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EFFECT OF UNAUTHORIZED ADDITION OF STOREYS IN A RESIDENTIAL BUILDING

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Abstract

In Nepal, it has become common practice to add stories and projections, without legal authorization and proper design for these extensions, which has led to much damage as observed in the recent 2015 Gorkha earthquake. Therefore, this paper studies the effect of unauthorized addition of storeys by FE modelling using response spectrum method. Two cases were considered: (1) replication of a typical storey until structural failure, (2) incorporation of 1-ft, 2-ft, and 3-ft extensions along with stepped projections, followed by vertical replication until failure. The study found that base shear and storey drift at the top storey increased with the addition of the first storey due to increased seismic mass but gradually decreased as more storeys were added. The ground and first floors were found to be most vulnerable to structural failure due to unauthorized addition of storeys particularly in cases coupled with horizontal extensions.

Keywords: Vertical extensions; Horizontal extension; Stepped projection; FEM; Seismic analysis

1. Introduction

Nepal lies in the seismically active region between Indian and Eurasian plate. Indian plate slides beneath the Eurasian plate at the rate of 4-5cm per year which is responsible for the frequent tremors and earthquake such as the devastating 2015 earthquake (Liu et al., 2021).That earthquake was a tragic event which ended up taking the lives of 8,790 people and left 22,300 people injured in Nepal alone, nearly 500,000 houses destroyed and over 250,000 houses partly damaged (UNDP, 2016).The damages exposed the weakness of structures that did not have any seismic resistant features or were not in accordance with the building codes. Poor construction quality, structural irregularities, and lack of engineering supervision may be some reasons that made them highly vulnerable to seismic forces. This catastrophic earthquake highlighted the numerous structural deficiencies in the construction practices of Nepal (Dizhur et al., 2016).

Addition of storeys without valid permit to structures that were initially designed for lesser number of storeys are termed as illegal/unauthorized storeys. 'Population growth', 'inadequate space', 'commercialization of facilities' and 'inadequate knowledge of the Building Regulations' are the major causes of addition of unauthorized storeys (Adinyira & Anokye, 2013).

In most cases, addition of storeys is done after construction without prior approval and consent from concerned authorities and horizontal projections are normally attached to the external faces of the main buildings that lead to threats to both passerby and occupants and can be responsible for serious failure in building or its structural member (Adinyira & Anokye, 2013).

1.1. Literature Review

In Ghana, Adinyira and Anokye (2013) identified through a questionnaire survey that growing population, lack of adequate space, commercialization of facilities and improper knowledge of building regulations are the major causes of illegal extension to buildings. Tatoyan and Aramyan (2023) studied how illegal changes in multiapartment buildings led to their damage during the 1988 Spitak earthquake in Armenia. Bahrami et al. (2022) studied the feasibility of vertically extending a specific reinforced concrete building of 3 storey using

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utilization ratio parameter. Al-Nu'man (2016) also studied the ways of adding more floors to an existing building without demolishing it using different concrete strength and design methods. Gunes et al. (2019) evaluated the seismic performance of structure when extra floor was not considered in the original structure.

1.2. Problem Statement and Objective

Large areas are required in city areas like Kathmandu to accommodate the population explosion due to the centralization of population. However, since there is only limited and expensive land in such areas, people opt for the vertical extension and horizontal extensions of existing structures. Such extensions are not taken into consideration during the design stage of the structure. As a result, when the structure is exposed to additional un-designed load, a change in performance of the structure might be encountered, it becomes necessary to study the response of the building under different vertical and seismic loads when there is unauthorized addition of storeys and projections in the building.

The objective of the study is to study the structural response of structural elements due to unauthorized addition of storeys and addition of horizontal projection.

2. FE Modelling

A residential building of 2 bays by 2 bays with G+2 number of storeys was selected. The thickness of slab obtained from preliminary design was 150mm and the sizes of beams and columns obtained from preliminary design were found to be (230 x 300) mm and (186.927 x 186.927) mm respectively. However, for analysis, a slab of thickness 150mm was adopted, size of beam was taken to be (250 x 350) mm, and square columns of (350 x 350) mm cross section were adopted. M20, M30 and M25 grades of concrete were used for slab, columns and beams respectively with M20 grade of concrete also being used for staircases. HYSD 500 rebar was used in reinforcing both beams and columns. Loading was done as per Indian standard (IS) code. Analysis of model was done using Equivalent Lateral Force (ELF) method as well as Response Spectrum method with the help of FEM software ETABS.

