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Analysis of MRT compliant buildings as per NBC 105:2020

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Abstract

From 1970 to 2015, there has been a rapid growth in construction of Reinforced Concrete Cement (RCC) buildings in Kathmandu valley. Ready to use dimensions and details provided in Mandatory Rule of Thumb (MRT) issued in 1994 was primarily used for up to three storey ordinary residential buildings. These MRT were designed to meet the Nepal Building Code: NBC 105:1994's minimum seismic safety requirements.
The minimum dimensions and detailing were updated in the draft code of MRT in 2012 which was still based on NBC 105:1994. Later in 2020, NBC 105 code for seismic design of buildings in Nepal was revised.
This paper studies the deficiencies in RCC buildings that has been constructed on the basis of different MRT guidelines. Since the seismic code has been updated and no retrofitting or strengthening guidelines have been issued for the existing MRT complaint buildings, it has become the need of hour to analyze these structures and identify its deficit structural members.This paper examines if the dimensions of frame components and their detailing of MRT compliant buildings is sufficient as per seismic design code NBC 105:2020. Structural analysis of three samples with detailing as per NBC 205:1994, NBC 201:1994 and NBC 205:2012 were done as per NBC 105:2020.

Keywords

MRT, Analysis, Detailing, NBC

1. Introduction

Nepal is prone to earthquake and it is suggested that a major earthquake with moment magnitude (Mw) greater than 8 is likely to occur in Nepal in every 50 to 70 years[1]. Almost half of the buildings in Kathmandu valley were non engineered as per JICA's report in 2002. Such buildings were highly vulnerable to earthquake damage[2]. MRT was issued in 1994 to provide detailing guideline for up to three story reinforced concrete building with floor area less than 1000 sqft to aid for seismic resistant design in local construction.

Due to excessively small RC column size recommended by MRT (NBC 201, 205:1994), as well as an insufficient amount and detailing of reinforcement, RC components in many buildings were unable to effectively resist earthquake-induced forces during the 2015 earthquake[3]. As all the MRTs were based on NBC 105:1994, the buildings that are already built as per those MRTs do not meet the minimum criteria for good seismic performance as per NBC 105:2020. The objective of this research is to analyse MRT compliant buildings as per NBC 105:2020 and identify major structural deficiencies.

2. Methodology

Quantitative structural assessment for three building samples with maximum allowable dimensions and number of storeys complying to the basic requirements of NBC 205:1994[4], NBC 201:1994[5] and NBC 205:2012[2] was done.
The analysis and design was carried out using finite element software ETABS. It creates, modifies, design and analyze the structural components in a building model[6]. The structural deficiencies and performance were assessed for each study.

3. Data Analysis

3.1 Load Calculations as per NBC 105:2020

For the structural analysis, dead loads were calculated based on unit weights of the specified construction materials in accordance with NBC 102:1994[7]. Load combinations and seismic loads were taken as per NBC 105:2020[8].

The buildings are located in Kathmandu and are used for residential purpose, so seismic zoning factor is taken as 0.3, soil type is taken as D and importance factor is taken as 1. The minimum number of bays suggested by MRT is 2 and to account for maximum allowable floor area, 4 bays were taken with maximum allowed bay length i.e 4.5m.

3.2 Sample 1: As per NBC 205:1994- Mandatory Rule of Thumb: Reinforced concrete buildings without masonry infill

The predefined specifications for sample 1 are as follows:

1. Ground floor plinth Area=91.51 sq.m
2. Total height of the building=11m
3. No of storeys=3 plus staircase cover
4. Floor height:
   Ground floor=3.2m
   First floor and second floor=2.8m
   Staircase cover=2.2m
5. Grade of concrete=M15
6. Reinforcement: Fe 415

