# Parametric Study on Seismic Behaviour of Setback Buildings

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***Abstract*—Space is an indispensable but inadequate resource in urban areas and high-rise buildings are the typical solutions to this issue. Most of these structures demand architectural prominence and it has become impossible to plan with regular shapes. Setbacks are a popular type of vertical geometrical irregularity preferred in tall buildings because of their functional benefits and aesthetic appeal. However, irregularities in setback buildings can also be a cause of structural failure under the action of dynamic loads like wind and earthquake. Hence, dynamic behaviour assessment of such reinforced concrete structures becomes important. This paper is an attempt to study the effect of number of bays and bay width on the seismic behaviour of RC structures with setback irregularity using modal analysis, pushover analysis and response spectrum analysis in SAP2000.**

***Keywords*—Setback building, geometric irregularity, setback ratio.***

## I. INTRODUCTION

Setback buildings are practical solutions for space constraint in urban areas where proximity of buildings is required. Figure 1 shows the Paramount building in New York which is a perfect example for setback buildings. Setback buildings are categorized by staggered abrupt reductions in floor area along the height of the building, with consequent drop in mass, stiffness and strength. Changes in mass and stiffness render the dynamic characteristics of these buildings different from regular buildings. Although setback structures are designed according to seismic codes, the increasing level of damage exhibit inadequate seismic performance of these structures. Thus it is necessary to study the seismic performance of setback structures.

Figure 2 shows the criteria for setback irregularity in a structure as specified by IS 1893 (Part 1):2002. The structure will be considered ‘irregular’ due to setbacks if these criteria are met. Lower levels of setback buildings with the largest number of bays is termed as ‘base’ and upper levels with the smallest number of bays is termed as ‘tower’.

Fig. 1 Paramount Building, New York
(Courtesy: Wikipedia)

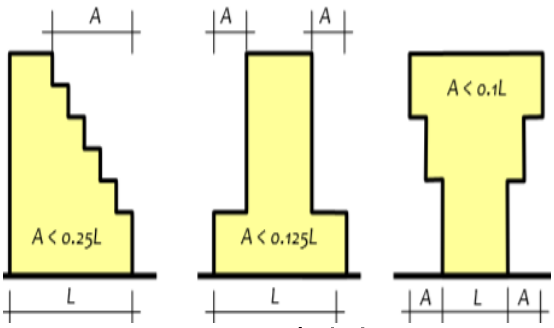



Fig. 2 Types of setbacks
(Courtesy: IS 1893 (Part 1):2002)

## II. OBJECTIVES

The objectives of the study are:

- To assess the effects of setbacks on the static and dynamic response of structures.
- To assess the influence of number of bays and bay width on the seismic behaviour of setback buildings.

## III. MODELLING AND ANALYSIS

The structure considered for study is a 12-storeyed RCC building with parameters as given in Table 1.Table 2 shows the loading conditions used for the study. The building was modeled and assessed in SAP2000 using modal analysis, pushover analysis and response spectrum analysis.

TABLE 1: BUILDING DESCRIPTION

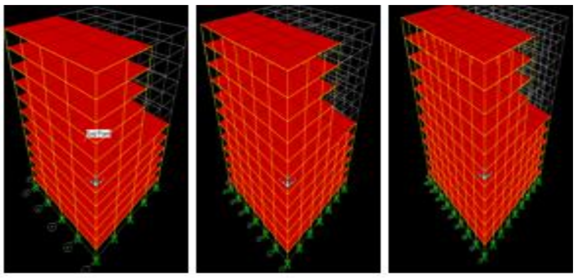
| *Parameter* | *Description* |
|---|---|
| Column size | 550 mm x 500 mm |
| Beam size | 230 mm x 300 mm |
| Slab thickness | 150mm |
| Storey height | 3m |
| Grade of concrete | M25 |
| Grade of reinforcement | Fe415 |

