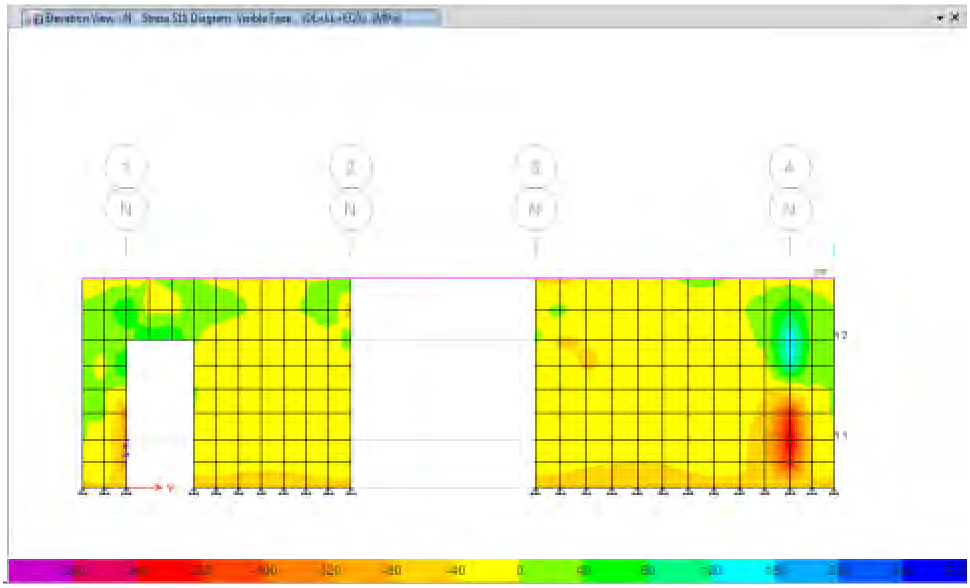
| Load Case | DL+LL+EQX | DL+LL-EQX | 0.7DL +EQX | 0.7DL -EQX | Max | Check |
|---|---|---|---|---|---|---|
| Compressive Stress: (S22) | 0.95 | 0.85 | 0.73 | 0.72 | 0.95 | ok |
| Tensile Stress: (S22) | 0.38 | 0.36 | 0.45 | 0.44 | 0.45 | Not ok |
| Shear Stress: (S23) | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | ok |

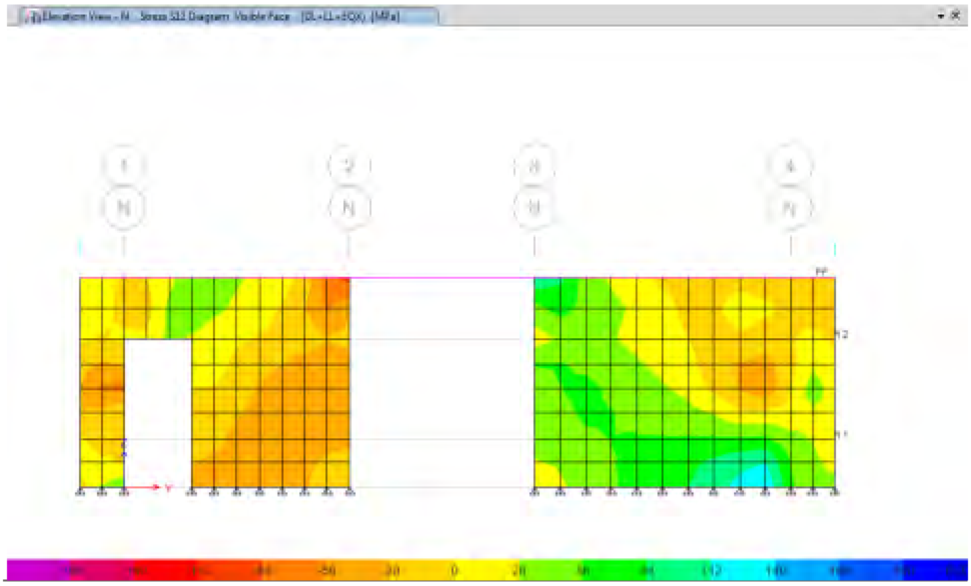




<u>Out of plane Stress Analysis (Horizontal Direction)</u>

| Load Case | DL+LL+EQX | DL+LL-EQX | 0.7DL +EQX | 0.7DL -EQX | Max | Check |
|---|---|---|---|---|---|---|
| Compressive Stress: (S11) | 0.28 | 0.25 | 0.27 | 0.25 | 0.28 | ok |
| Tensile Stress: (S11) | 0.24 | 0.23 | 0.24 | 0.24 | 0.24 | Not ok |
| Shear Stress: (S12) | 0.20 | 0.16 | 0.16 | 0.12 | 0.20 | ok |

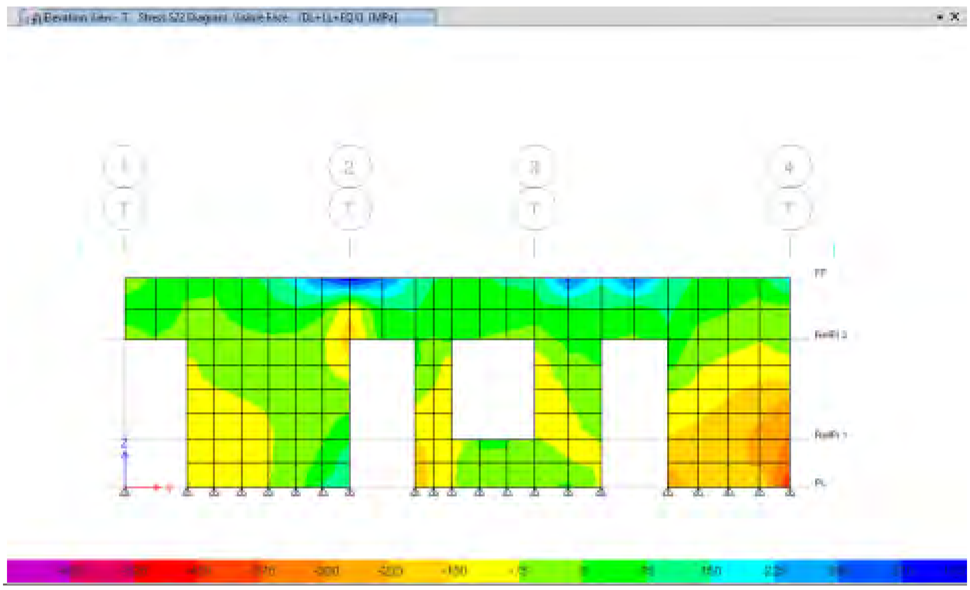


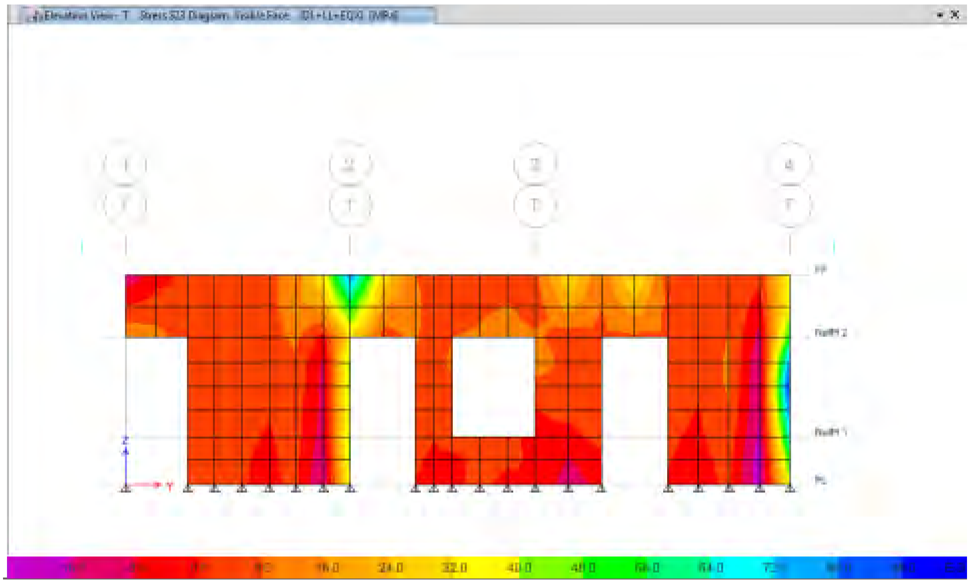


Grid T-T

Out of plane Stress Analysis (Vertical Direction)

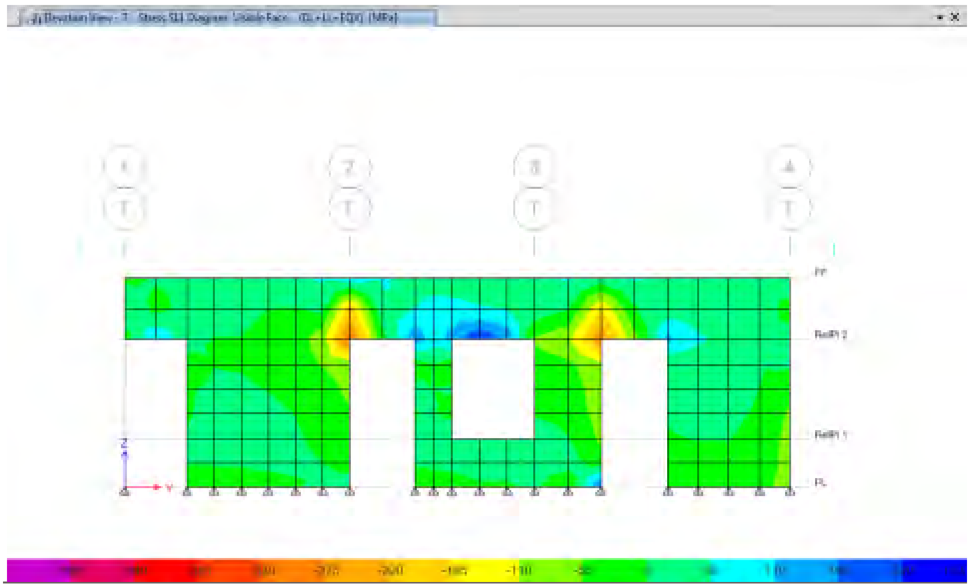
| Load Case | DL+LL+EQX | DL+LL-EQX | 0.7DL +EQX | 0.7DL -EQX | Max | Check |
|---|---|---|---|---|---|---|
| Compressive Stress: (S22) | 0.66 | 0.81 | 0.55 | 0.73 | 0.81 | ok |
| Tensile Stress: (S22) | 0.42 | 0.36 | 0.49 | 0.35 | 0.49 | Not ok |
| Shear Stress: (S23) | 0.09 | 0.10 | 0.10 | 0.10 | 0.10 | ok |