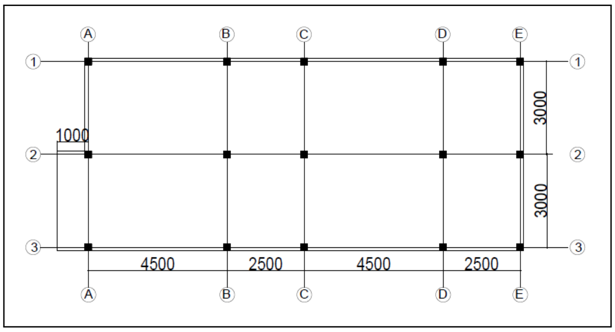

Figure 1: Floor Plan of Building

1. Column Details:
I. Size of Column: 230mmX230mm
II. Longitudinal Reinforcement of column:

Table 1: Column Rebar Detailing

Level	Rebar	Rebar Area(mm^2)
Ground Floor (Corner and Face)	4-16ϕ	803.84
Ground Floor (Interior)	8-12ϕ	904.32
First Floor (Corner and Face)	4-16ϕ	803.84
First Floor (Interior)	8-12ϕ	904.32
2nd+Roof (Corner)	4-16ϕ	803.84
2nd+Roof (Face)	4-12ϕ	452.16

III.Transverse Stirrups in all columns
- For 600mm from ends=8ϕ @100 mm c/c
- Remaining height=6 ϕ @125 mm c/c

2. Beam Details:
I. Size of Beam
- Plinth Beam Size: 200mmX230mm
- All Other Beam: 230mmX325mm

II. Longitudinal Reinforcement in beams
Along X-axis: (Maximum length of bay=4.5m)
For ($4.5 \leq l < 4$); where l = length of bay

Table 2: Beam Rebar Detailing- X Axis

Level	Top Rebar	Top Rebar Area(mm^2)
Plinth	2-12ϕ	226.08
1st	2-16ϕ+3-12ϕ(E)	741.04
2nd	2-16ϕ+1-16ϕ(E)	602.88
3rd+Roof	2-12ϕ+1-12ϕ(E)	339.12

Level	Bottom Rebar	Bottom Rebar Area(mm^2)
Plinth	2-12ϕ	226.08
1st	2-16ϕ+1-16ϕ(E)	602.88
2nd	2-16ϕ+1-12ϕ(E)	514.96
3rd+Roof	2-12ϕ+1-12ϕ(E)	339.12

- Transverse Stirrups:

For all length of beam=6ϕ (Fe250) @150 mm c/c (2 legged stirrups)
Along Y-axis: (Maximum length of bay=3m) Taking detailing for $l \leq 3$

Table 3: Beam Rebar Detailing- Y Axis

Level	Top Rebar	Top Rebar Area(mm^2)
Plinth	2-12ϕ	226.08
1st	2-16ϕ+1-12ϕ(E)	514.96
2nd	2-12ϕ+1-16ϕ(E)	427.04
3rd+Roof	2-12ϕ+1-10ϕ(E)	304.58

Level	Bottom Rebar	Bottom Rebar Area(mm^2)
Plinth	2-12ϕ	226.08
1st	2-16ϕ+1-12ϕ(E)	514.96
2nd	2-12ϕ+1-12ϕ(E)	339.12
3rd+Roof	2-12ϕ	226.08

- Transverse Stirrups ($4.5 \leq l < 3.5$) (All 2 legged Stirrups)

Level	Rebar(mm)
Plinth	6ϕ @ 100mm c/c
1st	End 0.3l-6 ϕ @80 mm c/c remaining 6 ϕ @150 mm c/c
2nd	End 900mm-6 ϕ @100 mm c/c remaining 6 ϕ @150 mm c/c
3rd+Roof	End 600mm-6 ϕ @100 mm c/c remaining 6 ϕ @150 mm c/c

3.Slab Details:
Slab thickness: 100 mm
Reinforcement: Longitudinal Top and Bottom= 8 ϕ @150 mm c/c
Top Distribution Bar= 10 ϕ @150 mm c/c

3.2.1 Analysis as per NBC 105:2020

Here, the height of the building is 11m, so, as per NBC 105:2020, the period of vibration was obtained as 0.566 sec and horizontal base shear coefficient at the Ultimate Limit state(ULS) was found to be 0.131.