TABLE 2: LOADING CONDITIONS

| *Type of loading* | *Parameter* | *Description* |
|---|---|---|
| Dead | Self-weight of slab | 3.75kN/$m^2$ |
| | Floor finish | 1.5 kN/$m^2$ |
| Live | Floor | 3 kN/$m^2$ |
| | Roof | 3 kN/$m^2$ |
| Earthquake | Importance factor | 1 |
| | Seismic zone factor | 0.36 |
| | Soil type | II |

*CASE 1: Analysis of setback buildings with different number of bays and constant setback ratio*

Setback buildings with different number of bays but constant setback ratio were modeled as shown in Figure 3. Setback ratio can be expressed as height setback ratio and area setback ratio. Height setback ratio (RH) is the ratio of tower height to base height. Area setback ratio (RA) is the ratio of tower area to base area. M1, M2 and M3 represent the building models with number of bays 4 x 4, 6 x 6 and 8 x 8 respectively and setback ratios RH=6/6 and RA=0.5.



M1 M2 M3

Fig.3 Building models with different no. of bays

From modal analysis of the building models, the natural time period of the structures and the corresponding mode shapes under seismic loads were obtained as shown in Table 3.The results indicate that the time period of vibration decreases with increase in number of bays. However, the time periods of the models determined as per IS 1893 (Part I):2002 does not show any variation with change in number of bays. The fundamental mode of vibration of the setback buildings is Y-translation with torsion.

TABLE 3: RESULTS OF MODAL ANALYSIS

| *Model* | *Time period (s)* | | *Mode shape (Mode-1)* |
|---|---|---|---|
| | *IS 1893: 2002* | *SAP 2000* | |
| M1 | 1.1022 | 1.512 | Y-Translation with torsion |
| M2 | 1.1022 | 1.564 | Y-Translation with torsion |
| M3 | 1.1022 | 1.631 | Y-Translation with torsion |

To study the effect of number of bays on the seismic behaviour of setback buildings in terms of base shear and displacement, response spectrum analysis was performed. Table 4 shows the results of response spectrum analysis of the structures. It can be observed from the table that increase in the number of bays results in increased base shear and displacement values.

TABLE 4: RESULTS OF RESPONSE SPECTRUM ANALYSIS

| *Model* | *Base shear (kN)* | *Displacement (m)* |
|---|---|---|
| M1 | 552.083 | 0.033 |
| M2 | 921.707 | 0.044 |
| M3 | 1428.463 | 0.067 |

To investigate the performance point of the building frame in terms of base shear and displacement, non-linear static pushover analysis was performed on the models. Table 5 shows the results of pushover analysis of the four models. It can be seen from the table that base shear and displacement values increase with increase in number of bays.

TABLE 5: RESULTS OF PUSHOVER ANALYSIS

| *Model* | *Base shear (kN)* | *Displacement(m)* |
|---|---|---|
| M1 | 1000.691 | 0.205 |
| M2 | 1512.975 | 0.258 |
| M3 | 3343.37 | 0.359 |

Figure 4 shows the capacity spectrum curve for the model M3. The demand and capacity curves obtained indicate the performance point of the structure as per ATC 40 capacity spectrum method.