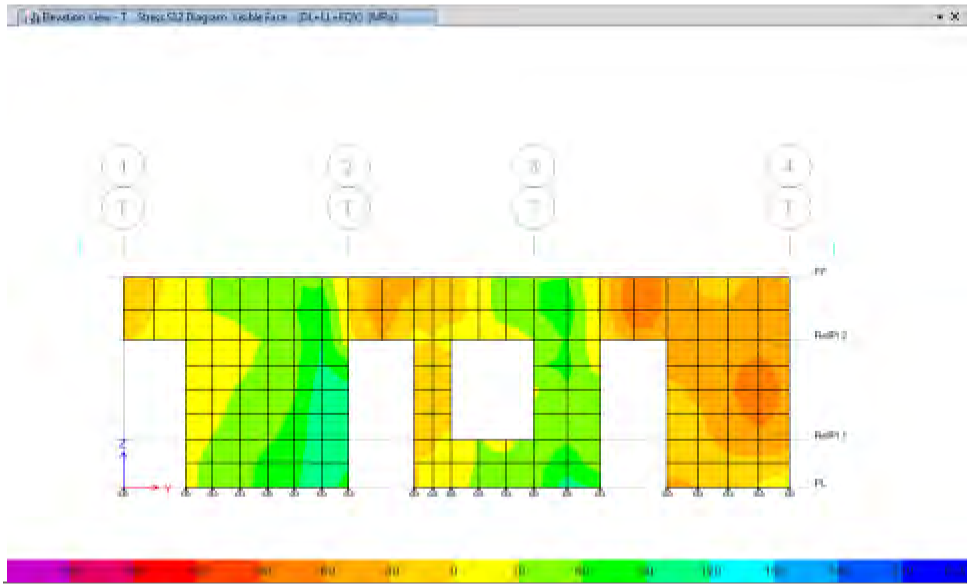




Out of plane Stress Analysis (Horizontal Direction)

| Load Case | DL+LL+EQX | DL+LL-EQX | 0.7DL +EQX | 0.7DL -EQX | Max | Check |
|---|---|---|---|---|---|---|
| Compressive Stress: (S11) | 0.54 | 0.26 | 0.45 | 0.24 | 0.45 | ok |
| Tensile Stress: (S11) | 0.22 | 0.28 | 0.20 | 0.31 | 0.31 | Not ok |
| Shear Stress: (S12) | 0.21 | 0.17 | 0.18 | 0.17 | 0.21 | Not ok |





## 7.12 FINDINGS AND RECOMMENDATIONS

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

- The drift ratio of the building complies with the codal provision. Hence building is safe in storey drift.
- Stress checks are made for maximum value of each wall panel. The building is safe in compression stress check while not safe in tensile and shear stress check for in-plane and out of plane earthquake loading.

# 8 RETROFIT DESIGN FOR MASONRY BUILDING

This chapter summarizes retrofitting strategies adopted and retrofitting design.

## 8.1 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

### 8.1.1 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.

### 8.1.2 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.

### 8.1.3 INCREASING DUCTILITY

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

## 8.2 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 splint and bandage, full wall 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:

- Separation of blocks to improve configuration of buildings.

- Increasing of wall length and closing of opening to increase shear length of wall.
- Full wall jacketing with steel mesh to improve strength, ductility and stability of wall structure.
- Splint and bandage to improve localize capacity and ductility of masonry walls.
- Steel bracing to improve stability of free standing wall and parapet wall.

## 8.3 RETROFIT DESIGN

Based on the retrofitting strategies as in section 6.1, retrofitting of masonry building is designed. In this section retrofitting design of masonry structure are summarized. The detail retrofitting designs are attached in Annex.

Since there are no changes in structural system, re-modeling and analysis of building has not carried out. The retrofit designed has done to strengthening the structural deficiency observed during detail seismic assessment.

Different retrofit options are calculated and the best option as per seismic demand for different panel of walls are proposed.

Calculation of Capacity of Different retrofits Options.

| Option ID | Description Jacketing | $t_w$ | fy | $\varphi$ | nos. | $\varphi$ | nos. | S | A | A | $\sigma_{ta}$ | $\sigma_{ca}$ | $\tau_s$ | T | C | V | $\sigma_t$ | $\sigma_c$ | $\tau_s$ | fm | $t_c$ | D | d | nd | z | Out of Plane Bending Capacity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mm | N/mm$^2$ | mm | nos. | mm | nos. | m | mm$^2$ | mm$^2$/m | N/mm$^2$ | N/mm$^2$ | N/mm$^2$ | kN/m | kN/m | kN/m | N/mm$^2$/m | N/mm$^2$/m | N/mm$^2$/m | N/mm$^2$ | mm | mm | mm | mm | mm | kN-m/m |
| 1 | Splint and Bandage (300 mm wide, 50mm thick, 3-4.75mm) | 400 | 415 | 0 | 0 | 4.75 | 3 | 1.5 | 53 | 35 | 230 | 190 | 230 | 10 | 8 | 10 | 0.025 | 0.021 | 0.025 | 2.5 | 50 | 500 | 475 | 8 | 472 | 4.812 |
| 2 | Splint and Bandage (300 mm wide, 50mm thick, 1-7mm+2-4.75mm) | 400 | 415 | 7 | 1 | 4.75 | 2 | 1.5 | 74 | 49 | 230 | 190 | 230 | 14 | 12 | 14 | 0.035 | 0.029 | 0.035 | 2.5 | 50 | 500 | 475 | 11 | 471 | 6.677 |
| 3 | Splint and Bandage (300 mm wide, 50mm thick, 2-7mm+1-4.75mm) | 400 | 415 | 7 | 2 | 4.75 | 1 | 1.5 | 95 | 63 | 230 | 190 | 230 | 18 | 15 | 18 | 0.045 | 0.037 | 0.045 | 2.5 | 50 | 500 | 475 | 15 | 470 | 8.533 |
| 4 | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 400 | 415 | 8 | 0 | 7 | 3 | 1.5 | 115 | 77 | 230 | 190 | 230 | 22 | 18 | 22 | 0.055 | 0.046 | 0.055 | 2.5 | 50 | 500 | 475 | 18 | 469 | 10.381 |
| 5 | Splint and Bandage (300 mm wide, 50mm thick, 1-8mm+2-7mm) | 400 | 415 | 8 | 1 | 7 | 2 | 1.5 | 127 | 85 | 230 | 190 | 230 | 24 | 20 | 24 | 0.061 | 0.050 | 0.061 | 2.5 | 50 | 500 | 475 | 20 | 468 | 11.425 |
| 6 | Splint and Bandage (300 mm wide, 50mm thick, 2-8mm+1-7mm) | 400 | 415 | 8 | 2 | 7 | 1 | 1.5 | 139 | 93 | 230 | 190 | 230 | 27 | 22 | 27 | 0.067 | 0.055 | 0.067 | 2.5 | 50 | 500 | 475 | 21 | 468 | 12.467 |
| 7 | Splint and Bandage (300 mm wide, 50mm thick, 3-8mm) | 400 | 415 | 8 | 3 | 7 | 0 | 1.5 | 151 | 101 | 230 | 190 | 230 | 29 | 24 | 29 | 0.072 | 0.060 | 0.072 | 2.5 | 50 | 500 | 475 | 23 | 467 | 13.506 |
| 8 | Splint and Bandage (300 mm wide, 50mm thick, 3-10mm) | 400 | 415 | 10 | 3 | 8 | 0 | 1.5 | 236 | 157 | 230 | 190 | 230 | 45 | 37 | 45 | 0.113 | 0.093 | 0.113 | 2.5 | 50 | 500 | 475 | 36 | 463 | 20.907 |
| 9 | Full Jacketing, (7mm @ 150 c/c spacing, 50mm thick) | 400 | 415 | 0 | 0 | 7 | 1 | 0.15 | 38 | 257 | 230 | 190 | 230 | 74 | 61 | 74 | 0.184 | 0.152 | 0.184 | 2.5 | 50 | 500 | 475 | 59 | 455 | 33.586 |
| 10 | Full Jacketing, (8mm @ 150 c/c spacing, 50mm thick) | 400 | 415 | 0 | 0 | 8 | 1 | 0.15 | 50 | 335 | 230 | 190 | 230 | 96 | 80 | 96 | 0.241 | 0.199 | 0.241 | 2.5 | 50 | 500 | 475 | 77 | 449 | 43.287 |
| 11 | Full Jacketing, (10mm @ 150 c/c spacing, 50mm thick) | 400 | 415 | 0 | 0 | 10 | 1 | 0.15 | 79 | 524 | 230 | 190 | 230 | 151 | 124 | 151 | 0.376 | 0.311 | 0.376 | 2.5 | 50 | 500 | 475 | 120 | 435 | 65.461 |

In plane Analysis:

Sample calculation of retrofit design for in- plane loading

X-direction loading

| Wall 1-1 | Type | DL+LL+EQx | DL+LL-EQx | 0.7DL+EQx | 0.7DL-EQx | Max. Stress | Avg. Stress | Permissible stress of wall | Check | Retrofit Option | Permissible stress of Retrofit Option | | No. of Face | Permissible stress of Wall after retrofit | Check |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Stress | Stress | Stress | Stress | | | | | Description | Tensile Stress | Compressive Stress | | | |
| | | N/mm² | N/mm² | N/mm² | N/mm² | N/mm² | N/mm² | N/mm² | | | | | | N/mm² | |
| Pier 1 | Comp. | 0.660 | 0.660 | 0.590 | 0.590 | 0.660 | 0.330 | 2.500 | OK | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 2.591 | OK |
| | Tensile | 0.290 | 0.270 | 0.360 | 0.250 | 0.360 | 0.135 | 0.140 | OK | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 0.251 | OK |
| Pier 2 | Comp. | 0.640 | 0.600 | 0.570 | 0.530 | 0.640 | 0.320 | 2.500 | OK | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 2.591 | OK |
| | Tensile | 0.240 | 0.280 | 0.310 | 0.350 | 0.350 | 0.131 | 0.140 | OK | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 0.251 | OK |
| Pier 3 | Comp. | 0.700 | 0.680 | 0.630 | 0.610 | 0.700 | 0.350 | 2.500 | OK | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 2.591 | OK |
| | Tensile | 0.270 | 0.280 | 0.350 | 0.360 | 0.360 | 0.135 | 0.140 | OK | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 0.251 | OK |
| Pier 4 | Comp. | 0.620 | 0.610 | 0.570 | 0.540 | 0.620 | 0.310 | 2.500 | OK | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 2.591 | OK |
| | Tensile | 0.250 | 0.290 | 0.310 | 0.350 | 0.350 | 0.131 | 0.140 | OK | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 0.251 | OK |
| Pier 5 | Comp. | 0.740 | 0.730 | 0.650 | 0.640 | 0.740 | 0.370 | 2.500 | OK | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 2.591 | OK |
| | Tensile | 0.270 | 0.270 | 0.310 | 0.310 | 0.310 | 0.116 | 0.140 | OK | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 0.251 | OK |
| Pier 6 | Comp. | 0.670 | 0.670 | 0.600 | 0.600 | 0.670 | 0.335 | 2.500 | OK | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 2.591 | OK |
| | Tensile | 0.290 | 0.280 | 0.350 | 0.350 | 0.350 | 0.131 | 0.140 | OK | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 0.251 | OK |
| Pier 7 | Comp. | 0.730 | 0.740 | 0.640 | 0.650 | 0.740 | 0.370 | 2.500 | OK | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 2.591 | OK |
| | Tensile | 0.270 | 0.240 | 0.330 | 0.310 | 0.330 | 0.124 | 0.140 | OK | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 0.251 | OK |
| Pier 8 | Comp. | 0.600 | 0.620 | 0.540 | 0.450 | 0.620 | 0.310 | 2.500 | OK | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 2.591 | OK |
| | Tensile | 0.330 | 0.260 | 0.380 | 0.320 | 0.380 | 0.143 | 0.140 | Not Ok | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 0.251 | OK |
| Pier 9 | Comp. | 0.650 | 0.690 | 0.580 | 0.620 | 0.690 | 0.345 | 2.500 | OK | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 2.591 | OK |
| | Tensile | 0.350 | 0.310 | 0.420 | 0.370 | 0.420 | 0.158 | 0.140 | Not Ok | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 0.251 | OK |
| Pier 10 | Comp. | 0.850 | 0.520 | 0.810 | 0.480 | 0.850 | 0.425 | 2.500 | OK | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 2.591 | OK |
| | Tensile | 0.280 | 0.450 | 0.320 | 0.530 | 0.530 | 0.199 | 0.140 | Not Ok | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 0.251 | OK |

Y-direction loading

| Wall T-T | Type | DL+LL+EQy | DL+LL-EQy | 0.7DL+EQy | 0.7DL-EQy | Max. Stress | Avg. Stress | Permissible stress of wall | Check | Retrofit Option | | Permissible stress of Retrofit Option | | No. of Face | Permissible stress of Wall after retrofit | Check |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Stress | Stress | Stress | Stress | | | | | ID | Description | Tensile Stress | Compressive Stress | | | |
| | | N/mm² | N/mm² | N/mm² | N/mm² | N/mm² | N/mm² | N/mm² | | | | | | | N/mm² | |
| Pier 1 | Comp. | 0.700 | 0.980 | 0.500 | 0.810 | 0.980 | 0.490 | 2.500 | OK | 4 | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 2.591 | OK |
| | Tensile | 0.530 | 0.220 | 0.630 | 0.290 | 0.630 | 0.236 | 0.140 | Not Ok | 4 | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 0.251 | OK |
| Pier 2 | Comp. | 0.660 | 0.630 | 0.570 | 0.510 | 0.660 | 0.330 | 2.500 | OK | 4 | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 2.591 | OK |
| | Tensile | 0.160 | 0.270 | 0.240 | 0.360 | 0.360 | 0.135 | 0.140 | OK | 4 | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 0.251 | OK |
| Pier 3 | Comp. | 0.510 | 0.660 | 0.420 | 0.590 | 0.660 | 0.330 | 2.500 | OK | 4 | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 2.591 | OK |
| | Tensile | 0.340 | 0.150 | 0.410 | 0.240 | 0.410 | 0.154 | 0.140 | Not Ok | 4 | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 0.251 | OK |
| Pier 4 | Comp. | 0.460 | 0.810 | 0.390 | 0.750 | 0.810 | 0.405 | 2.500 | OK | 4 | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 2.591 | OK |
| | Tensile | 0.470 | 0.210 | 0.530 | 0.270 | 0.530 | 0.199 | 0.140 | Not Ok | 4 | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 0.055 | 0.046 | 2.000 | 0.251 | OK |

Out of plane Analysis:

Sample calculation of retrofit design for out of plane loading

Horizontal bending

| Wall | DL+LL+EQy | DL+LL-EQy | 0.7DL+EQy | 0.7DL-EQy | Max. Moment | Moment M11 | Retrofit Option | | No. of face | Moment Capacity | Check |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | kN-m/m | | | | | kN-m | ID | Description | | kN-m | |
| 1-1 | 5.952 | 4.223 | 6.236 | 4.558 | 6.236 | 4.677 | 4 | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 2.000 | 20.761 | OK |
| 2-2 | 2.831 | 5.130 | 2.839 | 4.535 | 5.130 | 3.848 | 7 | Splint and Bandage (300 mm wide, 50mm thick, 3-8mm) | 2.000 | 27.012 | OK |
| 3-3 | 9.795 | 7.239 | 9.748 | 7.286 | 9.795 | 7.346 | 4 | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 2.000 | 20.761 | OK |
| 4-4 | 5.279 | 3.340 | 4.280 | 2.945 | 5.279 | 3.959 | 4 | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 2.000 | 20.761 | OK |

| Wall | DL+LL+EQx | DL+LL-EQx | 0.7DL+EQx | 0.7DL-EQx | Max. Moment | Moment M11 | Retrofit Option | | No. of face | Moment Capacity | Check |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | kN-m/m | | | | | kN-m | ID | Description | | kN-m | |
| K-K | 5.263 | 5.057 | 4.473 | 4.424 | 5.263 | 3.947 | 9 | Full Jacketing, (7mm @ 150 c/c spacing, 50mm thick) | 1.000 | 33.586 | OK |
| L-L | 4.538 | 4.681 | 4.542 | 4.677 | 4.681 | 3.511 | 8 | Splint and Bandage (300 mm wide, 50mm thick, 3-10mm) | 2.000 | 41.815 | OK |
| M-M | 6.222 | 6.667 | 6.264 | 6.625 | 6.667 | 5.000 | 7 | Splint and Bandage (300 mm wide, 50mm thick, 3-8mm) | 2.000 | 27.012 | OK |
| N-N | 6.706 | 6.377 | 6.637 | 6.447 | 6.706 | 5.030 | 7 | Splint and Bandage (300 mm wide, 50mm thick, 3-8mm) | 2.000 | 27.012 | OK |
| O-O | 5.946 | 6.767 | 6.064 | 6.649 | 6.767 | 5.075 | 4 | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 2.000 | 20.761 | OK |
| Q-Q | 4.963 | 6.265 | 5.920 | 6.255 | 6.265 | 4.699 | 4 | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 2.000 | 20.761 | OK |
| S-S | 6.938 | 6.461 | 6.826 | 6.573 | 6.938 | 5.204 | 4 | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 1.000 | 10.381 | OK |
| T-T | 8.889 | 5.329 | 8.075 | 6.143 | 8.889 | 6.667 | 4 | Splint and Bandage (300 mm wide, 50mm thick, 3-7mm) | 2.000 | 20.761 | OK |
| U-U | 3.744 | 3.270 | 3.579 | 3.352 | 3.744 | 2.808 | 9 | Full Jacketing, (7mm @ 150 c/c spacing, 50mm thick) | 3.000 | 100.758 | OK |

Check for Shear Stresses

Shear capacity of Reinforced Masonry Wall with vertical and horizontal reinforcing steels calculated as follows:

$F_v = F_{vm} + F_{vh} + F_{vv}$

Where,

$F_{vm}$: Shear strength of URM ($f_{vm}$ *A)

$F_{vh}$: Shear resistance due to horizontal bars ($\sum n * T_b$)

$F_{vv}$: Shear resistance due to vertical bars($0.806 * nd^2 \sqrt{(f_c f_s)}$)