3.2.2 Output

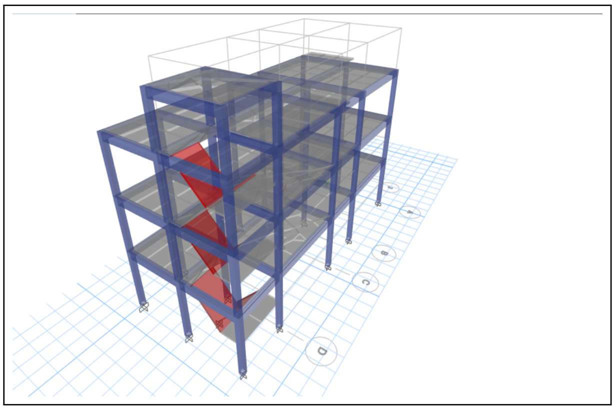

Figure 2: 3D model of Building

1. Story Drift and Displacement
It was found that maximum drift obtained was 0.0039 and 0.009 in EQx and EQy direction respectively. As per NBC 105:2020, maximum allowable drift is 0.00625 and for this sample allowable deflection is 68.75mm. Here, drift value in EQy exceeds the permissible limit. Similarly, maximum displacement was 32mm in EQx and 62.59mm in EQy which is less than allowable maximum displacement of 68.75mm.

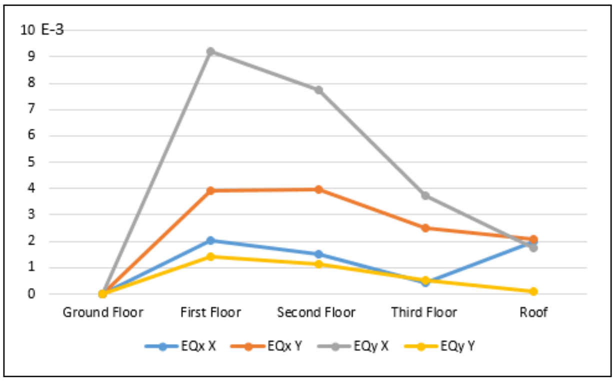

Figure 3: Maximum Story Drift

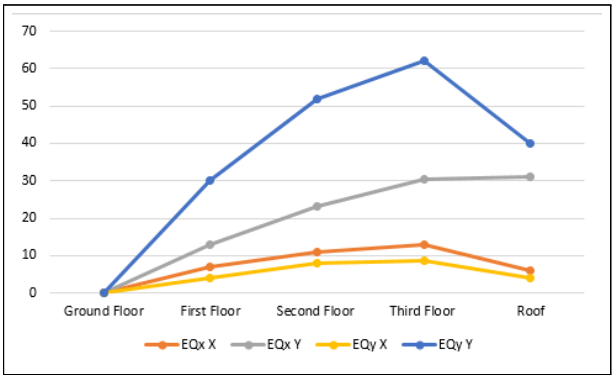

Figure 4: Maximum Story Displacement

2. Concrete frame design results

2.1 Beam
Two concrete member at first floor staircase failed i.e. size of beam used was insufficient.

2.1.1 Longitudinal reinforcement:
Maximum reinforcement required along X axis was 413mm^2 and provided reinforcement was 741.04 mm^2. Maximum reinforcement required along Y axis was 591mm^2 and provided reinforcement was 514.96 mm^2 which is deficit.

2.1.2 Shear reinforcement
Maximum shear reinforcement required was 1273.29 mm^2/m but only 565 mm^2/m was provided.

2.2 Column
Three concrete members failed in ground floor and one failed at first floor.

2.2.1 Longitudinal reinforcement:
Maximum reinforcement required was 2936 mm^2 but only 803.84 mm^2 was provided which is insufficient.

2.2.2 Shear reinforcement:
Maximum shear reinforcement required was 254.94 mm^2/m and provided reinforcement was 565 mm^2/m which is sufficient.