The stiffness modification factor for moment of inertia was taken as 0.35 for beams and 0.7 for columns to replicate the real-world conditions.

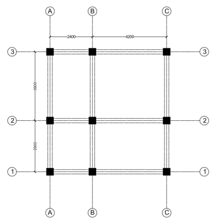
For every model, storey drift and base shear were recorded. The different configurations of vertical and horizontal extensions considered are as follows:

Model 1: 3 Storeyed residential building of 2 bays by 2 bays was modeled.

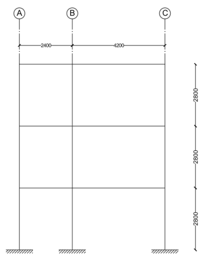
Model 2: Model 1 vertically extended until structural element failure.

Model 3: Model 1 horizontally extended with 1ft, 2ft, 3ft and stepped projection and vertically extended until structural element failure.

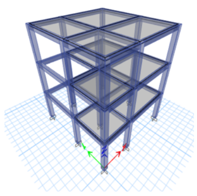
Figure 1 shows the layout and models of different configurations.



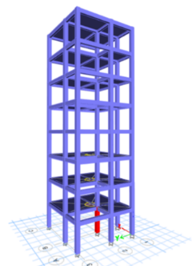
(a) General layout (plan) of the building



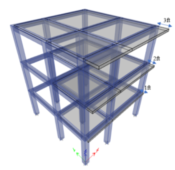
(b) General layout (section) of the building



(c) 3D model of the building



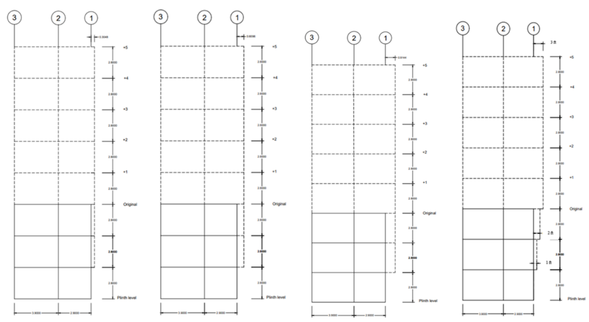
(d) Rendered view of a building after addition of five storeys showing failed members



(e) Rendered view of a building with horizontal extensions

Figure 1: layout and models of different configurations

Figure 2 shows schematic diagrams of different Hz. projection with addition of stories.



(a) 1 Ft (b) 2 Ft (c) 3 Ft (d) Stepped

Figure 2: Schematic diagrams of different horizontal projections with addition of stories.

3. Numerical Results

3.1. Case 1: Effect of Additional Storeys

For the first case study, the building was analyzed, and the requisite parameters (i.e. inter-storey drift and base shear) were recorded. Replicated storeys and their corresponding loads were added to the structure until failure was observed. The required parameters were recorded after each subsequent addition. The variation in each parameter is as shown below in Figure 3-17.

Inter-Storey Drift

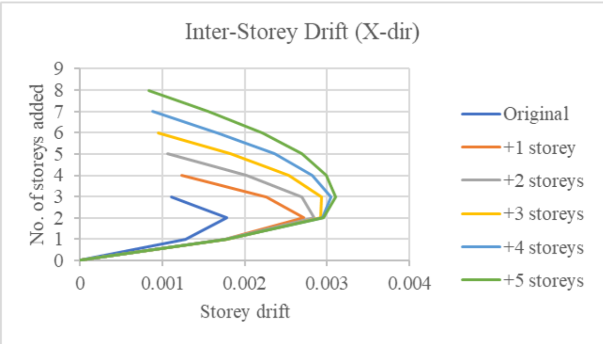


Figure 3: Inter-storey drift in X direction

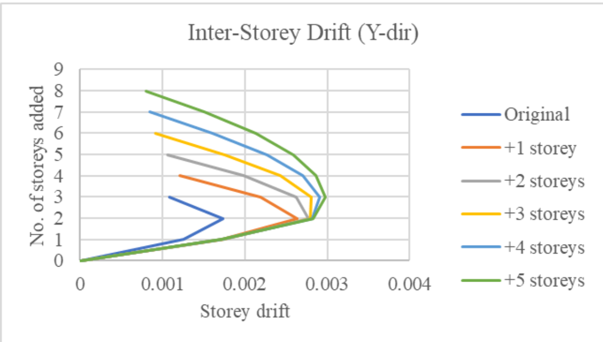


Figure 4: Inter-storey drift in Y direction

Maximum inter-storey drift was noted to have increased with each addition of storey. The maximum storey drift was observed to shift upwards from the second storey to the third after the addition of 3 storeys. The storey drift at the top floor was observed to decrease after the addition of 2 or more storeys.