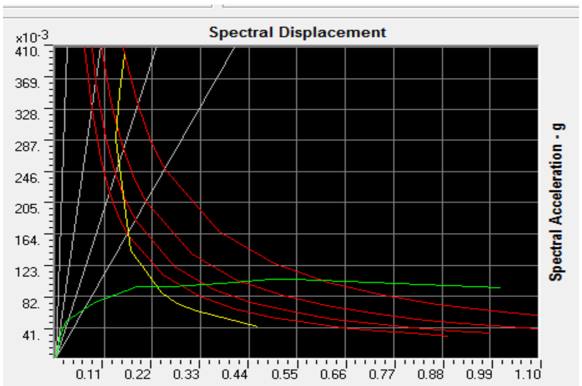



Fig.4 Capacity spectrum curve for model M3

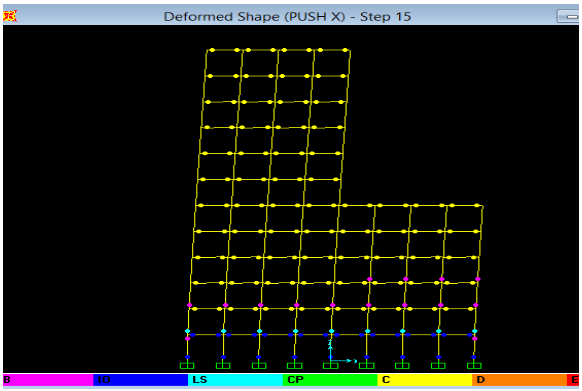


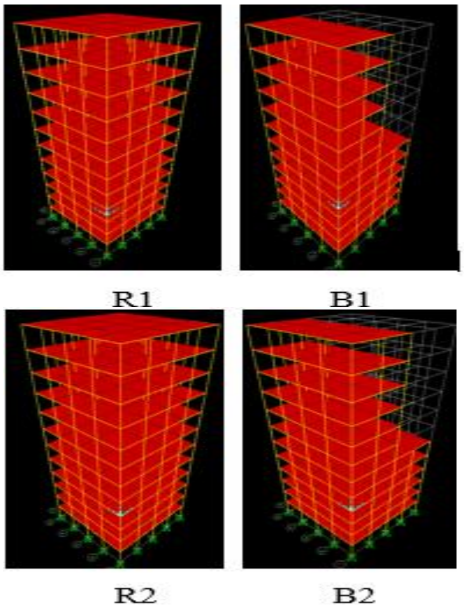

Fig.5 Hinge formation for model M3

Figure 5 shows the hinge formation pattern for the model M3. In the figure, IO, LS and CP represent immediate occupancy, life safety and collapse prevention conditions respectively. B and C represent yield point and collapse of the structure respectively. It can be inferred from the figure that the number of collapse hinges formed in the structure decreases as the number of bays increases.

*CASE 2: Analysis of setback buildings with different bay width and constant setback ratio*

Setback buildings with different bay width and constant setback ratio were modeled as shown in Figure 6. Setback ratios used in this study are: RA=0.5 and RH=6/6.

The control buildings with bay widths 3m, 3.5m and 4m and no setbacks are designated as R1, R2 and R3 respectively. B1, B2 and B3 are the corresponding building models with setbacks.



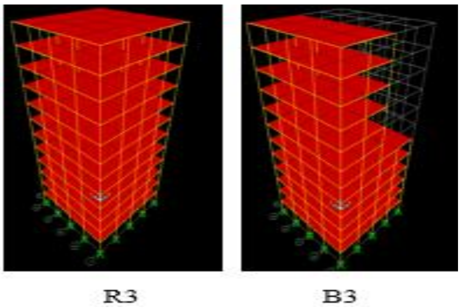




Fig. 6 Setback models with different bay widths

From modal analysis of the building models, the natural time period of the structures and corresponding mode shapes under seismic loads are obtained as shown in Table 6. The results indicate that time period increases with increase in bay width. However, the time periods of the models determined as per IS 1893 (Part I):2002 does not show any variation with change in bay width. Fundamental mode of vibration of the setback buildings is Y-translation with torsion.

TABLE 6: RESULTS OF MODAL ANALYSIS

| ***Model*** | ***Time period(s)*** | | ***Mode shape (mode-1)*** |
|---|---|---|---|
| | ***IS 1893:2002*** | ***SAP 2000*** | |
| R1 | 1.102 | 1.78 | Y-Translation |
| B1 | 1.102 | 1.38 | Y-Translation with torsion |
| R2 | 1.102 | 2.08 | Y-Translation |
| B2 | 1.102 | 1.60 | Y-Translation with torsion |
| R3 | 1.102 | 2.4 | Y-Translation |
| B3 | 1.102 | 1.8 | Y-Translation with torsion |

To study the effect of number of bays on the seismic behaviour of setback buildings in terms of base shear and displacement, response spectrum analysis is performed. Table 7 shows the results of response spectrum analysis of the structures. It can be observed from the table that increasing bay width results in increased base shear and displacement values.