2.3 Slab
The depth and reinforcements used in the slab was found to be sufficient.

3.3 Sample 2: As per NBC 201:1994- Mandatory Rule of Thumb: Reinforced concrete buildings with masonry infill

The predefined specifications for sample 2 are as follows:
1. Ground Floor plinth Area=91.51 sq.m
2. Total Height of the building=11m
3. No of Storeys=3 plus staircase cover
4. Floor height: Ground floor=3.2m
First Floor and Second Floor=2.8m
Staircase cover=2.2m
5. Grade of concrete=M15
6. Reinforcement: Fe 415

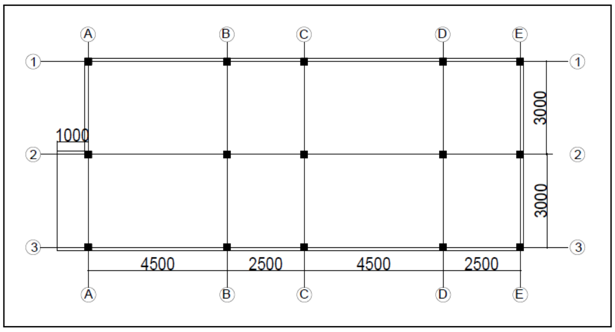

Figure 5: Floor Plan of Building

1. Column Details:
I. Size of Column:
Ground Floor:230mmX300mm
First Floor: 230mmX230mm
II. Longitudinal Reinforcement of column:

Table 4: Column Rebar Detailing

Level	Rebar	Rebar Area(mm^2)
Ground Floor (Corner and Face)	4-16ϕ	803.84
Ground Floor (Interior)	8-12ϕ	904.32
First Floor and All Above	4-12ϕ	452.16

III.Transverse Stirrups in all columns
• For 450mm from ends=8ϕ @75 mm c/c
• For next 500mm s=8ϕ @100 mm c/c
• Remaining height=6 ϕ @100 mm c/c

2. Beam Details:
I. Size of Beam
• Plinth Beam Size: 200mmX230mm
• All Other Beam: 230mmX325mm

II. Longitudinal Reinforcement in beams
Along X-axis: (Maximum length of bay=4.5m)
For (4.5≤ l < 4); where l= length of bay

Table 5: Beam Rebar Detailing- X Axis

Level	Top Rebar	Top Rebar Area(mm^2)
Plinth	2-12ϕ	226.08
1st	2-16ϕ+1-12ϕ(E)	514.96
2nd	2-16ϕ+1-12ϕ(E)	514.96
3rd+Roof	2-12ϕ+1-12ϕ(E)	339.12

Level	Bottom Rebar	Bottom Rebar Area(mm^2)
Plinth	2-12ϕ	226.08
1st	2-16ϕ+1-10ϕ(E)	480.42
2nd	2-16ϕ+1-10ϕ(E)	480.42
3rd+Roof	2-12ϕ+1-12ϕ(E)	339.12

Along Y-axis: (Maximum length of bay=3m) Taking detailing for l≤3

Table 6: Beam Rebar Detailing- Y Axis

Level	Top Rebar	Top Rebar Area(mm^2)
Plinth	2-12ϕ	226.08
1st	2-12ϕ+1-12ϕ(E)	339.12
2nd	2-12ϕ+1-12ϕ(E)	339.12
3rd+Roof	2-12ϕ+1-10ϕ(E)	304.58

Level	Top Rebar	Top Rebar Area(mm^2)
Plinth	2-12ϕ	226.08
1st	2-12ϕ+1-12ϕ(E)	339.12
2nd	2-12ϕ+1-12ϕ(E)	339.12
3rd+Roof	2-12ϕ+1-10ϕ(E)	304.58

• Transverse Stirrups for all sections:
For plinth level=6ϕ (Fe250) @100 mm c/c (2 legged stirrups)
For 1st Floor= End 630mm-8ϕ @90 mm c/c,

remaining 6ϕ @100 mm c/c
For 2nd Floor= End 600mm-8ϕ @100 mm c/c, remaining 6ϕ @150 mm c/c
For 3rd Floor and roof= End 600mm-6ϕ @100 mm c/c, remaining 6ϕ @150 mm c/c

3.Slab Details:
Slab thickness: 100 mm
Reinforcement: Longitudinal Top and Bottom= 8 ϕ @150 mm c/c
Top Distribution Bar= 10 ϕ @150 mm c/c

3.3.1 Analysis as per NBC 105:2020

Here, the height of the building is 11m, so, as per NBC 105:2020, the period of vibration was obtained as 0.566 sec and horizontal base shear coefficient at the Ultimate Limit state(ULS) was found to be 0.131.

