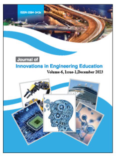

Journal of Innovations in Engineering Education
JIEE 2023, Vol. 6, Issue 1.

https://doi.org/10.3126/jiee.v6i1.56965

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Effects of cantilever projections on seismic performances of RC buildings

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ARTICLE INFO

Article history:

Received 26 July 2023
Revised in 30 Nov 2023
Accepted 16 Dec 2023

Keywords:

Cantilever projections
Response spectrum analysis
Seismic response parameters

Abstract

There is a common practice of extending the cantilever beams/slabs on the upper floors of a building in Nepal either to increase the room size or for aesthetic purposes. It ignores the increased seismic effects due to asymmetry. In most cases, reinforced concrete frame structures are designed without cantilevers. However, in reality, it's not always the same. Hence, the assumed effects during the structural analysis do not reflect the real behavior of the built structural system. This study aims at presenting the effects of cantilever projections in the seismic response parameters of regular RC frame building. For this, 3 and 5 story regular RC buildings along with 3 feet, 4 feet, 5 feet and 6 feet cantilever projections on one and two facades are selected resulting to a total of 18 models. All the models are analyzed using Response Spectrum Analysis method. The results demonstrate that the cantilever projections in regular building cause the significant increment in the seismic response parameters. The fundamental time period is increased by 10.93%, the base shear by 19.67%, the inter-story drift ratio by 52.57% and the overturning moment by 20.36% upon increase in mass by 19.69% due to cantilevers. The torsional moment in column is increased by 3.53 times and bending moment in column by 1.5 times whereas the cantilever deflection has exceeded the allowable limit. Therefore, proper engineering analysis and design is essential for cantilevers to ensure the overall safety and performance of the structure during seismic events.

1. Introduction

Nepal is one of such places that is situated in one of the most active seismic regions of the world. With a varying topography and complicated geology, Nepal has been exposed to many human-induced as well as natural hazards since its very formation. Nepal has a position among the top 20 multi-hazard countries of the world where hazard includes landslides, flood, droughts, extreme temperature, glacier lake outburst floods etc. along with earthquakes. It is ranked 11th in terms of global risk for earthquake occurrence. Global Climate Risk Index ranks Nepal 4th in terms of climate risk.[1]

Cantilevers are very critical when structures are built-in seismic zones. A cantilever can cause dynamic excitation when cyclic loads are applied. Special attention shall be made when cantilevers are designed. A cantilever could move in both upward and downward due to the vertical vibration induced by the earthquake. There will be a hogging bending moment at both top and bottom of the beam. Therefore, adequate reinforcement shall be provided for both the top and bottom of the beam or slab. Adequate shear links shall be provided to maintain the required condiments. This shall be done as per the relevant standards and detailed guidelines.(https://www.structuralguide.com/cantilever-beam)

The structures with different projections can have different response parameters. The difference in mass distribution can have different effect on structure with same projection area.[2] The earthquake performance is negatively affected by the increase in the amount of closed heavy overhang.[3]The overhangs in buildings must be as short as possible. Also, since overhangs

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make load calculation of a building more complex and also decrease earthquake strength of the structure the best choice for the earthquake resistance of the building is not constructing overhangs at all.[4] The seismic analysis of unsymmetrical structure with cantilever depends upon factors which are load distribution, joint displacements, eccentricity between the center of stiffness and the center of mass etc. The seismic behavior of unsymmetrical structures with cantilever sections may cause interruption of force flow and stress concentration. This induces twisting in the structure, which causes an increase in shear force, lateral displacement, and eventually failure. Hence it is necessary to identify an appropriate technique suitable for the analysis of large span cantilevers in unsymmetrical structure.[5]

NBC: 105:2020 code has provisions that cover the required parameters for seismic analysis and design of various building structures to be constructed in the territory of the Federal Republic of Nepal which is also applicable to all types of building structures, low to high rise buildings, in general.[6]

Despite the efforts of researchers to investigate the effects of different kinds of irregularities on the building[7][8][9][10][11][12][13], little attention was paid to consider the asymmetry and irregularity created due to cantilever projections specially in context of Nepal.