$f_{vm}$: Shear stress of masonry

A: Cross sectional area of wall

n: Number of horizontal (or vertical) reinforcing bars

$T_b$: Tensile strength of one bar

d: Diameter of reinforcing bar

$f_c$: Allowable compressive strength of the embedding mortar or grout

$f_s$: Allowable tensile stress in reinforcing bar

## Sample calculation of retrofit design for shear stresses

| | A. Shear Stress induced in wall | | | | | | B. Shear strength of the masonry wall as per in place shear test result | | C. Dowel action of bar in vertical band : {Ref, Miha Tomazevic, Earthquake resistant design of masonry buildings} | | | | | | | | | D. Shear resistance due to direct tension in the horizontal band | | | E. Shear resistance due to horizontal bars in both face jacketing | | | | F. Dowel action due to vertical bars in two face jacketing | | | | | | | Total shear capacity of wall | Comparision of Shear stresses | | Remark |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grid | Length of Wall (L) | Thk. (t) | Length of opening ($l_o$) | Area of wall (A) | Shear force in wall (from Analysis) Fv | Average shear stress in wall fvi | Allowable shear strength value (as per test value) | F1 | N1 | d1 | n1 | d2 | n2 | fc | fy | fs | F2 | N | fs | F3 | N | $F_{vj}$ | h | F4 | N | d | n | fc | fy | fs | F5 | $F_t$ | $f_{vr}$ | $f_{vi}$ | |
| | m | mm | m | $m^2$ | kN | $N/mm^2$ | $N/mm^2$ | kN | | | | | | | | | kN | | | kN | | | | kN | | (mm) | | MPa | MPa | MPa | kN | kN | $N/mm^2$ | $N/mm^2$ | Text |
| Grid, 1-1 | 35.17 | 400 | 20.11 | 6.02 | 1036.16 | 0.172 | 0.210 | 1265.04 | 40 | 8 | 0 | 7 | 3 | 4 | 415 | 230 | 179.69 | 4 | 33.19 | 132.77 | 0 | 73.76 | 3.77 | 0.00 | 0 | 7.000 | 102 | 4 | 415 | 230 | 0.00 | 1577.50 | 0.262 | 0.172 | Hence OK |
| Grid, 2-2 | 32.33 | 250 | 8.85 | 5.87 | 1324.43 | 0.226 | 0.210 | 1232.70 | 26 | 8 | 3 | 7 | 0 | 4 | 415 | 230 | 152.55 | 4 | 33.19 | 132.77 | 0 | 73.76 | 3.77 | 0.00 | 0 | 7.000 | 158 | 4 | 415 | 230 | 0.00 | 1518.02 | 0.259 | 0.226 | Hence OK |
| Grid, 3-3 | 17.95 | 250 | 5.05 | 3.23 | 725.16 | 0.225 | 0.210 | 677.25 | 14 | 8 | 0 | 7 | 3 | 4 | 415 | 230 | 62.89 | 4 | 33.19 | 132.77 | 0 | 73.76 | 3.77 | 0.00 | 0 | 7.000 | 87 | 4 | 415 | 230 | 0.00 | 872.91 | 0.271 | 0.225 | Hence OK |
| Grid, 4-4 | 35.17 | 400 | 17.70 | 6.99 | 1243.69 | 0.178 | 0.210 | 1467.48 | 40 | 8 | 0 | 7 | 3 | 4 | 415 | 230 | 179.69 | 4 | 33.19 | 132.77 | 0 | 73.76 | 3.77 | 0.00 | 0 | 7.000 | 118 | 4 | 415 | 230 | 0.00 | 1779.94 | 0.255 | 0.178 | Hence OK |
| Grid, K-K | 8.85 | 400 | 0.00 | 3.54 | 698.76 | 0.198 | 0.210 | 742.98 | 0 | 8 | 0 | 7 | 0 | 4 | 415 | 230 | 0.00 | 0 | 33.19 | 0.00 | 1 | 73.76 | 3.77 | 278.08 | 1 | 8.000 | 60 | 4 | 415 | 230 | 117.20 | 1138.26 | 0.322 | 0.198 | Hence OK |
| Grid, L-L | 6.55 | 250 | 0.00 | 1.64 | 272.22 | 0.166 | 0.210 | 343.88 | 8 | 10 | 3 | 7 | 0 | 4 | 415 | 230 | 73.34 | 4 | 33.19 | 132.77 | 0 | 73.76 | 3.77 | 0.00 | 0 | 4.750 | 45 | 4 | 415 | 230 | 0.00 | 549.99 | 0.336 | 0.166 | Hence OK |
| Grid, M-M | 5.32 | 400 | 0.00 | 2.13 | 237.39 | 0.112 | 0.210 | 446.46 | 8 | 8 | 3 | 7 | 0 | 4 | 415 | 230 | 46.94 | 4 | 33.19 | 132.77 | 0 | 73.76 | 3.77 | 0.00 | 0 | 4.750 | 37 | 4 | 415 | 230 | 0.00 | 626.17 | 0.295 | 0.112 | Hence OK |
| Grid, N-N | 9.23 | 400 | 0.00 | 3.69 | 626.88 | 0.170 | 0.210 | 775.07 | 12 | 8 | 3 | 7 | 0 | 4 | 415 | 230 | 70.41 | 4 | 33.19 | 132.77 | 0 | 73.76 | 3.77 | 0.00 | 0 | 4.750 | 63 | 4 | 415 | 230 | 0.00 | 978.25 | 0.265 | 0.170 | Hence OK |
| Grid, O-O | 5.75 | 400 | 0.00 | 2.30 | 395.52 | 0.172 | 0.210 | 482.58 | 8 | 8 | 0 | 7 | 3 | 4 | 415 | 230 | 35.94 | 4 | 33.19 | 132.77 | 0 | 73.76 | 3.77 | 0.00 | 0 | 4.750 | 40 | 4 | 415 | 230 | 0.00 | 651.29 | 0.283 | 0.172 | Hence OK |
| Grid, P-P | 5.75 | 400 | 0.00 | 2.30 | 49.21 | 0.021 | 0.210 | 482.58 | 4 | 10 | 3 | 7 | 0 | 4 | 415 | 230 | 36.67 | 4 | 33.19 | 132.77 | 0 | 73.76 | 3.77 | 0.00 | 0 | 4.750 | 40 | 4 | 415 | 230 | 0.00 | 652.02 | 0.284 | 0.021 | Hence OK |
| Grid, Q-Q | 4.15 | 250 | 0.00 | 1.04 | 174.69 | 0.169 | 0.210 | 217.61 | 4 | 8 | 0 | 7 | 3 | 4 | 415 | 230 | 17.97 | 4 | 33.19 | 132.77 | 0 | 73.76 | 3.77 | 0.00 | 0 | 4.750 | 29 | 4 | 415 | 230 | 0.00 | 368.35 | 0.355 | 0.169 | Hence OK |
| | 6.30 | 400 | 0.00 | 2.52 | 438.61 | 0.174 | 0.210 | 529.20 | 8 | 8 | 0 | 7 | 3 | 4 | 415 | 230 | 35.94 | 4 | 33.19 | 132.77 | 0 | 73.76 | 3.77 | 0.00 | 0 | 4.750 | 43 | 4 | 415 | 230 | 0.00 | 697.91 | 0.277 | 0.174 | Hence OK |
| Grid, R-R | 1.60 | 400 | 0.00 | 0.64 | 38.84 | 0.061 | 0.210 | 134.40 | 4 | 10 | 3 | 7 | 0 | 4 | 415 | 230 | 36.67 | 4 | 33.19 | 132.77 | 0 | 73.76 | 3.77 | 0.00 | 0 | 4.750 | 12 | 4 | 415 | 230 | 0.00 | 303.84 | 0.475 | 0.061 | Hence OK |
| Grid, S-S | 10.45 | 400 | 0.00 | 4.18 | 694.85 | 0.166 | 0.210 | 877.38 | 12 | 8 | 0 | 7 | 3 | 4 | 415 | 230 | 53.91 | 4 | 33.19 | 132.77 | 0 | 73.76 | 3.77 | 0.00 | 0 | 4.750 | 71 | 4 | 415 | 230 | 0.00 | 1064.06 | 0.255 | 0.166 | Hence OK |
| Grid, T-T | 12.24 | 400 | 5.08 | 2.87 | 438.55 | 0.153 | 0.210 | 601.78 | 12 | 8 | 0 | 7 | 3 | 4 | 415 | 230 | 53.91 | 4 | 33.19 | 132.77 | 0 | 73.76 | 3.77 | 0.00 | 0 | 4.750 | 49 | 4 | 415 | 230 | 0.00 | 788.45 | 0.275 | 0.153 | Hence OK |
| Grid, U-U | 13.84 | 400 | 4.99 | 3.54 | 515.14 | 0.146 | 0.210 | 743.40 | 0 | 8 | 0 | 7 | 0 | 4 | 415 | 230 | 0.00 | 0 | 33.19 | 0.00 | 1 | 73.76 | 3.77 | 278.08 | 1 | 8.000 | 60 | 4 | 415 | 230 | 117.20 | 1138.68 | 0.322 | 0.146 | Hence OK |

## 8.4 CONCLUSION AND RECOMMENDATION

The following retrofit options are recommended.

| Grid ID | Retrofit Option |
|---|---|
| Grid K-K | Full jacketing with 7mm diameter bar @ 150mm c/c spacing, single face.<br>**Vertical bars:** 7mm diameter, 150mm c/c spacing<br>**Horizontal bars:** 7mm diameter, 150mm c/c spacing |
| Grid L-L | **Vertical Splint:** 300mm wide, 50mm thick, 3-10mm bar, both side<br>**Horizontal bandage:** 300mm wide, 50mm thick, 3-7mm bar, both side |
| Grid M-M and N-N | **Vertical Splint:** 300mm wide, 50mm thick, 3-8mm bar, both side<br>**Horizontal bandage:** 300mm wide, 50mm thick, 3-7mm bar, both side |
| Grid O-O, Q-Q, S-S and T-T | **Vertical Splint:** 300mm wide, 50mm thick, 3-8mm bar, both side<br>**Horizontal bandage:** 300mm wide, 50mm thick, 3-7mm bar, both side |
| Grid 1-1 ,4-4 | **Pier:** Full jacketing with 7mm diameter bar @ 150mm c/c spacing, both faces.<br>**Horizontal bandage:** 300mm wide, 50mm thick, 3-7mm bar, both side |
| Grid 2-2 | **Vertical Splint:** 300mm wide, 50mm thick, 3-8mm bar, both side<br>**Horizontal bandage:** 300mm wide, 50mm thick, 3-7mm bar, both side |
| Grid 3-3 | **Vertical Splint:** 300mm wide, 50mm thick, 3-7mm bar, both side<br>**Horizontal bandage:** 300mm wide, 50mm thick, 3-7mm bar, both side |

