

# Fundamental Time Period of RC Framed Structures with Setbacks

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**ABSTRACT:** Setback buildings contribute a large portion of urban infrastructure. They are characterised by staggered abrupt reductions in floor area, with consequent drops in mass, strength and stiffness along the building height. The estimation of the fundamental period of vibration is unavoidable in seismic analysis and design of buildings. The empirical equations of fundamental period given in the design codes are function of building height only. Hence, to study accuracy of existing code based equations used to calculate fundamental period and suggest needed improvements, fundamental time period of 90 T shaped building models with varying heights, bay widths and irregularities were found using different code based equations, Rayleigh's method and ETABS 2015 software. A comparative study was made between all these building configurations and amount of irregularity was calculated using various methods. Subsequently, modified equations are proposed on basis of the regression analysis for estimating the fundamental period of the buildings.

**KEYWORDS:** Setback Buildings, Fundamental Period, Modal Analysis, Height of Structures, Base Dimensions, Regularity Index, Regression Analysis.

## I. INTRODUCTION

During an earthquake, failure of structure starts at points of weakness. This weakness arises due to discontinuity in mass, stiffness and geometry of structure. Such discontinuities between stories are often associated with sudden variations in the frame geometry along the height. Symmetry and regularity are usually recommended for a sound design of earthquake resistant structures; however, in many cases, these two requirements cannot be met. The structures having this discontinuity are termed as Irregular structures. [1].

The setback irregularity is one of the most common types of vertical geometric irregularity in the modern buildings. These buildings are very useful in urban areas, where the buildings are closely spaced. The setback buildings are usually provided when a relatively narrow road separates two multistorey buildings, as it permits adequate sunlight and ventilation to the lower stories. These types of buildings are preferred due to its functional and aesthetic benefits. The presence of a setback in the building results in abrupt reductions of the floor area, which in turn results in change of mass and stiffness along the building height. [2].

The fundamental periods of building frames are highly scattered. The Empirical formulae suggested in building codes are used to calculate the design base shear and lateral forces. This study presents the design code perspective of this building category. Most of the available design codes for earthquake resistant building including IS 1893: 2002 [3], ASCE 7: 2010 [4], UBC 97 [5], recommend dynamic analysis for design of setback buildings with scaled up base shear corresponding to the fundamental period as per the code specified empirical formula. However, the empirical equations of fundamental period given in these codes are a function of building height, which is ambiguous for a setback building. [1]. Building periods predicted by these expressions are widely used in practice although it has been observed that there is scope for further improvement in these equations since the height alone is inadequate to explain period variability.

The fundamental periods found from these expressions are highly conservative. Hence in this study an attempt is made to improve the estimation of periods of steel moment resisting frames without infill. As such, the goal of this research is to investigate the accuracy of existing code-based equations for estimation of the fundamental period of

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irregular building structures and to provide suggestions and develop modifications needed for code based equations used for calculating fundamental time period of RC framed structures to improve their accuracy. Based on free vibration analysis of 90 T shaped setback frames with varying heights, bay widths and irregularities, this study critically reviews the empirical code formula for fundamental period, to render it applicable for setback buildings. Modal analysis performed using the well-known software ETABS 2015.

## II. RELATED WORK

A number of studies have been performed on the fundamental period of building structures. Humar et al. [6] studied the dynamic behavior of multistorey steel rigid frame buildings with setback towers and observed higher drift demand at the upper portion of the setback. The important conclusion of the study was that the higher modes of vibration of a set-back building can make a very substantial contribution to its total seismic response. Shahrooz et al. [7] studied the effect of setbacks on the earthquake response of multistorey buildings. They conducted both experimental and analytical tests to improve previous design methodologies for design of setback buildings. Based on their analytical study that damage is concentrated in the tower portion of a set-back structure due to high rotational ductility and concluded that fundamental mode dominates the response in the direction parallel to the setback.

Saraswathy et al. [2] studied the effect of vertical irregularity on performance of reinforced concrete framed buildings. They observed that the top storey drift increases with setback ratio; maximum storey drift was found for the building with greatest setback ratio, near to the storey where irregularity was introduced and the base shear was found to decrease with increase in setback ratio. Sarkar et al. [8] proposes a new method of quantifying irregularity in stepped building frames, which deals with the dynamic characteristics i.e. stiffness and mass. This paper discusses some of the important issues regarding analysis and design of stepped buildings. They proposed a fresh method for quantifying the irregularity in stepped building. The total 78 stepped frames with varying irregularity and height were taken in this study. They proposed a correction factor to the empirical code formula for fundamental period, to provide it applicable for vertical geometric stepped buildings.