TABLE 7: RESULTS OF RESPONSE SPECTRUM ANALYSIS

| ***Model*** | ***Base shear (kN)*** | ***Displacement (m)*** |
|---|---|---|
| R1 | 451.385 | 0.028 |
| B1 | 362.015 | 0.035 |
| R2 | 478.765 | 0.033 |
| B2 | 381.95 | 0.040 |
| R3 | 506.04 | 0.038 |
| B3 | 473.58 | 0.039 |

To investigate the performance point of the building frame in terms of base shear and displacement, non-linear static pushover analysis is performed on the models. Performance point base shear and displacement values for the setback models are shown in the table 8.

TABLE 8: RESULTS OF PUSHOVER ANALYSIS

| ***Model*** | ***Base shear (kN)*** | ***Displacement (m)*** |
|---|---|---|
| R1 | 969.05 | 0.28 |
| B1 | 615.77 | 0.31 |
| R2 | 1001.07 | 0.34 |
| B2 | 674.35 | 0.36 |
| R3 | 2037.20 | 0.20 |
| B3 | 1777.47 | 0.24 |

From Table 8, it is inferred that as the bay width increases base shear also increases. Model B3 is found to have maximum base shear. The capacity spectrum curve and hinge formation pattern for model B3 is shown in figures 7 and 8 respectively.

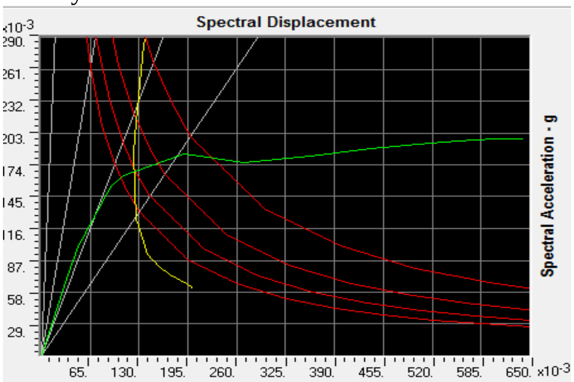


Fig.7 Capacity spectrum curve for model B3

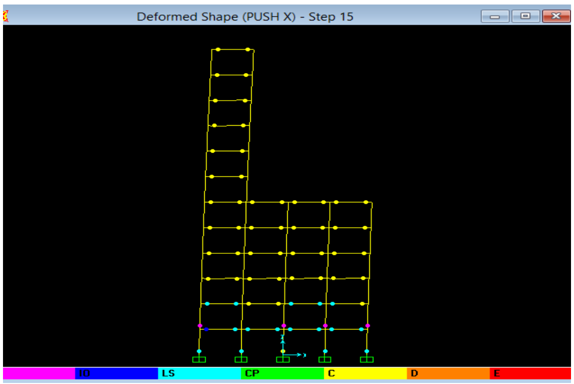


Fig.8 Hinge formation pattern for model B3

## IV. CONCLUSIONS

1. According to IS 1893:2002 the fundamental natural period of vibration of a moment resisting frame of overall height without brick infill is given by:

$$T=0.075h^{0.75}$$

   This empirical equation of fundamental period is a function of overall building height alone and does not account for the variations in height due to setbacks which is applicable for setback buildings.
2. Natural time period of a setback building depends not only on the height of the building but also on the bay width and number of bays. Increasing number of bays and bay width increases the time period of the structure.
3. It is found that as number of bays and bay width increases, performance point base shear increases.
4. Fundamental mode shape of a setback building was found to be translation with torsion.
5. Greater damage is concentrated at the vicinity of the tower portion of a setback building due to change in stiffness, strength and mass.

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