# 9 NHSSP'S RESPONSE ON REVIEWERS' COMMENTS & SUGGESTION

The following are the NHSSP's response on Comments/Suggestion from Peer Reviewer on the consultation meeting conducted on 19th June 2018 at NHSSP office & during Field Visit on June 7-9, 2018

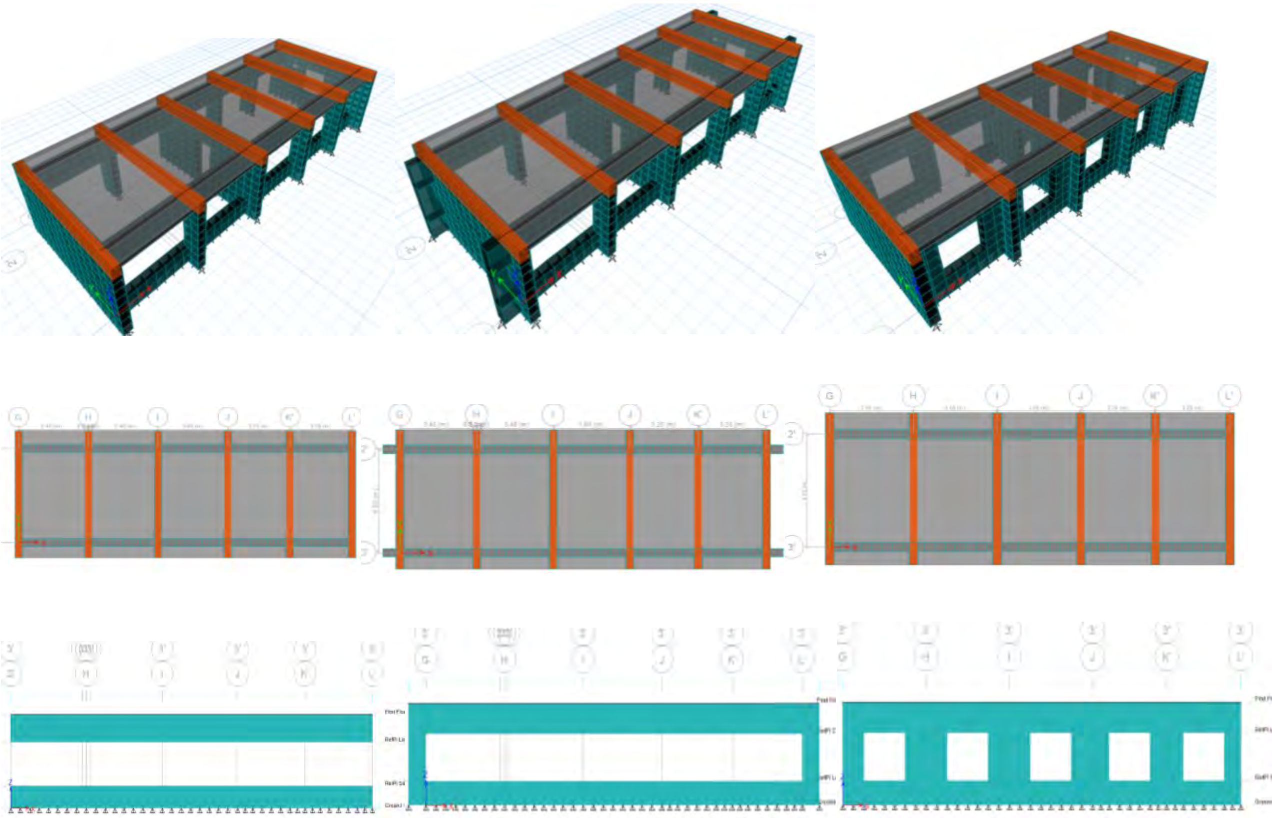
**<u>Reviewer's Comments # 1 :</u>**

In the Pharmacy Block,

- Check for existing building without deducting opening as an alternative option adding buttress in longitudinal direction and/or bands for shear transfer.

**<u>NHSSP Response</u>:**

Three different cases – 1) Existing building, 2) Building with buttress in longitudinal direction and seismic bands, and 3) building with deducting of opening and seismic bands as shown in the following figures.



**Case – I: Existing Building** **Case-II: Building with buttress & bands** **Case-III: Building with opening reduction**

The following table presents the comparison of the results.

| Description | Case - I | Case –II | Case -III | Remarks |
|---|---|---|---|---|
| Shear strength of the masonry wall (Grid 3-3, outer long wall) | | | | |
| Average Shear Stress in wall | 0.472 N/mm² | 0.365 N/mm² | 0.170 N/mm² | |
| Allowable Shear Stress value (as per test value) | 0.210 N/mm² | 0.210 N/mm² | 0.210 N/mm² | |
| | Unsafe | Unsafe | Safe | |
| Shear resistance due to direct tension in horizontal band | | | | |
| Number of Horizontal Bands | | 3x2 = 6 | 3x2 = 6 | |
| No. of reinforcement | | # 4 - 10 mm | # 3 - 7 mm | |
| Tensile capacity of each band (Diameter bar) | | 39.27 KN | 21.25 KN | |
| Total shear capacity of the wall | | 773.20 KN | 941.50 KN | |
| Shear Stress | | 0.303 N/mm² | 0.277 N/mm² | |
| | | < 0.365 N/mm² (Unsafe) | > 0.170 N/mm² (Safe) | |

From above table, it is cleared that Case-II – addition of four number of buttress in longitudinal direction with seismic bands with 4 nos of 10mm dia bar is not safe in shear stress check. However, Case –III – reducing opening satisfies the shear demand. Based on these results, it is recommended the Case-III – reducing opening with necessary seismic bands for retrofitting solutions.

**Reviewer's Comments # 2 :**

In the Maternity Block:

- Load path correction

**NHSSP Response**: It has already corrected

- Horizontal Diaphragm connection

**NHSSP Response**: **Diaphragm beams have already provided**

- Gable wall framing

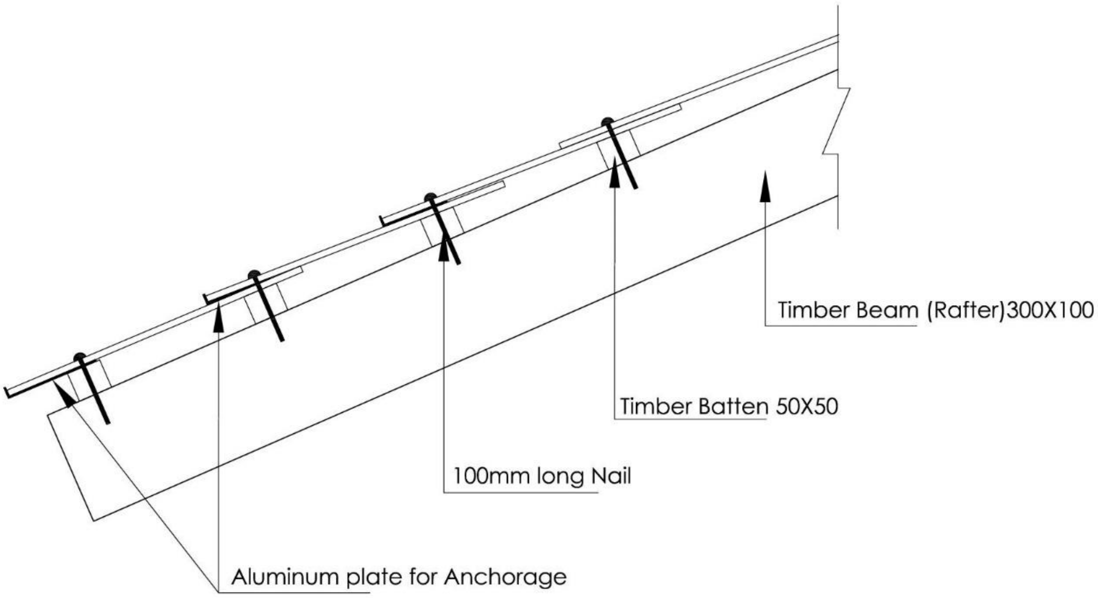
**NHSSP Response**: **Already provided**

- Provision of timber test

**NHSSP Response**: **Already included in BOQ. Will test during construction**

- Slate roof anchoring at least three rows at bottom

**NHSSP Response**: Anchoring of slate at roof are proposed as shown in the following figure.




Slate Anchorage Detail
Scale: 1:10

**NHSSP Response**: **Already provided**

- Expose steel should be covered with concrete or zinc rich paint

**NHSSP Response**: **Included in design and specification**

- No need to reduce gable height after proper framing

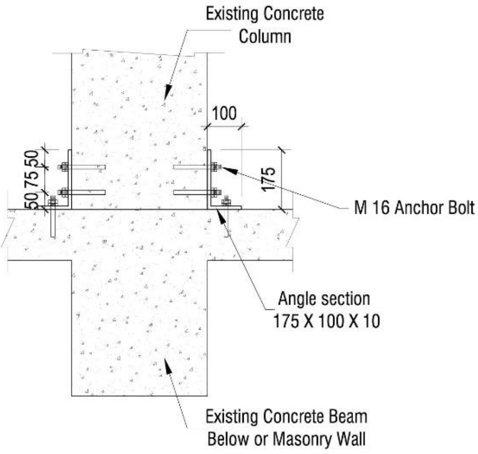
**Reviewer's Comments # 3:**

In Dental Block:

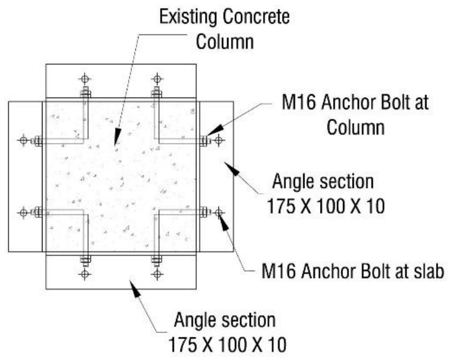
- Check connection of first floor column with slab/beam & request for a deep scanner for check of the connection