Figure 1: Damage of Structure Overhangs during 1999 Turkey Earthquake[4]

2. Objective

The main objective of this research study is to compare the effects of cantilever projections on the seismic response parameters of regular RC structures by analyzing using Response Spectrum Analysis methodology. The next objective is to determine seismic response parameters of regular RC building as well as of RC building with various cantilever projections.

3. Methodology

3.1. Static analysis

The total base shear is distributed throughout the structure's height in this method of seismic analysis. The seismic coefficient, which is determined by the total weight of the structure and the location's exposure to seismic hazards, is used to calculate the base shear. Even though this method is static, it incorporates dynamic structure properties like the fundamental period and response reduction factor. However, this method only works with regular structures whose maximum response is determined by the first vibration mode as majority of the structures of low to mid height would provide maximum response in the first mode.

3.2. Response spectrum analysis

This technique makes advantage of the peak modal responses discovered through dynamic analysis of a system with a single degree of freedom. For the model, the peak acceleration is determined for various periods, and a plot of spectral acceleration vs period results in a curve known as the response spectrum curve. Although the smoothed curve is recommended by the rules, this curve is typically fairly rough. In contrast to high period models, low period models maintain constant values whereas high period models vary them. If the site-specific spectrum is available, there is no need to use the code-specified spectrum. By conducting linear superimposition of modes forms utilizing modal combination techniques like SRSS (square roots of the sum of squares) and CQC (Complete quadratic combination), this methodology is extended to the multi-degree-of-freedom system. The shortcoming of SRSS is that, unlike CQC, it cannot take into account very near modes. Only the peak structural reactions at appropriate damping levels are provided as a consequence of this investigation.

3.3. Building description

For the purpose of this study, a building having regular plan with three bays of 9.84 feet span in the X direction and four bays of 11.48 feet span in the Y direction was considered for both 3 and 5 story. The cantilever width of 3 feet, 4 feet, 5 feet and 6 feet were added in frontal face in both 3 and 5 story. Similarly, the cantilever width of 3 feet, 4 feet, 5 feet and 6 feet were added in frontal and adjacent sides both 3 and 5 story creating a total of 18 models. Similar static approach is used to initially design and approve all models. Following that, response spectrum analysis is used in accordance with NBC 105:2020's clause 3.2.1. The response spectrum method is then used to create all models in accordance with clause 7, taking into account the type of residential building and the location's soil type C. For modeling, ETABS.20 software is utilized. For walls, only the weight of the masonry wall is applied to the underlying member as a uniformly distributed load via manual calculation, taking into account the opening percentage of 30% for outer walls and 20% for inner walls. The beam columns are regarded as the frame elements. The slab is modeled as a shell element with rigid diaphragms at each story level. Three representative models among all the building models considered are as follows:

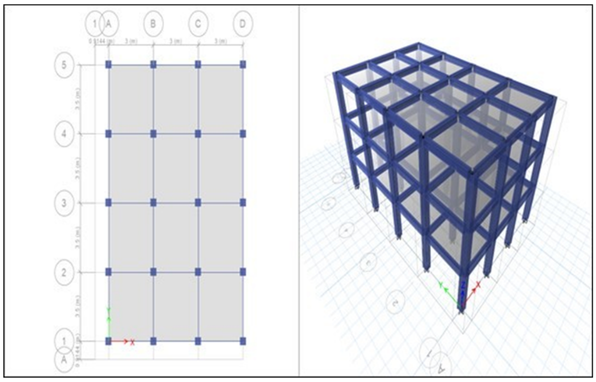

Figure 2: Plan and 3D of 3 story regular model

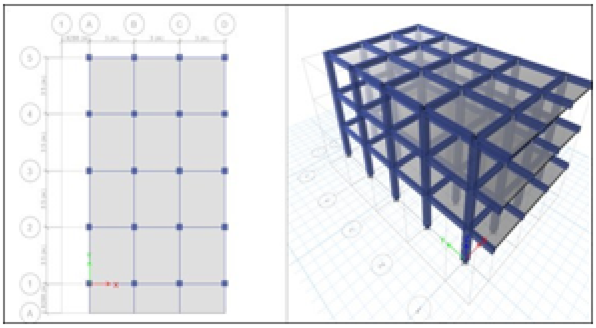

Figure 3: Plan and 3D of 3 story with one side cantilever model

Other data adopted during analysis are given below. Concrete grade of M25 and re-bar as Fe 500 is used for all building models during modeling in ETABs.20.