Agrawal et al. [1] carried a detailed comparative analytical study on fundamental period of RC setback framed buildings and this paper presented the design code perspective of this building category. Based on modal analysis of 90 setback buildings with varying irregularity and height, Fundamental period of all the selected building models were estimated as per different methods and the results were critically analysed. The buildings are assumed to have setback only in one direction. They concluded that, it is difficult to quantify the irregularity in a setback building with any single parameter and there is very poor correlation between fundamental periods of three dimensional buildings with any of the parameters used to define the setback irregularity by the previous researchers or design codes. And also they observed that, period of setback buildings was found to be always less than that of similar regular buildings.

Prakash Sangamnerkar et al. [9] has done the comparative study on the static and dynamic behavior of reinforced concrete framed regular building. Comparison of static and vibrant behavior of a six stories structure was considered in this paper and it was analyzed by using computerized solution available in all four seismic zones i.e. II, III, IV and V. It was observed that, parameters like base shear, nodal displacements and beam ends forces varies in the same ratio.

## III. DESIGN CODE PERSPECTIVE

Most of the available design codes for earthquake resistant building including IS 1893:2002 [3], ASCE 7:2010 [4], UBC 97 [5] recommend an empirical formula for the determination of fundamental time period of building.

### 1) Fundamental Time Period:

Design code recommends dynamic analysis to obtain the design seismic force for all irregular buildings. The fundamental period for a building that is yet to be designed cannot be computed, so the design codes recommend certain empirical equations for determination of fundamental time period, so as to compute the design seismic base shear. [1].

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The fundamental natural period of vibration,  $T_a$  (in seconds), of a RC moment resisting frame of overall height  $h$  (in meter) without brick infill, as per IS 1893:2002 [3] is given by:

$$T_a = 0.075h^{0.75} \quad (1)$$

For the determination of fundamental natural period of vibration,  $T$  (in seconds), of a RC moment resisting frame of overall height  $h_n$  (in meter) Uniform Building Code 97 [5] recommends the formula as shown:

$$T = 0.0731(h_n)^{0.75} \quad (2)$$

In a similar way as per ASCE 7:2010 [4], the approximate fundamental period  $T_a$  (in second) of a structure with over all height  $h_n$  (in meter) for a RC moment resisting frame building is given by:

$$T_a = 0.0466(h_n)^{0.9} \quad (3)$$

ASCE 7:2010 [4] permits to determine fundamental period  $T_a$  (in second) of RC buildings from the following equation for structures not exceeding 12 stories in height provided storey height to be at least 3 m. The equation is of the following form where,  $N$  is the number of stories:

$$T_a = 0.1N \quad (4)$$

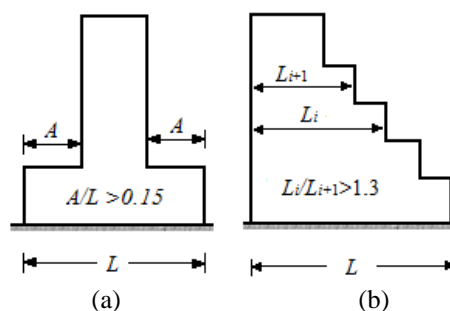
The fundamental period can be determined through an alternative substantiated analysis such as normal mode analysis or Rayleigh's method, both of which require the use of a computer program, making these theory based methods of determining the fundamental period difficult for most practicing engineers. The Rayleigh equation is based on structural properties and deformational characteristics. Rayleigh's formula for the computation of fundamental period  $T$  (in second) is given by:

$$T = 2\pi \sqrt{\frac{(\sum_{i=1}^n w_i \delta_i^2)}{g(\sum_{i=1}^n f_i \delta_i)}} \quad (5)$$

Where  $w_i$  = the portion of the total seismic dead load located at or assigned to level  $i$ ;  $\delta_i$  = the horizontal displacement at level  $i$  relative to the base due to applied lateral forces;  $g$  = acceleration due to gravity;  $f_i$  = the lateral force at level  $i$  and  $n$  is the total number of stories in the building [10].