- Metal shoe as an option for beam column joints or Concrete confining the wall below the column

**NHSSP Response**: As per suggestion, a metal shoe is included as shown in the following figures




SHOE ANGLE FOR COLUMN SLAB CONNECTION_SECTION




SHOE ANGLE FOR COLUMN SLAB CONNECTION_PLAN

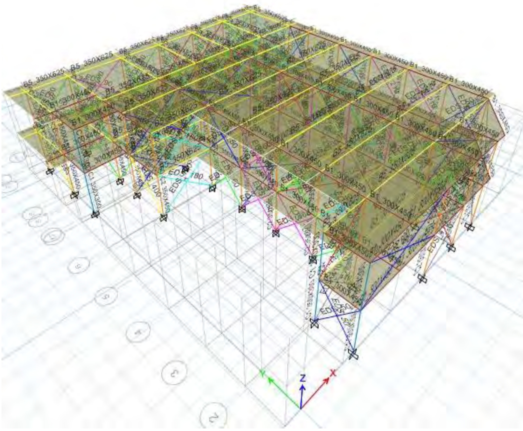
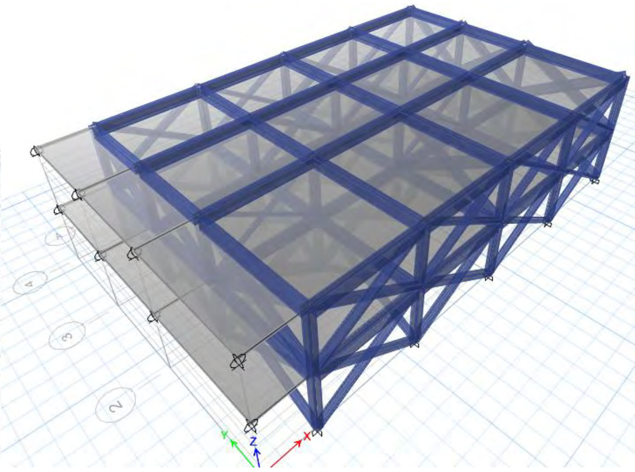
**Reviewer's Comments # 4 :**

In RCC Frame Building – CT Scan & ENT block

- Check for column jacketing for CT scan block
- Consider stiffness of infill masonry wall in frame building analysis

**NHSSP Response**:

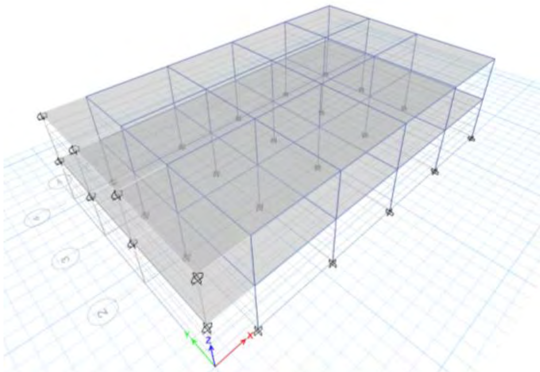
As per reviewers' suggestion, both the RC Frame buildings are analyzed considering stiffness of infill masonry wall. As recommended by IS 1893 2015, the Equivalent Diagonal Strut method is used in order to analyze infill masonry wall as shown in the following figures.

The comparison of the analysis results of EDSM and the bare famed analysis method are presented in the following.

CASE - I: Without consideration of infill masonry

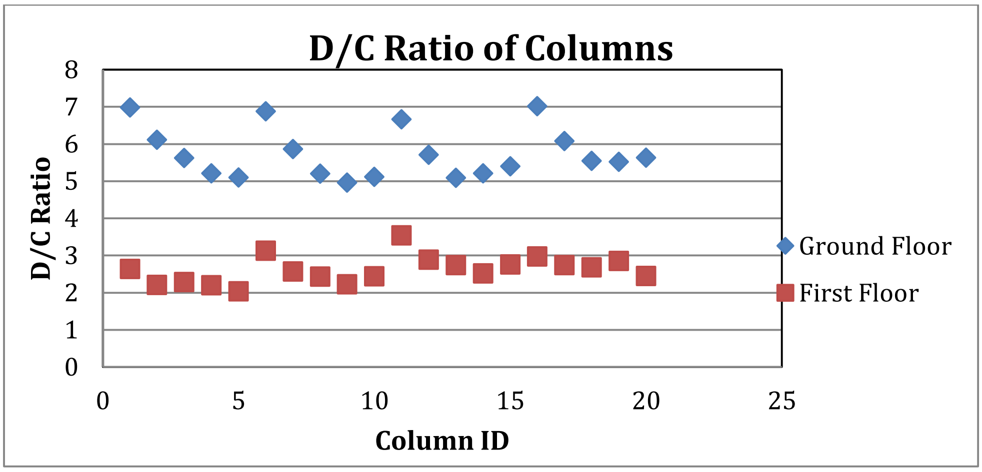
ENT BLOCK



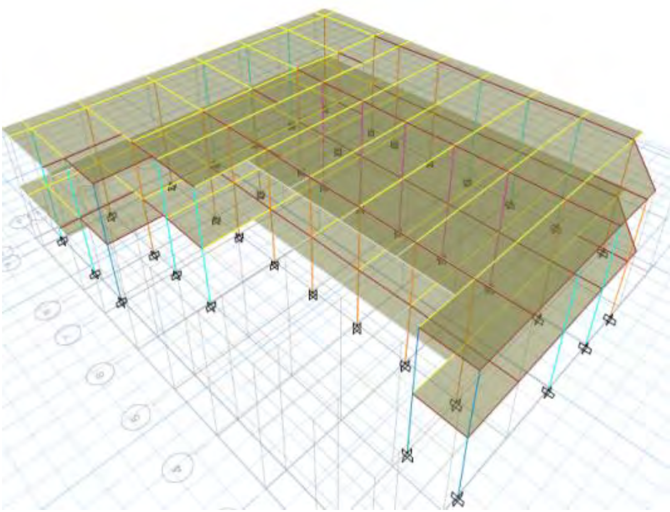
1) Drift Check

| Storey | Elevation | Storey Displacement (mm) | | Storey drift (%) | |
|---|---|---|---|---|---|
| | m | X Dir'n | Y Dir'n | X Dir'n | Y Dir'n |
| Storey2 | 7.240 | 56.302 | 72.177 | 0.595 | 0.747 |
| Storey1 | 3.600 | 34.987 | 45.430 | 0.956 | 1.241 |
| Base | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

2) Demand Capacity Ratio Check



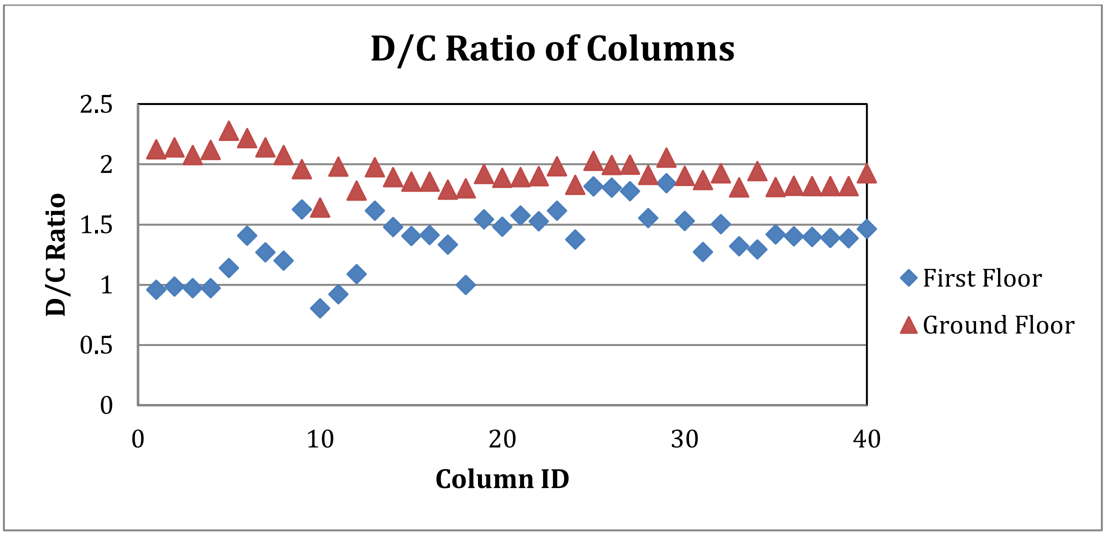

CT SCAN BLOCK



1) Drift Check

| Storey | Elevation | Storey Displacement (mm) | | Storey drift (%) | |
|---|---|---|---|---|---|
| | m | X Dir'n | Y Dir'n | X Dir'n | Y Dir'n |
| Storey2 | 7.000 | 16.254 | 23.512 | 0.193 | 0.276 |
| Storey1 | 3.500 | 9.501 | 13.842 | 0.271 | 0.395 |
| Base | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

2) Capacity Demand Ratio Check



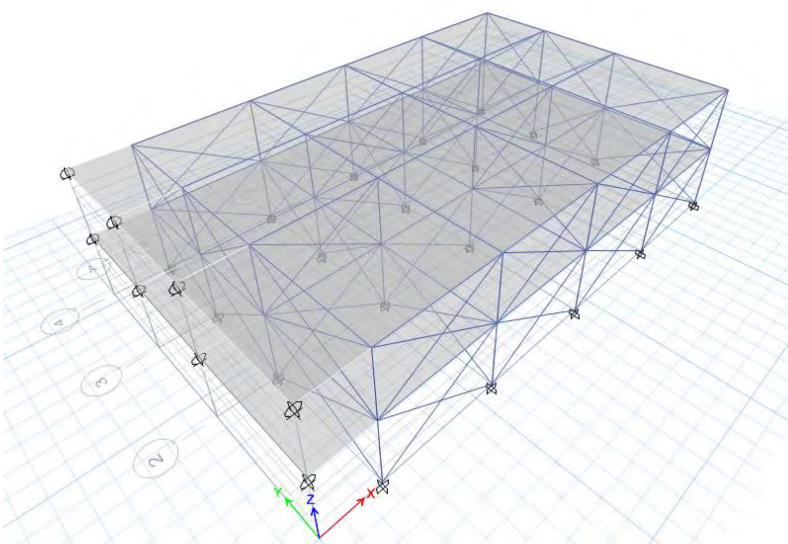

3) Check for Seismic Gap Between ENT Block and CT Scan Block

| | CT Scan | ENT |
|---|---|---|
| Total Displacement | 23.512 mm | 56.302 mm |
| Response reduction Factor (R) | 3 | |
| Gap required: | (23.512+56.302)*3 = 239.44 mm | |

The seismic gap required between CT scan and ENT blocks is 240mm and existing gap between two blocks is about 25mm.Thus the lateral stiffness building should be increased to control lateral displacement in order to control possible seismic.