Inter-story height of building: 9.84 feet

Column Size: 1.31 feet * 1.31 feet

Beam Size: 0.82 feet x 1.23 feet

Depth of Slab: 0.41 feet

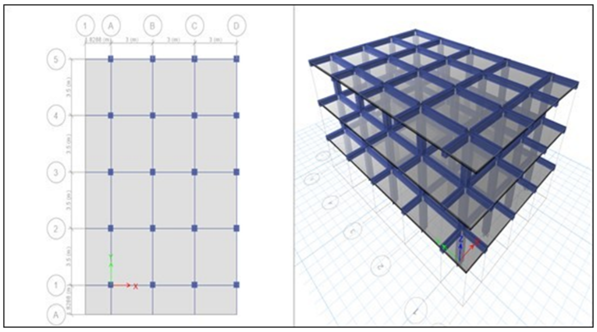

Figure 4: Plan and 3D of 3 story with two sides cantilever model

Table 1: Dead and Live load

Load Type	Intensity (KN/m^2)
Floor Live Load	2.0
Roof Live Load	1.5
Floor Finish	1.5

Table 2: Design Parameters (NBC: 105:2020)

Factor Name	Value
Seismic Zoning Factor (Z)	0.35
Importance Factor (I)	1.00
Overstrength Factor (Ou)	1.50
Ductility Factor (Ru)	4.00
Soil Type	C (SOFT)

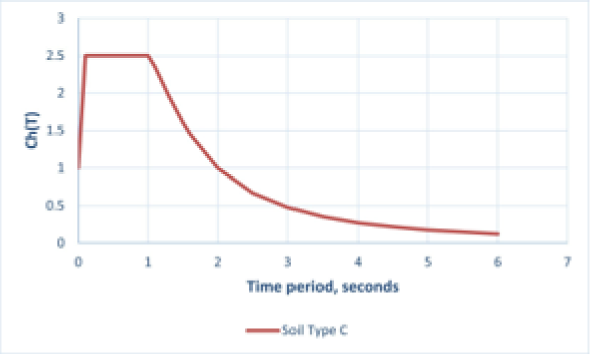

Figure 5: Response Spectrum for Soil Type-C

4. Result and discussions

4.1. Fundamental time period

The fundamental period of vibration depends on the mass and the stiffness of the building system. By addition of the cantilever in the structure, both the stiffness and the mass change and thus the effect is observed in the fundamental period of vibration of a structure.

Table 3: Building models description with notation and mass

No.	Description	Notation	Mass (MT)
1	3-story regular	3-RM	472
2	5-story regular	5-RM	840
3	3-story 1 side 3 ft.	3-C1-3	490
4	3-story 1 side 4 ft.	3-C1-4	496
5	3-story 1 side 5 ft.	3-C1-5	502
6	3-story 1 side 6 ft.	3-C1-6	509
7	3-story 2 sides 3 ft.	3-C2-3	517
8	3-story 2 sides 4 ft.	3-C2-4	533
9	3-story 2 sides 5 ft.	3-C2-5	549
10	3-story 2 sides 6 ft.	3-C2-6	565
11	5-story 1 side 3 ft.	5-C1-3	871
12	5-story 1 side 4 ft.	5-C1-4	882
13	5-story 1 side 5 ft.	5-C1-5	892
14	5-story 1 side 6 ft.	5-C1-6	903
15	5-story 2 sides 3 ft.	5-C2-3	917
16	5-story 2 sides 4 ft.	5-C2-4	945
17	5-story 2 sides 5 ft.	5-C2-5	973
18	5-story 2 sides 6 ft.	5-C2-6	1001