## 2) Vertical Geometric Irregularity:

Vertical geometric irregularity is one among the vertical irregularity defined in all design codes. As per IS 1893:2002 [3], such buildings are to be considered as setback buildings where the horizontal direction of the lateral force resisting system in any story is more than 150 percent of that in its adjacent storey, as shown in Fig.1(a). As per ASCE 7:2010 [4], setback building is defined as, when the horizontal direction of the seismic force resisting system in any story is more than 130 percent of that in its adjacent storey, as shown in Fig.1(b). Design codes consider this ratio of lateral dimension of two adjacent stores as criteria to define vertical geometric irregularity. [1].



**Fig. 1:** Vertical Geometric Irregularity According to (a) IS 1893:2002 [3] and (b) ASCE 7:2010 [4]

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## IV. METHODOLOGY & OBJECTIVES

- 1) **Objectives:** As a future scope of the work by Agrawal et al. [1] the salient objectives were chosen for the present study are: (a) To perform a parametric study on the fundamental period of different types of RC moment resisting frames considering different number of stories, number of bays, configuration and types of irregularities. (b) To compare the fundamental periods of each structure obtained using a) Code empirical equations b) Rayleigh's method with generated fundamental period based on modal analysis by using ETABS 2015 [12] software. (c) Develop improved equations to estimate fundamental time period of RC framed structures improve their accuracy.
- 2) **Methodology:** The steps undertaken in the present study to achieve the objectives are as follows: (a) An exhaustive set of regular and setback T shaped building frame models with varying heights, bay widths in both horizontal direction and different irregularities (limit to 90 setback building models) was selected and modelled in ETABS 2015 [12] as per required specifications in the software. (b) Free vibration analysis for each of the 90 building models was performed. (c) The fundamental time periods by using ETABS 2015 [12], Code empirical equations and Rayleigh's method were computed and compared by plotting respective graphs. (d) The amounts of setback irregularity present in the selected buildings as per the definition given in the available literature as well as the international design codes were calculated (e) Regression analysis was performed by considering height, base dimension and irregularity as parameters. (f) The modifications needed for code equations used for calculating fundamental time period of RC framed structures, to improve their accuracy was derived.

## V. STRUCTURAL GEOMETRY AND MODELLING

The work is based on 3D RC building with varying heights and widths. Different building geometries were taken for the study. These building geometries represent varying degree of irregularity or amount of setback. Three different bay widths, i.e. 5m, 6m and 7m (in both the horizontal direction) were considered for this study. It should be noted that bay width of 4m-7m is the usual case, especially in Indian and European practice. Similarly, five different height categories (18m, 36m, 54m, 72m and 90m) were considered for the study, ranging from 6 to 30 stories, with a uniform storey height of 3m. Altogether 90 building frames (T shape) with different amount of setback irregularities due to the reduction in width and height were selected. There are altogether six different building geometries, one regular and five irregular, for each height category considered in the present study. The structures are modelled by using computer software ETABS 2015 [12]. The regular frame is designated as R. The classification of the buildings considered are expressed in the form of S-X-Y, where S represents the type of irregularity (i.e., S1 to S5 or R). X represents the number of storeys and Y represents the number of bay in both the horizontal direction.

**Table 1:** Dimensions of Beams and Columns for Setback Buildings

Building Type According To Number To Stories	Column Dimensions	Beam Dimensions		
		5m Bay Width	6m Bay Width	7m Bay Width
Six storey building	400 mm × 400 mm	300 mm × 450 mm	300 mm × 500 mm	300 mm × 550 mm
Twelve storey building	500 mm × 500 mm	300 mm × 500 mm	300 mm × 550 mm	300 mm × 600 mm
Eighteen storey building	600 mm × 600 mm	400 mm × 600 mm	400 mm × 650 mm	400 mm × 700 mm
Twenty four storey building	750 mm × 750 mm	400 mm × 600 mm	400 mm × 650 mm	400 mm × 700 mm
Thirty storey building	900 mm × 900 mm	450 mm × 600 mm	450 mm × 650 mm	450 mm × 700 mm

The cross sectional dimensions of beams and columns of different setback buildings are taken as shown in Table 1. All the selected models were designed with M-20 grade of concrete and Fe-415 grade of reinforcing steel as per Indian Standards. Gravity (dead and imposed) load and seismic load corresponding to seismic zone V of IS