Case II: Consideration of infill masonry (Equivalent Diagonal Strut method)

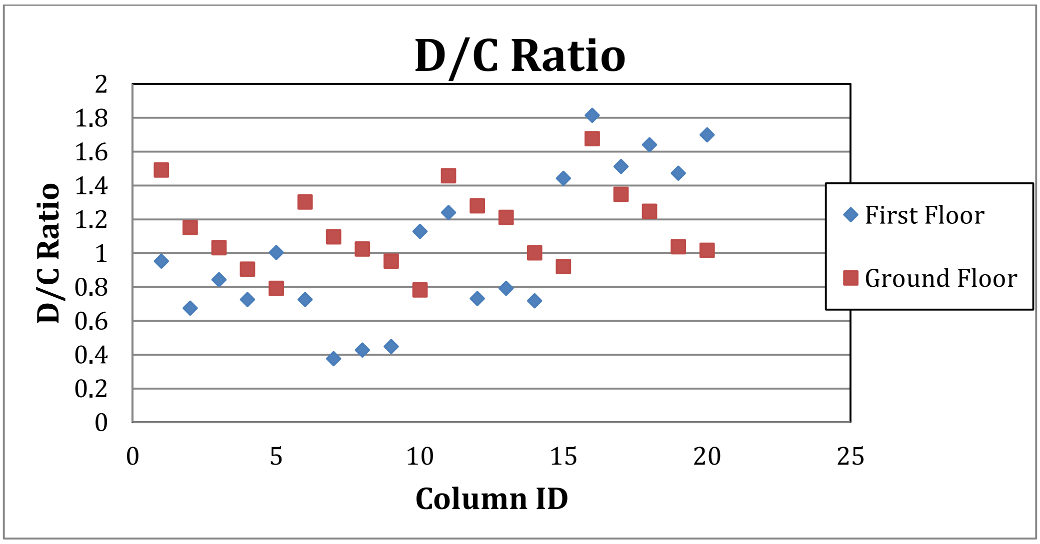
ENT BLOCK

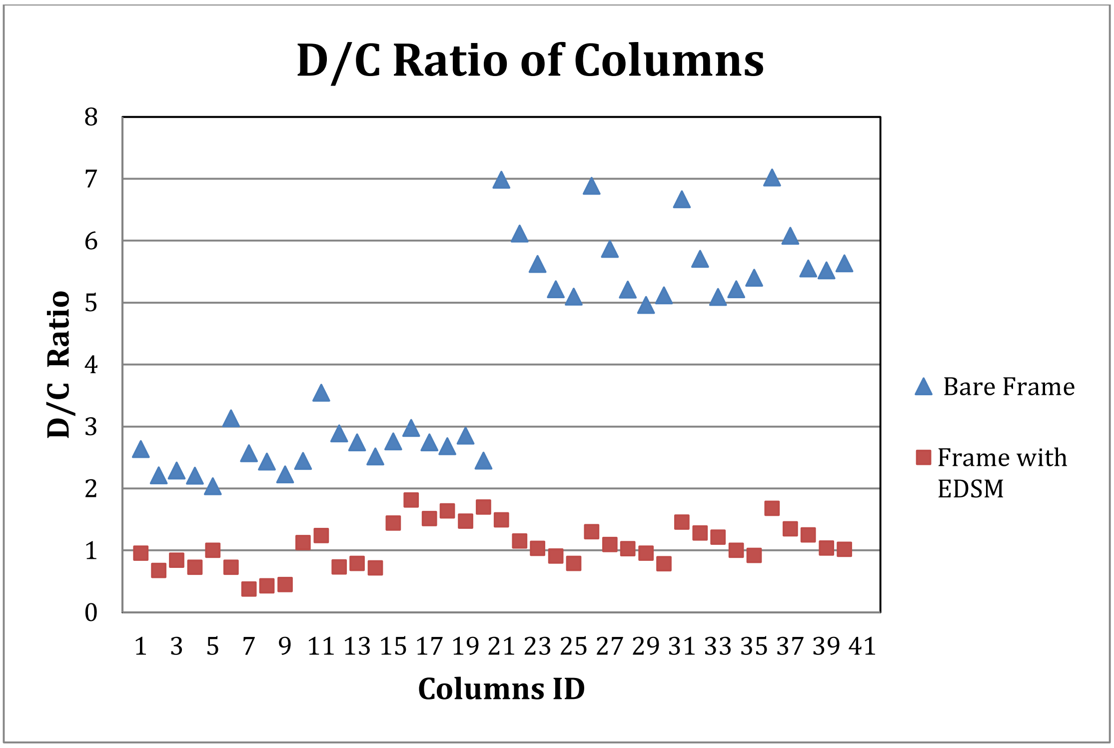


1) Drift Check

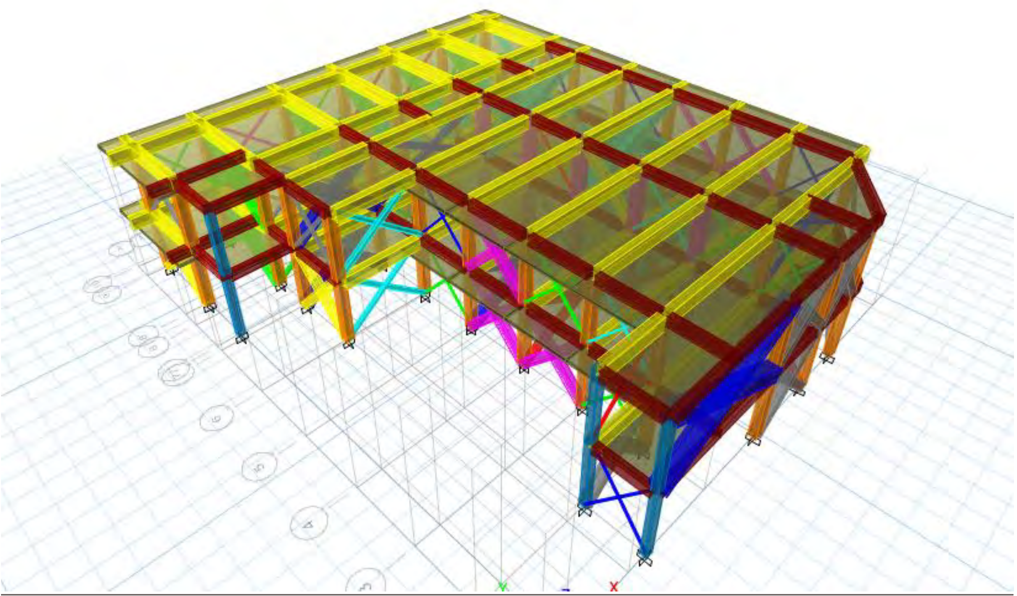
| Storey | Elevation | Storey Displacement (mm) | | Storey drift (%) | |
|---|---|---|---|---|---|
| | m | X Dir'n | Y Dir'n | X Dir'n | Y Dir'n |
| Storey2 | 7.240 | 7.971 | 16.670 | 0.098 | 0.137 |
| Storey1 | 3.600 | 4.459 | 11.766 | 0.122 | 0.321 |
| Base | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