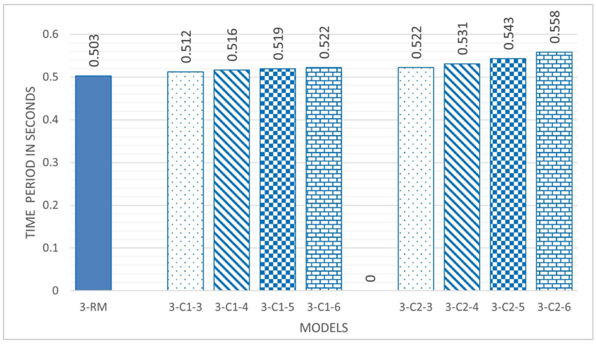

Figure 6: Fundamental Time Period for 3-story models

Figure shows the change of 1.79%, 2.58%, 3.18%, 3.78%, 3.78%, 5.57%, 7.95% and 10.93% in the time period for the increase in mass by 3.73%, 5.09%, 6.39%, 7.69%, 9.44%, 12.80%, 16.21% and 19.69% respectively due to addition of cantilevers in 3 story building. Similarly, it shows the change of 1.87%, 2.42%, 3.08%, 3.74%, 3.30%, 4.85%, 6.94%and 9.69% in the time period for the increase in mass by 3.71%, 4.99%, 6.27%, 7.54%, 9.21%, 12.48%,15.80% and 19.19% respectively due to addition of cantilevers in 5 story building.

4.2. Base shear

Base shear is obtained by multiplying the seismic weight of the structure with the horizontal base shear coefficient as per clause 6.1 of NBC:105:2020. The results for the base shear for all the models from the analysis is shown in figure.

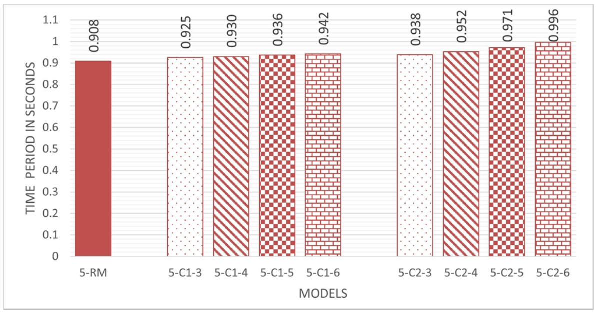

Figure 7: Fundamental Time Period for 5-story models

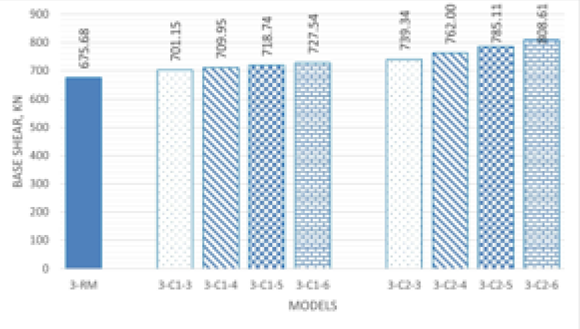

Figure 8: Base Shear for 3-story models

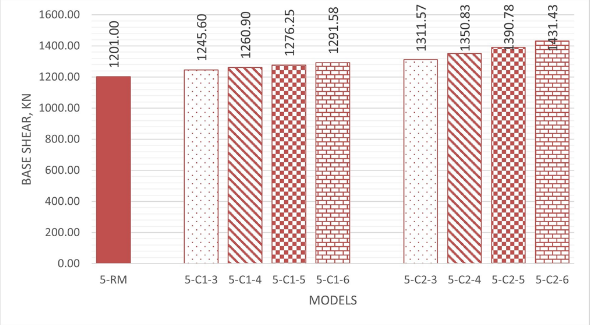

Figure 9: Base Shear for 5-story models

Above figure shows the change of 3.77%, 5.07%, 6.37%, 7.68%, 9.42%, 12.78%, 16.20% and 19.67% in the base shear for the increase in mass by 3.73%, 5.09%, 6.39%, 7.69%, 9.44%, 12.80%, 16.21% and 19.69% respectively due to addition of cantilevers in 3 story building. Similarly, it shows the change of 3.71%, 4.99%, 6.27%, 7.54%, 9.21%, 12.48%,15.80% and 19.19% in the base shear for the increase in mass by 3.71%, 4.99%, 6.27%, 7.54%, 9.21%,12.48%, 15.80% and 19.19% respectively due to addition of cantilevers in 5 story building.