3.3.2 Output

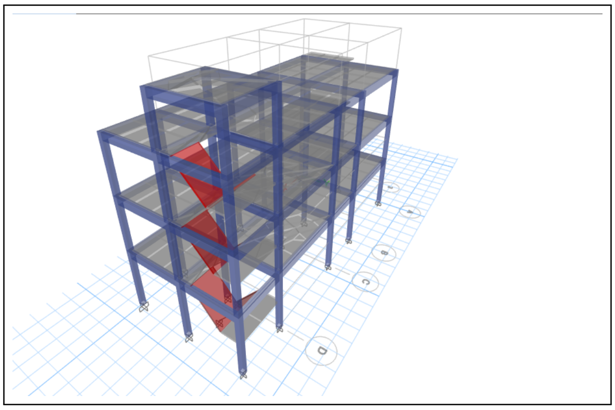

Figure 6: 3d model of building

1. Story Drift and Displacement
From the software analysis, it was found that maximum drift obtained was 0.0037 and 0.007 in EQx and EQy direction respectively. Drift in EQy exceeds the permissible value of 0.00625. Similarly,maximum displacement was 28.11mm in EQx and 46.41 mm in EQy which is less than allowed 68.75mm.

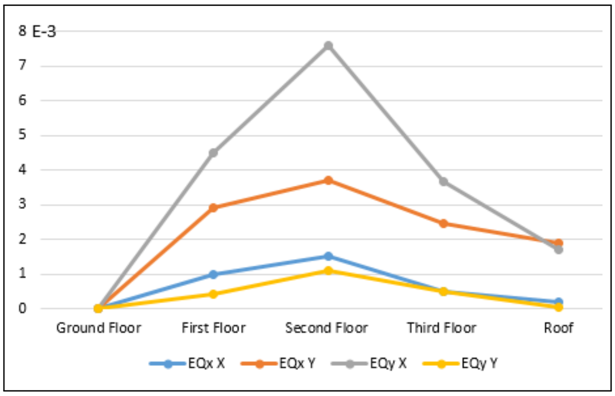

Figure 7: Maximum Story Drift

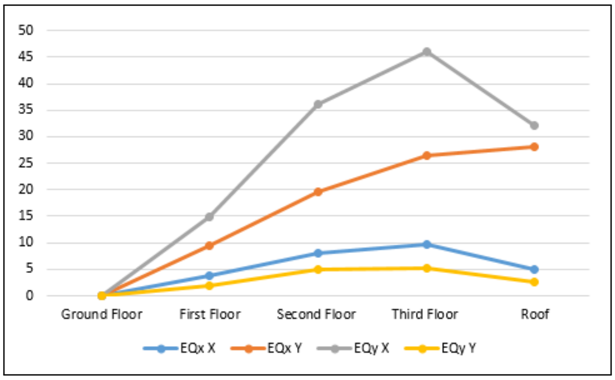

Figure 8: Maximum Story Displacement

2. Concrete frame design results

2.1 Beam
One concrete member failed at first floor staircase failed i.e. size of beam used was insufficient.

2.1.1 Longitudinal reinforcement:
Maximum reinforcement required along X axis was 353 mm^2 and 515 mm^2 was provided. Maximum reinforcement required along Y axis is 527mm^2 but only 339 mm^2 was used which is deficit.

2.1.2 Shear reinforcement
Maximum shear reinforcement required was 1182.4 mm^2/m but only 670 mm^2/m was used which is insufficient.