From the Figure 5 above, we see that the value of base shear increases with the addition of one storey but an unusual decrease in the base shear after addition of two storeys was seen. Generally, the value of base shear is expected to increase with increase in seismic weight of the structure. This is because as the height increases, time period increases and when time period increases, the Spectral Acceleration Coefficient (S_a/g) decreases as per IS 1893 (Part 1):2016. This value is directly proportional

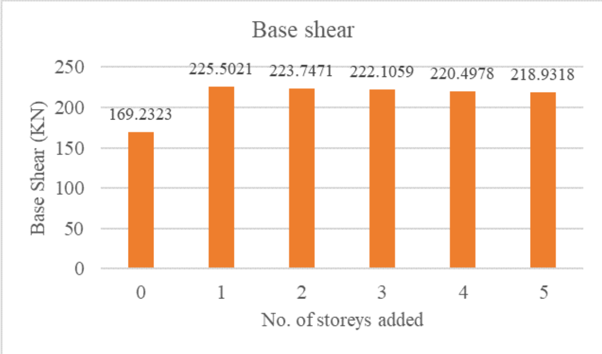


Figure 5: Base Shear

to the horizontal seismic coefficient (A_h). And as the value of Ah decreases the value of base shear also decreases. Mathematically,

$$V_b = A_h \times W$$

Where:

- V_b = Base shear
- A_h = Horizontal seismic coefficient
- W = Seismic weight of the structure

3.2. Case 2: Effect of Additional Stories with Horizontal Extension

In case 2, models with both horizontal and vertical extensions were compared. Models with uniform 1 ft, 2ft and 3ft projections on each storey were prepared. The models with 1 ft. and 2 ft. horizontal extensions were modeled without cantilever beams, whereas the one with 3 feet extensions were modeled with cantilever beams. The comparisons of inter-storey drift and base shear were done in both the x and y directions. Observations were made for each additional storey until building member failure, which occurred on the addition of the fifth storey in all cases. The variations in our study parameter for each model are as shown as follows.

Inter-Storey drift

As seen from Figure 6-11, the values of drift exhibit similar patterns in both X and Y direction. The peak drift values in both directions increases with the addition of storeys with the peak values being obtained at second floor up to the addition of two storeys. However, after the addition of 3 storeys to the original structure the peak value shifts towards the third floor across all the models in both X and Y direction.