4.3. Inter-story drift

The inter-story drift ratio was calculated corresponding to the maximum roof displacement response for all the models both in X and Y direction. Because story drift beyond a certain level may cause damage to the structure, this parameter is used in performance-based seismic analysis to assess damage.

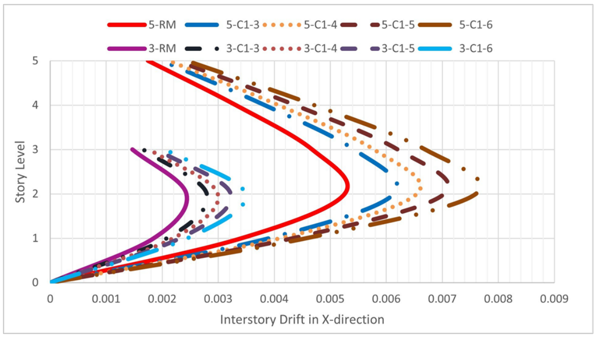

Figure 10: Inter-Story Drift in X-direction of regular building and with one side cantilever projection

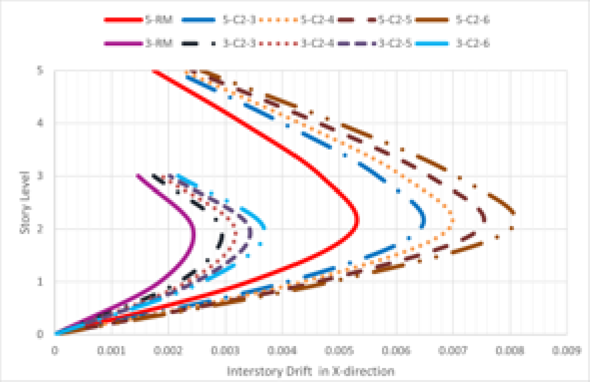

Figure 11: Inter-Story Drift in X-direction of regular building and with two side cantilever projections

Above figure shows the inter-story drift changes by 14.81%, 23.05%, 32.51%, 43.42%, 20.58%, 30.45%, 41.15% and 51.44% for the increase in mass by 3.73%, 5.09%, 6.39%, 7.69%, 9.44%, 12.80%, 16.21% and19.69% respectively due to addition of cantilevers in 3 story building. Similarly, it shows the change of 16.90%, 24.57%, 34.10%, 44.76%, 22.29%, 31.81%,42.29% and 52.57% in the inter-story drift for the increase in mass by 3.71%, 4.99%, 6.27%, 7.54%,9.21%, 12.48%, 15.80% and 19.19% respectively due to addition of cantilevers in 5 story building.

4.4. Torsional moment and bending moment in column

The maximum torsion and bending moment in the column were obtained from response spectrum function in X direction as:

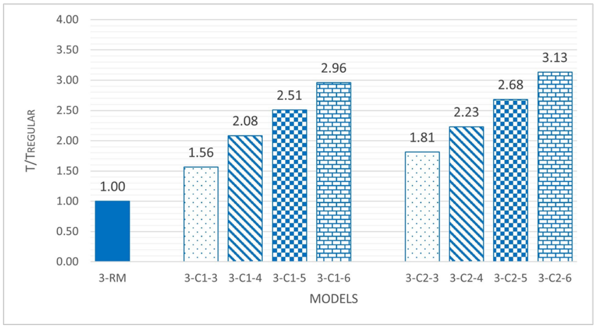

Figure 12: Maximum Torsional moment ratio in X-direction in column of 3-story models