2.2 Column
All Column members passed i.e.size used is sufficient.

2.2.1 Longitudinal reinforcement:
Maximum reinforcement required was 2982 mm^2 but only 803.84 mm^2 was provided. If 16 mmϕ rebar is used, then total numbers required is 15. Hence, the size of the column is not sufficient to adjust reinforcement requirement.

2.2.2 Shear reinforcement
Maximum reinforcement required was 338.07 mm^2/m while 565 mm^2/m was provided which is sufficient.

2.3 Slab
Slab depth and reinforcement used was sufficient.

3.4 Sample 3: As per NBC 205:2012- Ready to use guideline for detailings of low rise reinforced concrete buildings without masonry infill

The predefined specifications used for sample 3 are as follows:

1. Ground Floor plinth Area=91.51 sq.m
2. Total Height of the building=10.45m
3. No of Storeys= 3 plus staircase cover
4. Floor height:
   Ground floor to second floor=2.75m
   Staircase cover=2.2m
5. Grade of concrete=M20
6. Reinforcement: Fe 415

1. Column Details:
I. Size of Column:300mmX300mm
II. Longitudinal Reinforcement of column:

Table 7: Column Rebar Detailing

Level	Rebar	Rebar Area(mm^2)
Ground Floor (Corner and Face)	4-16ϕ+4-12ϕ	1256
Ground Floor (Interior)	4-16ϕ+4-12ϕ	1256
First Floor (Corner and Face)	4-16ϕ+4-12ϕ	1256
First Floor (Interior)	8-12ϕ	904.32
Second Floor+Roof	8-12ϕ	904.32

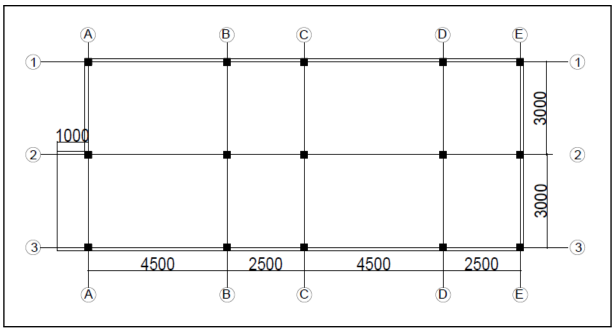

Figure 9: Floor Plan of Building

III.Transverse Stirrups in all columns
- For 600mm from ends=8ϕ @100 mm c/c
- Remaining height=8 ϕ @150 mm c/c

2. Beam Details:
I. Size of Beam
- Plinth Beam Size: 230mmX230mm
- All Other Beam: 230mmX350mm

II. Longitudinal Reinforcement in beams
Along X-axis: (Maximum length of bay=4.5m)
For ($4.5 \leq l < 4$); where l= length of bay

Table 8: Beam Rebar Detailing- X Axis

Level	Top Rebar	Top Rebar Area(mm^2)
Plinth	2-12ϕ	226.08
1st	2-16ϕ+1-16ϕ(E)	602.88
2nd	2-16ϕ+3-12ϕ(E)	565.2
3rd+Roof	2-12ϕ+1-12ϕ(E)	339.12

Level	Bottom Rebar	Bottom Rebar Area(mm^2)
Plinth	2-12ϕ	226.08
1st	2-16ϕ+1-12ϕ(E)	514.96
2nd	2-16ϕ+3-12ϕ(E)	565.2
3rd+Roof	2-12ϕ	226.08

Along Y-axis: (Maximum length of bay=3m) Taking detailing for $l \leq 3$

Table 9: Beam Rebar Detailing- Y Axis

Level	Top Rebar	Top Rebar Area(mm^2)
Plinth	2-12ϕ	226.08
1st	2-16ϕ+1-12ϕ(E)	514.96
2nd	2-12ϕ+1-16ϕ(E)	427.04
3rd+Roof	2-12ϕ	226.08

Level	Bottom Rebar	Bottom Rebar Area(mm^2)
Plinth	2-12ϕ	226.08
1st	2-16ϕ+1-12ϕ(E)	514.96
2nd	3-12ϕ	427.04
3rd+Roof	2-12ϕ	226.08