Base shear

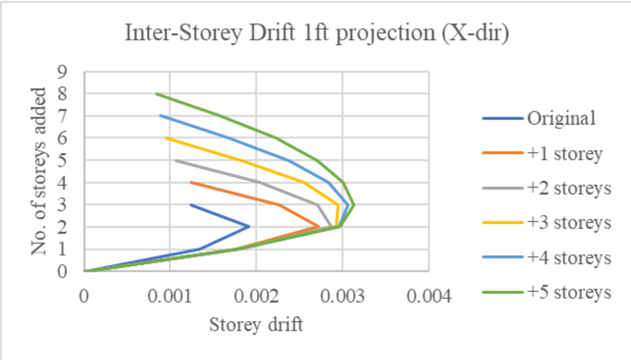


Figure 6: Inter-storey drift in X direction for 1ft. extension

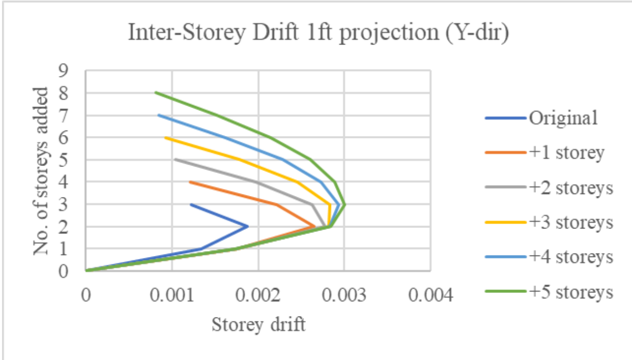


Figure 7: Inter-storey drift in Y direction for 1ft. extension

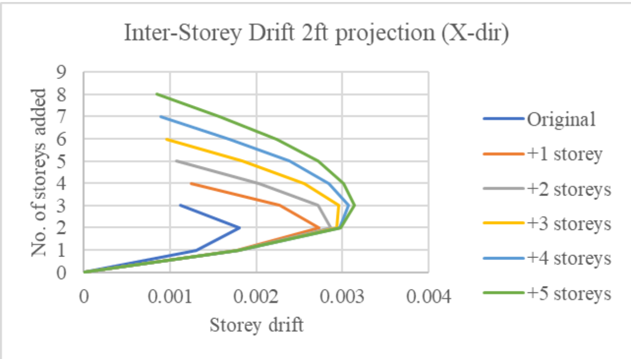


Figure 8: Inter-storey drift in X direction for 2ft. extension

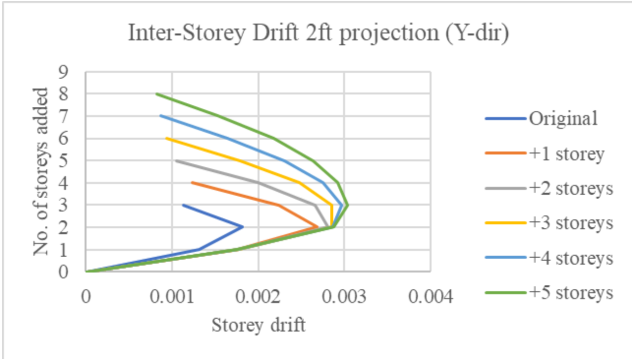


Figure 9: Inter-storey drift in Y direction for 2ft. extension

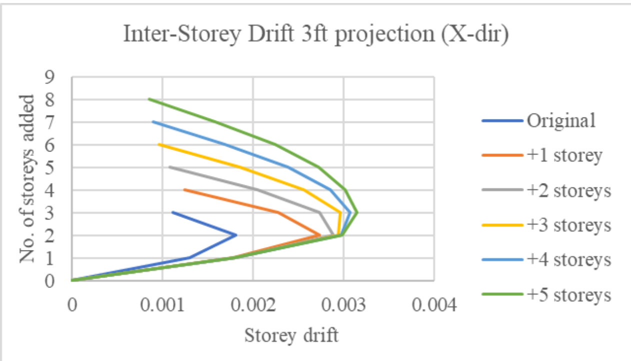


Figure 10: Inter-storey drift in X direction for 3ft. extension

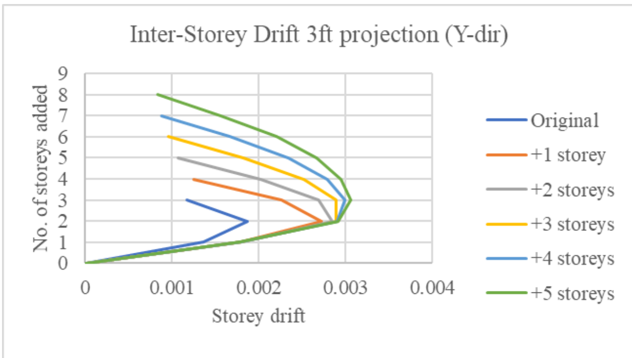


Figure 11: Inter-storey drift in Y direction for 3ft. extension

The base shear seen from Figure 12-14 was observed to have increased after the addition of the first storey but a gradual decrease was noted after every subsequent addition. This anomalous behavior of decrease in base shear when it is expected to increase with height is because it has been calculated using an empirical formula as per the IS code.

3.3. Case 3: Stepped Extension

In case 3 a model with stepped projection was modeled where stepped projection refers to the progressive outward extension of each floor relative to the one below it. This study considers projections ranging from 1ft to 3ft in increments of 1ft per storey. The comparisons of the parameters, inter-storey drift and base shear, were made in both the x and the y direction.