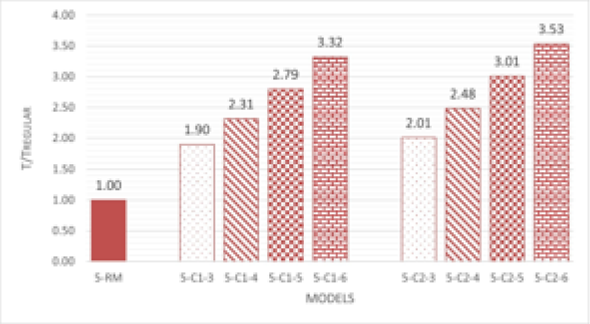

Figure 13: Maximum Torsional moment ratio in X-direction in column of 5-story models

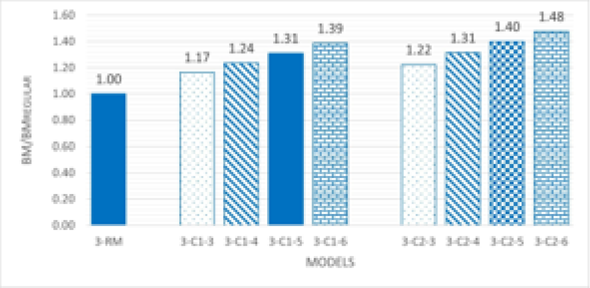

Figure 14: Maximum Bending Moment ratio in column of 3-story models

It is seen that the maximum torsional moment in column is significantly increasing from 1.5 times to 3.53

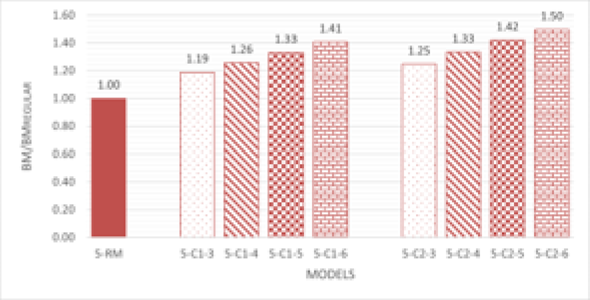

Figure 15: Maximum Bending Moment ratio in column of 5-story models

times when the cantilever projections are added. But, the maximum bending moment in column is increasing upto 1.5 times when the cantilever projections are added. Hence, cantilever projections seem to have major effect on the torsional mode of the building due to creation of irregularity. Also, the results show that the torsion and bending moment depends merely upon the direction of addition of cantilever overhang. The addition of mass creating more asymmetry leads to more torsion and bending moment whereas addition of mass that brings the building towards more symmetry leads to reduction of torsion and bending moment.

4.5. Overturning moment

The maximum overturning moment in the column was obtained from response spectrum function in X direction as:

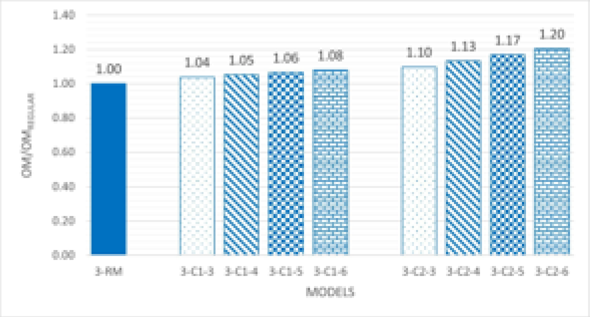

Figure 16: Overturning Moment ratio of 3-story models

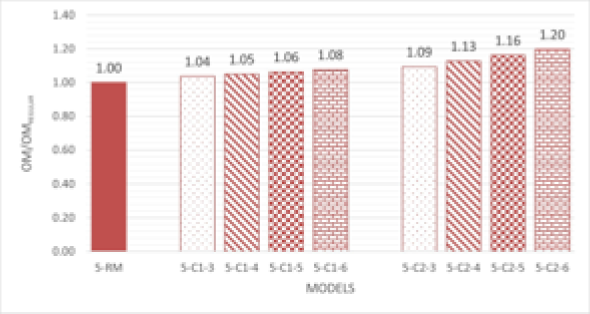

Figure 17: Overturning Moment ratio of 5-story models

Above figure shows the overturning moment changes by 3.83%, 5.16%, 6.50%, 7.83%, 9.72%, 13.20%, 16.75% and 20.36% for the increase in mass by 3.73%, 5.09%, 6.39%, 7.69%, 9.44%, 12.80%, 16.21% and 19.69% respectively due to addition of cantilevers in 3 story building. Similarly, it shows the change of 3.74%, 5.03%, 6.32%, 7.62% 9.39%,12.74%, 16.15% and 19.71% in the overturning moment for the increase in mass by 3.71%, 4.99%, 6.27%, 7.54%, 9.21%, 12.48%, 15.80% and 19.19% respectively due to addition of cantilevers in 5 story building.

4.6. Cantilever deflection

The maximum deflection for one side cantilever was found at around mid-region while for two adjacent sides cantilevers, it was seen at the junction point of two sides cantilevers.

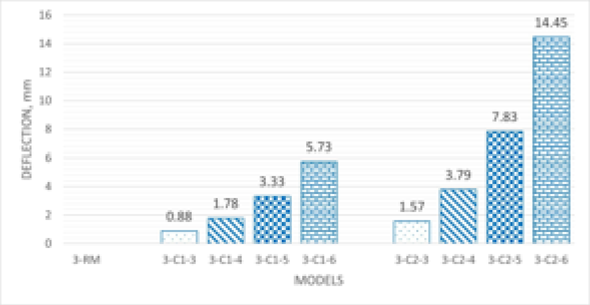

Figure 18: Cantilever Deflection in 3-story models

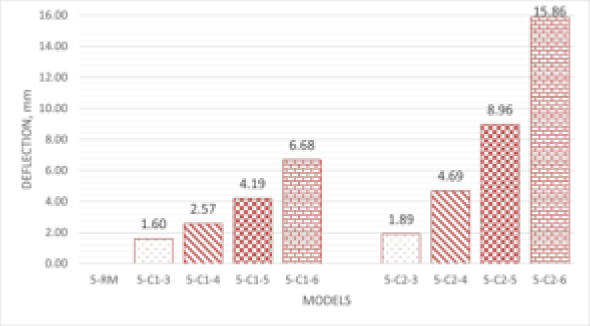

Figure 19: Cantilever Deflection in 3-story models

It is seen that the maximum elastic deflection in the cantilever increases drastically when the cantilever width is increased. In case of 5 feet and 6 feet cantilever projections on two sides, the deflections are found exceeding the allowable deflection limit of L/250. This reflects that on long term plastic deflection, the cantilever overhangs are even more vulnerable. Hence by proper analysis, either the cantilever beam section needs to be redesigned or the projection length needs to be limited.

5. Conclusion

The cantilever projection with overhangs in the buildings have a significant influence on the seismic performance of buildings. The following main conclusions were drawn from the analysis and results of the different models:

1. The fundamental time period increases by 1.79% -10.93% due to change in mass by 3.73%-19.69% for 3 story regular model and by 1.87%-9.69% due to change in mass by 3.71%-19.19% for 5 story regular model due to addition of cantilevers. The time period increases as its directly proportional with the mass of the building. The fundamental time period from the empirical equation of NBC code provides a constant natural time period for same story height building without considering the plan dimensions, mass and stiffness of the building. The Rayleigh method, which is a function of displacement and energy-based method gives significantly greater time period than code provision and lesser than free vibration method.
2. The base shear increases by 3.77% -19.67% due to change in mass by 3.73%- 19.69% for 3 story regular model and by 3.71% -19.19% due to change in mass by 3.71%-19.19% for 5 story regular model due to addition of cantilevers. The base shear increases as its also directly proportional with the mass of the building.
3. 3. The inter-story drift ratio increases by 14.81%-51.44% due to addition in mass by 3.73%-19.69% for 3 story regular model and by 16.90%-52.57% due to addition in mass by 3.71%-19.19% for 5 story regular model due to addition of cantilevers. The result also shows that the drift distribution reaches its maximum value at the 2nd story level and then decreases at the higher levels for all building models in x-direction. The inter story drift ratios of 3 story models are within the permissible limit for both the ultimate limit state (0.025) and the serviceability limit state (0.006) as prescribed by the NBC:105:2020. But for all the 5 story building models except the regular one, the inter story drift ratios are exceeding the permissible limit of both the serviceability limit state (0.006) and the ultimate limit state (0.025).
4. The maximum torsional moment in column is seen to be significantly increasing from 1.5 to 3.53 times when the cantilever projections are added increasing mass by 3.71% up to 19.69%. The maximum bending moment in column is increasing up to 1.5 times for the same cases. Hence, cantilever projections seem to have major effect on the torsional mode of the building due to creation of irregularity. Also,the results show that the torsion and bending moment depends merely upon the direction of addition of cantilever overhang. The addition of mass creating more asymmetry leads to more torsion and bending moment whereas addition of mass that brings the building towards more symmetry leads to reduction of torsion and bending moment.
5. The overturning moment changes by 3.83%-20.36% for the increase in mass of building by 3.73%-19.69% for 3 story models. Similarly, it changes by 3.74%-19.71% for the increase in mass of building by 3.71%-19.19% respectively for 5 story models. Also, the results show that the overturning moment in the building increases as the mass increases irrespective of the direction of the cantilever added.
6. It is seen that the maximum elastic deflection in the cantilever increases drastically when the cantilever width is increased. In case of 5 feet and 6 feet cantilever projections on two sides of both 3 and 5 story, the deflections are found exceeding the allowable deflection limit of L/250. This reflects that on long term plastic deflection, the cantilever overhangs are even more vulnerable. Hence, either the cantilever beam section needs to be redesigned or the projection length needs to be limited.

References

[1] Khanal B N. Nepal: A brief country profile on disaster risk reduction and management[Z]. Ministry of Home Affairs, Government of Nepal, 2020: 1-34.

[2] Saha S. Projection effect on seismic response of square symmetric structure[Z]. 2018.

[3] Ercan I, Akat F. The effect of different heavy overhang on structural performance in reinforced concrete structures[J]. Bitlis Eren Üniversitesi Fen Bilimleri Dergisi, 12(1): 261-271.

[4] Mizan D, Eşref U, Hakan O. Earthquake failures of cantilever projections buildings[J]. Engineering Failure Analysis, 2007, 14(8): 1458-1465.

[5] Pandey S, Bhardwaj A, Pastariya S. Seismic behavior of symmetrical & unsymmetrical structure with cantilever section[J]. 2021.

[6] Banjara R, Thapa D, Katuwal T B, et al. Seismic behaviour of buildings as per nbc 105: 1994, nbc 105: 2020 and is 1893: 2016[J]. 2021.

[7] Akhilesh H, Naveen B. Dynamic analysis of vertical irregular tall structural system[C]// IOP Conference Series: Materials

Science and Engineering: volume 1006. IOP Publishing, 2020: 012021.

[8] Chaudhari A N, Talikoti R. Study of seismic behavior of building with different positions and types of floating column[J]. International Journal of Engineering Science and Computing, 2017, 7(7): 14056-14063.

[9] Chaulagain H, Rodrigues H, Spacone E, et al. Seismic response of current rc buildings in kathmandu valley[J]. Structural Engineering and Mechanics, 2015, 53(4): 791-818.

[10] Dimova S, Negro P. Influence of construction deficiencies on the seismic response of structures[J]. Earthquake Engineering & Structural Dynamics, 2005, 34(6): 613-635.

[11] Nady O, Mahfouz S Y, Taher S E D F. Quantification of vertical irregularities for earthquake resistant reinforced concrete buildings[J]. Buildings, 2022, 12(8): 1160.

[12] Abraham N M, Anitha Kumari SD e a. Analysis of irregular structures under earthquake loads[J]. Procedia Structural Integrity, 2019, 14: 806-819.

[13] Sayyed O, Kushwah S S, Rawat A. Seismic analysis of vertical irregular rc building with stiffness and setback irregularities[J]. IOSR Journal of Mechanical and Civil Engineering, 2017, 14 (01): 40-45.