- Transverse Stirrups for all sections:(All 2 legged stirrups)

For plinth level=8ϕ @150 mm c/c
1st Floor= End(2D from column) 8 ϕ @100 mm c/c, remaining 8 ϕ @150 mm c/c

2nd Floor= End(2D from column) 8 ϕ @100 mm c/c, remaining 8 ϕ @150 mm c/c
3rd Floor and roof= End(2D from column) 8 ϕ @100 mm c/c, remaining 8 ϕ @150 mm c/c

3.Slab Details:
Slab thickness: 125 mm
Reinforcement: Longitudinal Top and Bottom= 8 ϕ @150 mm c/c
Top Distribution Bar= 8 ϕ @150 mm c/c

3.4.1 Analysis as per NBC 105:2020

Here, the height of the building is 10.45m. As per NBC 105:2020, the period of vibration was obtained as 0.545 sec and horizontal base shear coefficient at the Ultimate Limit state(ULS) was found to be 0.131.

3.4.2 Output

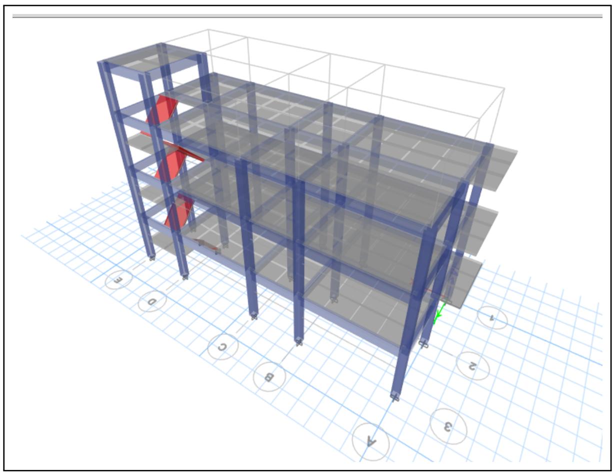

Figure 10: 3d model of building

1. Story Drift and Displacement
From the software analysis, it was found that maximum drift obtained was 0.001 and 0.003 in EQx and EQy direction respectively. Both values are less than allowed maximum drift of 0.00625.

Similarly,maximum displacement was 14.33mm in EQx and 21.73 mm in EQy. Both values are less than allowed displacement of 65.31mm.

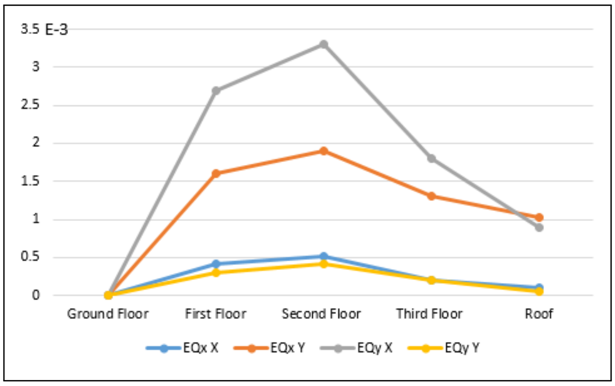

Figure 11: Maximum Story Drift

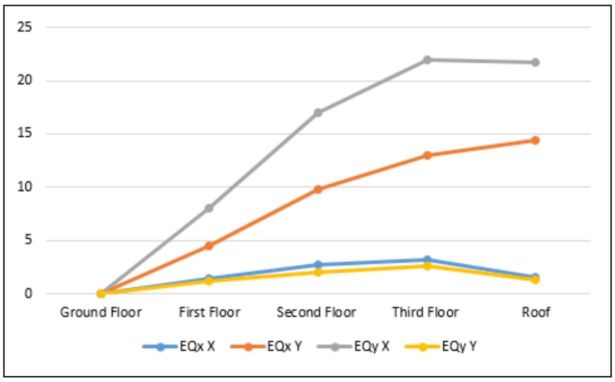

Figure 12: Maximum Story Displacement

2. Concrete frame design results

2.1 Beam
All concrete member passed i.e. size of beam provided was sufficient.

2.1.1 Longitudinal reinforcement:
Maximum reinforcement required along X axis was 311 mm^2 and 602.88mm^2 was provided. Similarly, maximum reinforcement required along Y axis was 410 mm^2 and 514.96 mm^2 was provided. Thus, the longitudinal reinforcement provided was sufficient.