The graphs (Figure 15-16) of storey drift obtained in

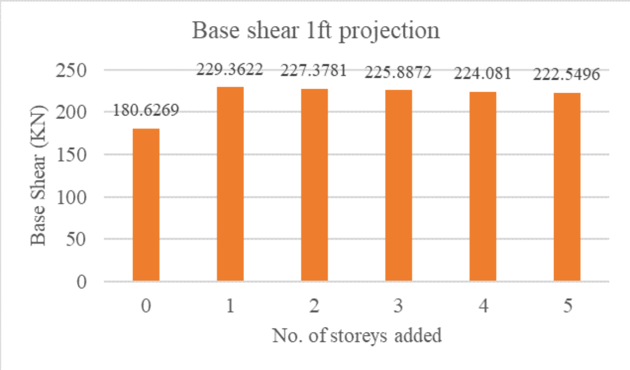


Figure 12: Base shear 1ft. extension

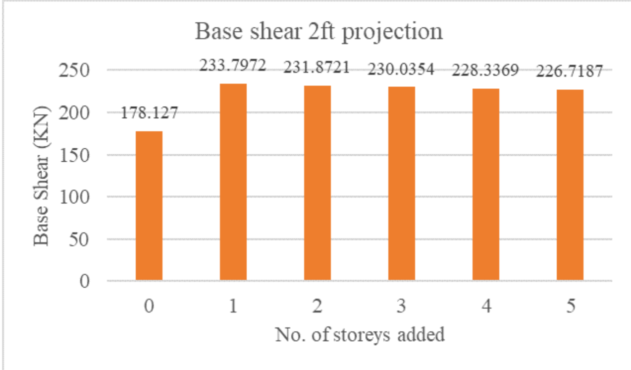


Figure 13: Base shear 2ft. extension

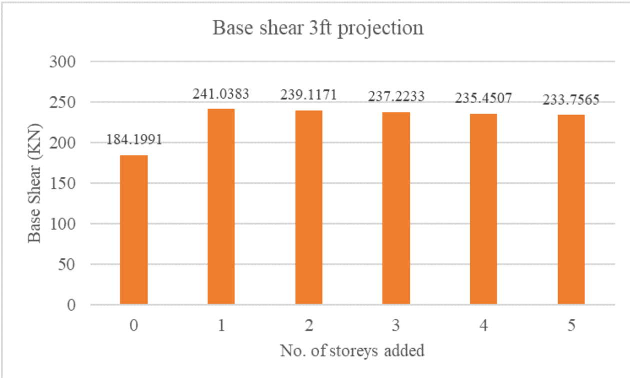


Figure 14: Base shear 3ft. extension

both X and Y direction are of similar nature suggesting that like the previous cases, stepped projection does not have a directional bias. The value of maximum inter-storey drift increases with the increase in number of storeys. However, the location of the maximum drift is observed to shift from second storey to third upon addition of three or more storeys.

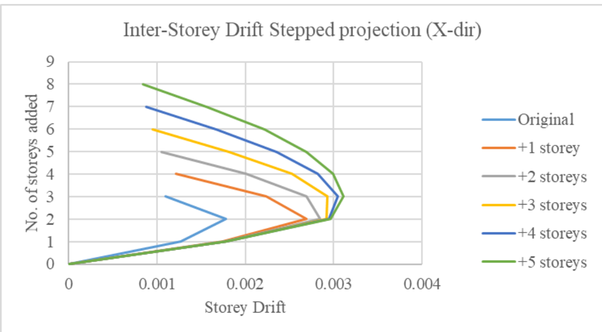


Figure 15: Inter-storey drift in X dir for stepped extension

The graphs (Figure 15-16) of storey drift obtained in both X and Y direction are of similar nature suggesting that like the previous cases, stepped projection does not have a

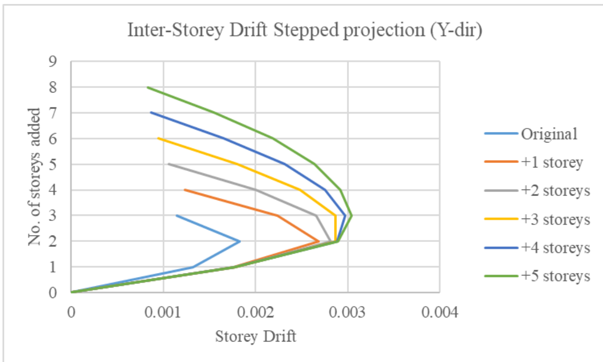


Figure 16: Inter-storey drift in X dir for stepped extension

directional bias. The value of maximum inter-storey drift increases with the increase in number of storeys. However, the location of the maximum drift is observed to shift from second storey to third upon addition of three or more storeys.