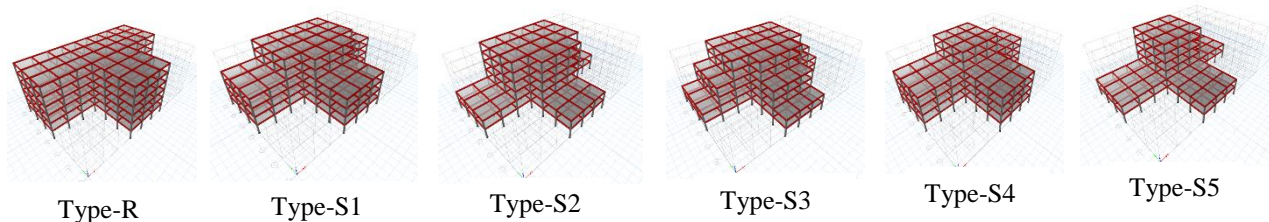
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1893:2002 [3] are considered for the design. The slab thickness was considered as 120mm for all the buildings, Infill walls in the exterior and interior were assumed as 230mm thickness. The parapet wall was assumed to be of 230 mm thickness and of 1000mm height for all the selected buildings. The unit weight of brick was taken as 20kN/m<sup>3</sup> and concrete as 25kN/m<sup>3</sup>. All supports are taken as fixed. Special moment resisting frame was considered in all the cases having response reduction factor (RF) as 5 and importance factor as 1. Buildings were treated as commercial buildings as huge number of multistorey buildings are built for commercial purposes

Fig. 2 presents the 3D view of all six different geometries. The same building configurations are repeated in all the cases considered in this study. Setback frames are named as S1, S2, S3, S4 and S5 depending on the percentage reduction of floor area and height as shown in the Figure below.



**Fig.2:** 3D View of 6-Storey T Shaped Building Variants (R, S1 to S5) with 5m bay width

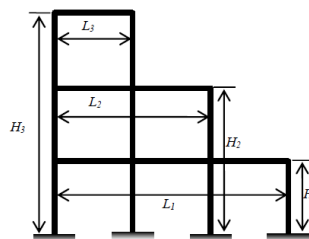
## VI. INDICES AVAILABLE IN LITERATURE

One of the main objectives of the study is to formulate an improved equation to evaluate fundamental period of setback buildings. Therefore, it is required to know the important parameters which control the fundamental period of a setback building. There is need to quantify the irregularity in a setback building and relate the empirical equation of fundamental period of the setback building with its irregularity. Some of the previous works proposed some measure of quantifying the irregularity in setback buildings.

A parametric study on the multistorey steel frames with setback irregularity was conducted by Karavasilis et al. [11]. They proposed an alternative approach to quantify the irregularity in a building frame due to the presence of steps. This paper defines two irregularity indices for stepped buildings,  $\Phi_s$  and  $\Phi_b$  (for storey-wise and bay-wise stepping respectively) as follows:

$$\Phi_s = \frac{1}{n_s - 1} \sum_{i=1}^{n_s-1} \frac{L_i}{L_{i+1}} \quad \text{and} \quad \Phi_b = \frac{1}{n_b - 1} \sum_{i=1}^{n_b-1} \frac{H_i}{H_{i+1}} \quad (6)$$

Where,  $n_s$  is the number of stories of the frame and  $n_b$  is number of bays at the first storey of the frame.  $H_i$  and  $L_i$  were height and the width respectively of the  $i^{\text{th}}$  storey as shown in Fig 3.



**Fig. 3:** Frame Geometry for Definition of Irregularity Indices (Karavasilis et al. [11])

These indices represent the irregularity in stepped frame in an improved manner compared to the code procedures. Large value of the  $\Phi_s$  index reveals large reductions of the floor area and large value of the  $\Phi_b$  index reveals a tower-like structure, while for the extreme case of a regular frame without setbacks both of the above indices take their minimum value, i.e. unity.



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Varadharajan et al. [13] carried a detailed analytical study of the seismic response of setback frames. He proposed an irregularity index for quantifying the setback irregularity based on the dynamic characteristics of the buildings. This study also proposed a modified equation for the fundamental period of vibration, for building frames with setback irregularity. Furthermore, the equations for estimating the maximum inter storey drift ratio ( $I_r$ ) and maximum displacement ductility ( $\mu_{max}$ ) were also proposed. The proposed equations were represented as a function of the irregularity index, and were validated for 2D and 3D building models with setback irregularity. To obtain the modified time period, the correction factor  $\lambda'$  and irregularity index  $\eta_{ir}$  have been obtained to quantify the vertical setback irregularity as

$$\lambda' = \frac{T_i}{T_r} = 4.4032 \eta_{ir}^2 - 10.582 \eta_{ir} + 7.2936 \quad \text{and} \quad \eta_{ir} = \frac{\omega_i}{\omega_r} \quad (7)$$