2) Demand Capacity Ratio Check





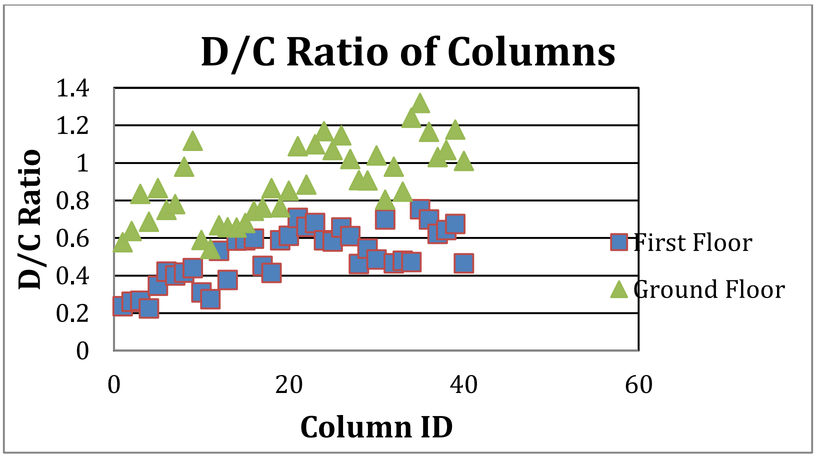

CT SCAN BLOCK

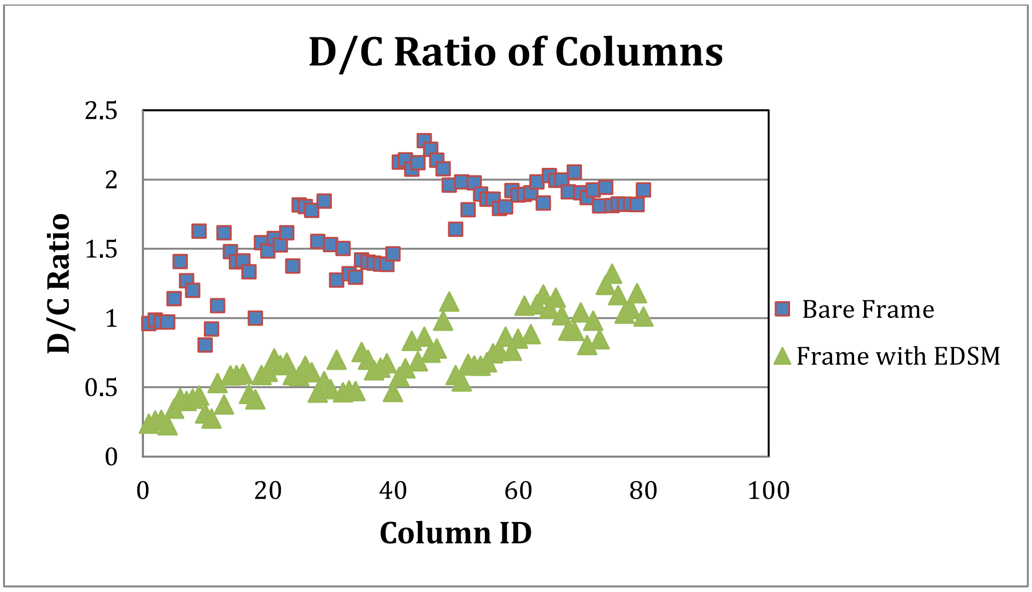


3) Drift Check

| Storey | Elevation | Storey Displacement (mm) | | Storey drift (%) | |
|---|---|---|---|---|---|
| | m | X Dir'n | Y Dir'n | X Dir'n | Y Dir'n |
| Storey2 | 7.000 | 9.946 | 4.923 | 0.103 | 0.063 |
| Storey1 | 3.500 | 6.338 | 2.716 | 0.181 | 0.078 |
| Base | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

4) Capacity Demand Ratio Check




5) Check for Seismic Gap Between ENT Block and CT Scan Block

| | CT Scan | ENT |
|---|---|---|
| Total Displacement | 4.923 mm | 7.971 mm |

| | |
|---|---|
| Response reduction Factor (R) | 3 |
| Gap required: | (4.923+7.971)*3 = 38.682 mm |

The seismic gap required between CT scan and ENT blocks is 38.682mm and existing gap between two blocks is about 25mm.Thus, the lateral stiffness of these buildings should be increased to control lateral displacement for seismic pounding affects.

Based on these results, shear wall with column jacketing is proposed as a retrofitting solution to increase lateral stiffness for controlling lateral displacement

**Reviewer's Comments # 5:**

General: (For all buildings)

- Agree on opening vertical jammer at new construction of walls
- Steel jacketing of stone columns at corridors

**NHSSP Response**:

The steel jacketing has designed and proposed for stone masonry columns at corridors as shown in the following figures

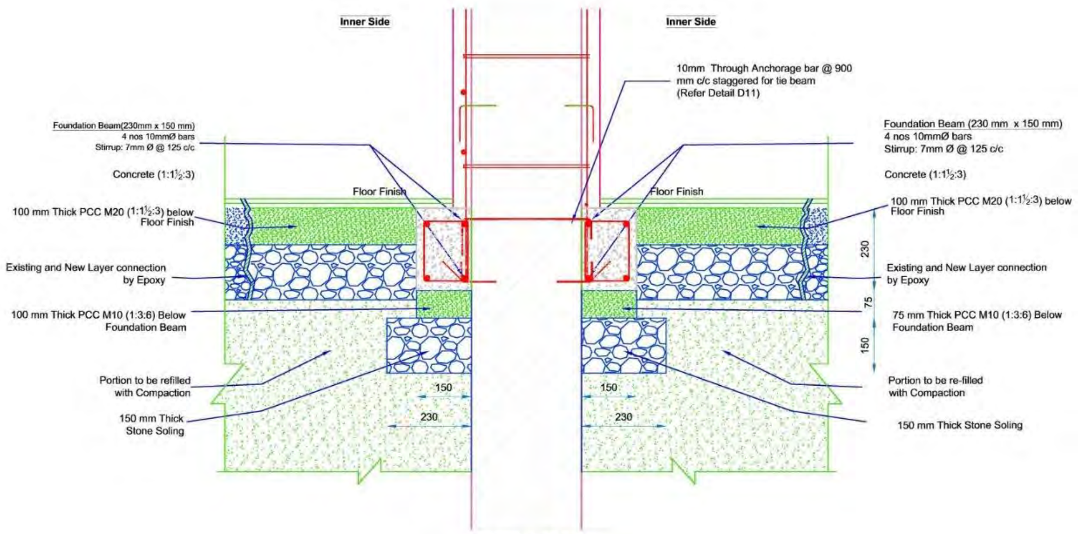

TYPICAL STONE COLUMN STEEL JACKETING DETAIL

SCALE:1:10

- Through anchorage for tie beam @ interval of 1m spacing

  **NHSSP Response**:

  The through anchorage has included for tie beam and other bands as shown in the following figures

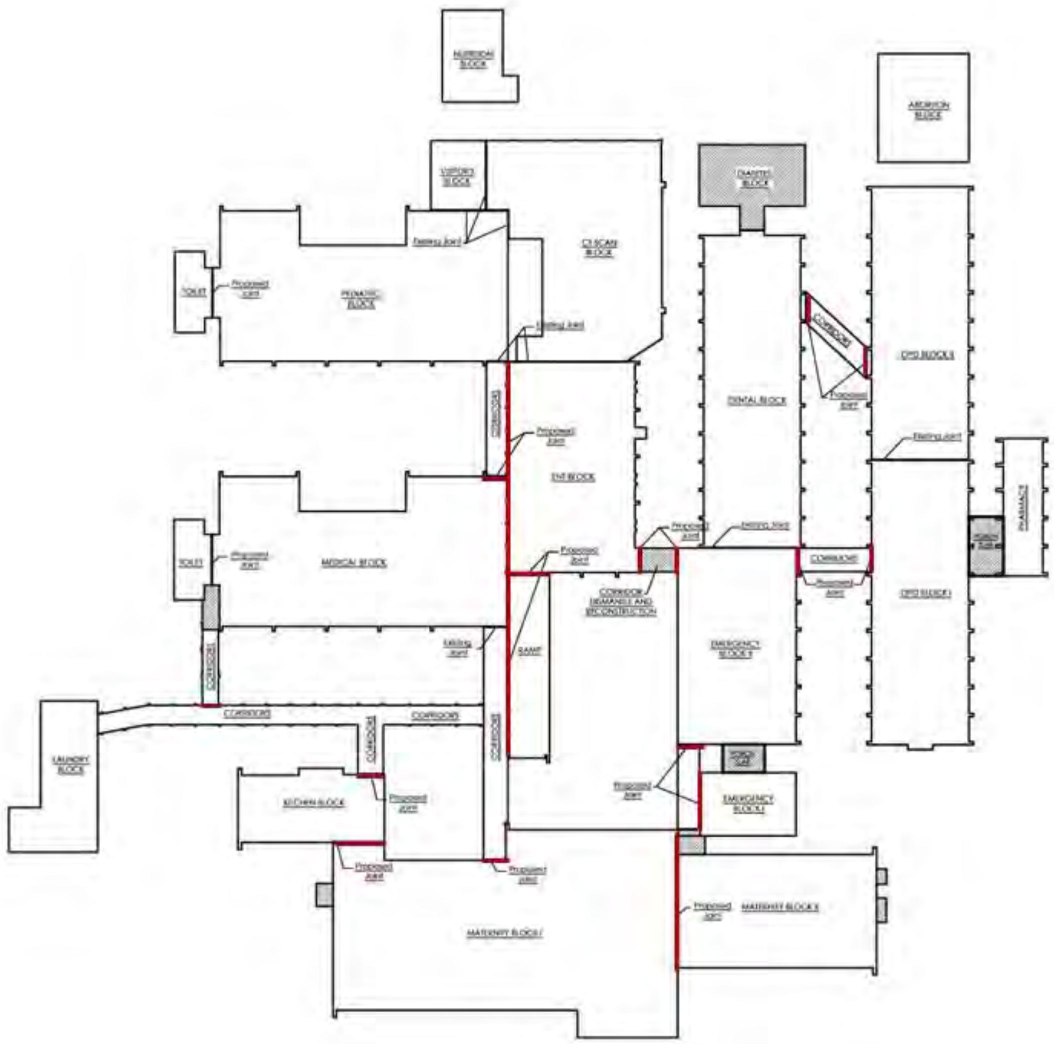



SECTION D2-D2
DETAILS OF TIE BEAM
FOR INNER SIDES OF WALL
SCALE = 1:10

- Separation of blocks from one another

  **NHSSP Response**:

  It has already incorporated. The proposed seismic gap (in red) and the existing gap are as shown in the following figure




Ramp:

- Agree on the proposed plan to demolish of roof cover slab and replace place with light steel structure and column jacketing upto slab level

Visitor Block:

- Agree on the proposed plan to demolish visitor block attached with CT scan block and Pediatric block

**Reviewer's Comments # 6:**

1. Make code uniform for all type of buildings (follow either NBC or IS for both RC or Masonry building)

**NHSSP Response**:

As per suggestion, the RC framed building are analyzed using NBC to make codal uniformity with masonry buildings. Some of the check - torsional irregularity, soft storey, mass irregularity, and eccentricity, which are not available in NBC are assessed using IS1893:2002& IS 1588.2013. The analysis reports of these buildings are included in the report

**Reviewer's Comments # 6:**

Write executive summary defining intervention applied for each building. (Including Reviewer comments and suggestion)

**NHSSP Response**:

As per suggestion an executive summary is included in the report.

# 10 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