Base shear

Also, in the base shear analysis, like all the previous cases, the models with stepped projection (Fig 17) showed the same behaviour of initial increase in base shear on addition of one storey but an anomalous gradual decrease

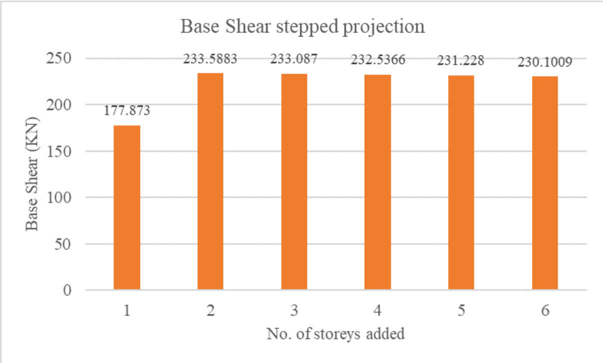
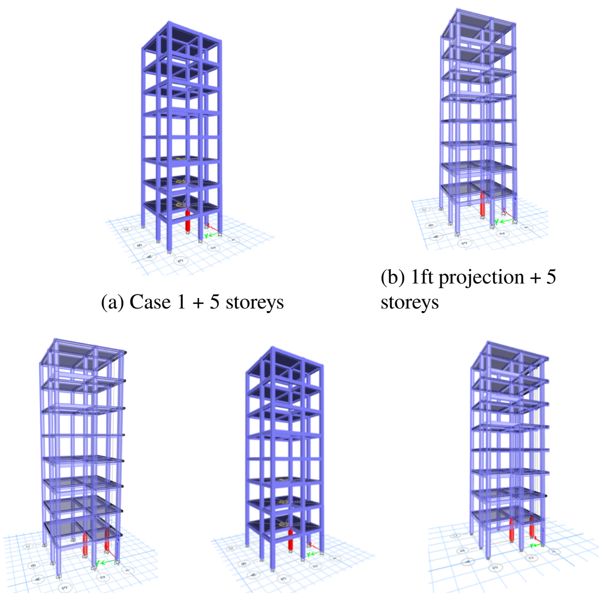


Figure 17: Base shear for stepped extension

in the value upon further addition of storeys. This gradual decrease is supported by the empirical relation given in IS 1893 (Part 1):2016.

3.4. Failed Members After Addition of Storeys

Inter-storey drift and base shear were the main parameters under study but check for structural member failure after addition of each storey was made. In each case the columns at the ground floor level failed upon the addition of fifth storey. This failure justified the termination of further addition of storeys. Figure 18 shows the failed members in different cases. A table summarizing the type, name, location and the reason for failure is shown in Table 1.



(a) Case 1 + 5 storeys

(b) 1ft projection + 5 storeys

(c) 2ft projection + 5 storeys

(d) 3ft projection + 5 storeys

(e) Stepped projection + 5 storeys

Figure 18: Failed members in different cases.

4. Conclusion

Summing up, base shear increases with the addition of the first storey due to increased seismic mass but gradually decreases as more storeys are added due to increased time period reducing spectral acceleration in all the cases. The maximum storey drift in every case increases significantly with addition of one storey but as the mass and stiffness of structure also increases with the addition of storeys, the storey drift shows a decreasing rate of increase when more than one storey is added. The location of maximum storey drift shifts towards higher floors with increase in number of storeys indicating a change in the structure's dynamic behavior. We also found out that the value of drift increases initially with height, but the rate of increase diminishes with additional storeys, likely due to the gradual increase in time period and corresponding reduction in seismic acceleration coefficient.

Also, The ground and first floors most vulnerable to structural failure during vertical extension, especially in horizontally extended models. This is likely due to stress concentration and higher demand in lower storey columns. Ultimately, all types of extension exhibited similar patterns in terms of maximum drift which is shown by the graphs in the report.

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Table 1: Description of failed members

S.N.	Case	Projection	Failed members			Location	Reasons
			No.	Type of member	Name	Storey	
1	1	+5 storeys	1	Column	B2	Storey 1	Column factored load exceeds maximum limit of $0.4 f_{ck}$ for seismic design as per IS 13920:2016 Section 7.1
2	2	1 ft. +5 storeys	1	Column	B2	Storey 1	Column factored load exceeds maximum limit of $0.4 f_{ck}$ for seismic design as per IS 13920:2016 Section 7.1
3	2	2 ft. +5 storeys	2	Column	B1 and B2	Storey 1	Column factored load exceeds maximum limit of $0.4 f_{ck}$ for seismic design as per IS 13920:2016 Section 7.1
4	2	3 ft. +5 storeys	2	Column	B1 and B2	Storey 1	Column factored load exceeds maximum limit of $0.4 f_{ck}$ for seismic design as per IS 13920:2016 Section 7.1
5	3	Stepped +5 storeys	2	Column	B1 and B2	Storey 1	Column factored load exceeds maximum limit of $0.4 f_{ck}$ for seismic design as per IS 13920:2016 Section 7.1

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