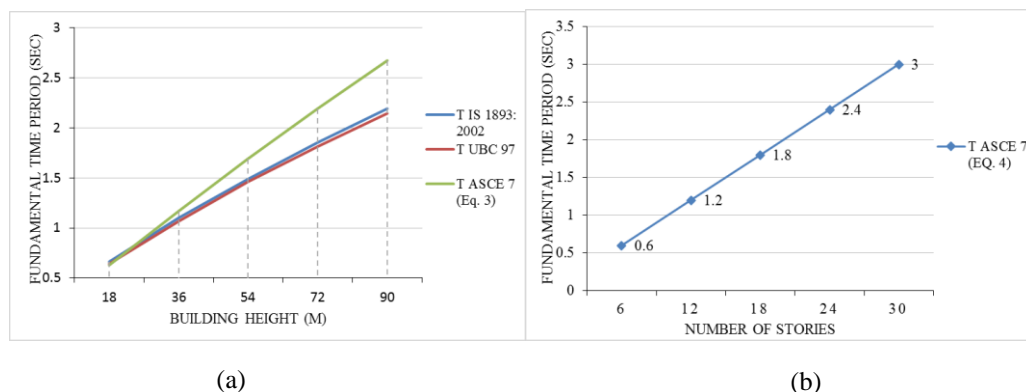
Where,  $\omega_i$  and  $\omega_r$  are the modal combinations of frequency of vibration of the irregular and regular building frames. The proposed irregularity index yielded better results as compared to the existing measures adopted by codes and other research works (Karavallis et al. [11]) proposed, to quantify the setback irregularity. And the modified time period can be expressed as

$$T = \lambda' 0.075 h^{0.75} \quad (8)$$

The results obtained from the proposed equation of the fundamental period of vibration were compared with the results of dynamic analysis for four building models with different location of setbacks. From analytical studies, it was found that, the fundamental period of vibration evaluated by the proposed method yielded the accurate estimates of fundamental period and base shear, when compared with the results of dynamic analysis.

## VII. RESULTS AND DISCUSSIONS

All the building models taken for this study are analyzed for linear dynamic behaviour using commercial software ETABS 2015 [12] and the fundamental time periods of all the 90 selected setback buildings were calculated using different methods including different code based empirical equations such as IS 1893:2002 [3], ASCE7 (Eq. 3) [4] and UBC 97 [5] as well as Rayleigh method, and modal analysis. Fig. 4(a) represents the fundamental period of setback buildings that are obtained from IS 1893:2002 [3], ASCE7 (Eq. 3) [4] and UBC 97 [5] for all the bay widths considered: 5m, 6m and 7m. Similarly, Fig. 4(b) represents fundamental period obtained from ASCE7 (Eq. 4) [4]. The obtained values of fundamental time period using Rayleigh's methods and modal analysis are different for each bay width. So, they are plotted separately and are compared with that obtained from IS 1893:2002 [3] empirical equation in Figs. 5 (a) and 5(b).



**Fig. 4:** Fundamental Time Period of Setback Buildings Obtained from (a) IS 1893:2002, UBC 97 and ASCE7 (Eq. 3) and (b) ASCE7 (Eq. 4) for 5m, 6m and 7m Bay Width

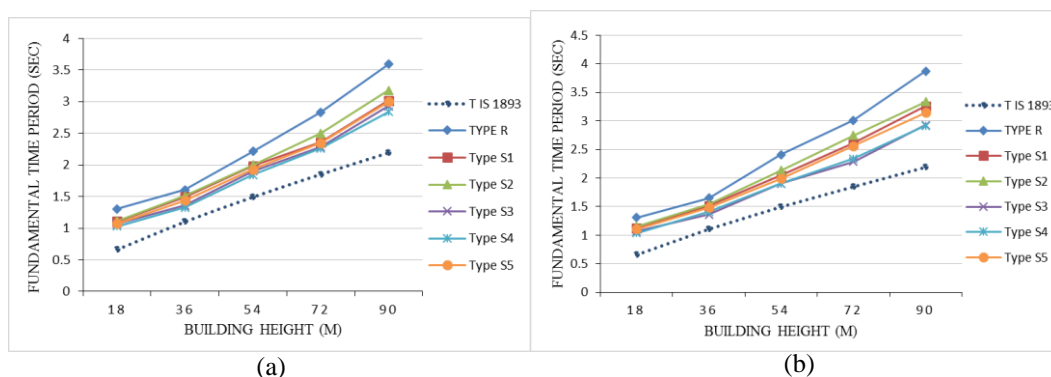
A similar conclusions to that of work by Agrawal et al. [1] can be made from the results presented in Figs. 4 - 6. Figs. 5(a) and 5(b) show that Period of the building so calculated by the code formula will remain same in all the cases