2.1.2 Shear reinforcement
Maximum shear reinforcement required was 1081.91 mm^2/m but only 1005mm^2/m was provided. Hence, shear reinforcement was deemed to be insufficient.

2.2 Column
All Column members passed i.e. provided size was sufficient.

2.2.1 Longitudinal reinforcement:
Maximum reinforcement required was 3219mm^2 while reinforcement provided was 1256 mm^2 which is not sufficient.

2.2.2 Shear reinforcement

Maximum shear reinforcement required was 338.07 mm^2/m while 1005mm^2/m was provided which is sufficient.

2.3 Slab
Provided depth and reinforcement of slab was sufficient.

4. Discussion

For sample 1, it was found that four column members and two beam members failed in concrete i.e. provided dimensions were insufficient. Columns were also found to be insufficient in longitudinal reinforcement. The longitudinal reinforcement deemed insufficient along Y axis in beams. Shear reinforcement for beams was found to be deficit as well. The results suggests that overall dimensions and reinforcement of column and beam members must be increased.

For sample 2, all concrete members passed except one beam section. Hence, dimension of beam must be increased. Further, rebars for beams and columns was insufficient for longitudinal reinforcement due to which the size of the member must be increased to adjust additional reinforcements. Similarly, the shear reinforcement for beams were insufficient. Hence, columns and beams are deficit in dimension as well as reinforcements.

For sample 3, all concrete members passed but number of rebars were insufficient for some columns and for shear reinforcement of beams. Stirrups should be increased for beams. Depth of slab was sufficient for all samples.

5. Conclusion

From the sample data, it can be concluded that ready to use dimension, detailing and material properties defined by MRT 205:1994, MRT 201:1994 are not sufficient for seismic loading as per NBC 105:2020. For MRT 205:2012, ductile detailing for beams was deemed to be insufficient. Overall, the performance of sample 3 was better than sample 1 and sample 2 in terms of storey drift and deflection.

Hence, interventions for strengthening i.e. retrofitting is required for such buildings. It is suggested to evaluate the performance of MRT compliant buildings for future studies on case by case basis to opt for suitable retrofitting techniques. The stiffness of brickwall is not considered in this study but can be taken for further research.

References

[1] R. Bilham. Earthquakes in India and the Himalaya: tectonics, geodesy, and history. 2004.

[2] Government of Nepal,Ministry of Physical Planning and Works,Department of Urban Development and Building Construction. *NBC 205 :2012; Ready to use guideline for detailings of low rise reinforced concrete buildings without masonry infill*.

[3] Svetlana Brzev, Bishnu Pandey, Dev Kumar Maharjan, and Carlos Ventura. Seismic vulnerability assessment of low-rise reinforced concrete buildings affected by the 2015 gorkha, nepal, earthquake. 2017.

[4] Government of Nepal,Ministry of Physical Planning and Works,Department of Urban Development and Building Construction. *NBC 205 : 1994; Mandatory rules of thumb reinforced concrete buildings without masonry infill)*.

[5] Government of Nepal,Ministry of Physical Planning and Works,Department of Urban Development and Building Construction. *NBC 201 : 1994; Mandatory rules of thumb reinforced concrete buildings with masonry infill)*.

[6] Nima Sthapit and Nisha Sthapit. Retrofitting of an RC frame building damaged in "April 2015 Gorkha earthquake" in Kathmandu valley. 2021.

[7] Government of Nepal,Ministry of Physical Planning and Works,Department of Urban Development and Building Construction. *NBC 102:1994; Unit weight of materials)*.

[8] Government of Nepal,Ministry of Urban Development. *NBC 105:2020;Seismic design of buildings in Nepal)*.