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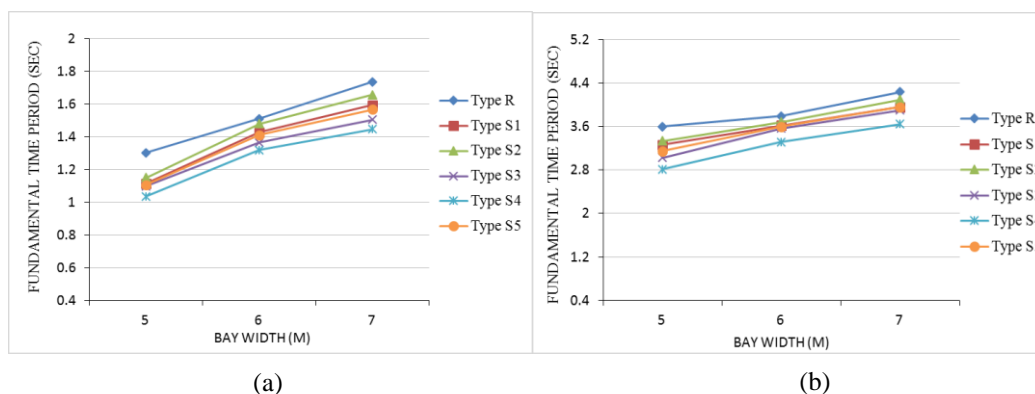
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and the code empirical formula gives the lower-bound of the fundamental periods obtained from Modal Analysis and Rayleigh's Method. Therefore, it can be concluded that the code (IS 1893: 2002 [3]) always gives conservative estimates of the fundamental periods of setback buildings with 6 to 30 stories. Eq. 4 from ASCE 7: 2010 [4] does not consider the height of the building but it considers only the number of storeys of the buildings. It also show that the buildings with same height and same bay width may have different period depending on the amount of irregularity present in the setback buildings. Generally, the period decreases with the increased irregularity. This variation of the fundamental periods due to variation in irregularity is found to be more for taller buildings and comparatively less for shorter buildings. Variation of fundamental periods calculated from modal analysis and Rayleigh method are quite similar.



**Fig. 5:** Fundamental Time Period of Setback Buildings Obtained from (a) Rayleigh's and (b) Modal Analysis Method for 5m Bay Width

All the major international design codes including IS 1893: 2002 [3] does not specify bay width or plan dimension as a parameter which affects the fundamental period of RC framed building without considering brick infill. Figs. 6(a) and 6(b) presents the variation in fundamental period with the change in bay width of 6 stories and 30 stories setback buildings. From these figures it is clear that bay width affects the fundamental period of such type of buildings and this change in fundamental period due to change in bay width is found to be considerable and it cannot be ignored. The code based empirical equation for the estimation of fundamental period does not take in account the bay width of the building for RC moment resisting frames without brick infill. However, in design codes, the empirical equations considering the brick infill does depend on bay width. Therefore it should be accounted for the code based empirical equations for the calculation of fundamental period of RC frame buildings without infill also.



**Fig. 6:** Variation of Fundamental Time Period with Bay Width for (a) 6-Storey and (b) 30-Storey Setback Buildings

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For a regular building there is no ambiguity as the height of the building is same throughout both the horizontal directions. However, this is not the case for setback buildings where building height is not constant. Therefore, there is need to define the irregularity for a setback building and relate the empirical equation of fundamental period of the setback building with its irregularity. Design codes do not directly quantify the irregularity in setback buildings but it gives a parameter to distinguish the regular and setback irregular buildings. Some of the previous works addressed this issue of defining irregularity and proposed some measure of quantifying the irregularity in setback buildings. So the amounts of setback irregularity present in the selected buildings are calculated as per the definition given in the available literatures (Karavasilis et.al. [11] and Varadharajan et al. [13]) as well as the international design codes (IS1893:2002 [3] and ASCE.7:2010 [4]). Varadharajan et al. [13] defined the irregularity in terms of the modal parameters. From the results, it is clear the measures to quantify the irregularity given in literatures are found to be not very efficient as a parameter for formulation. But according to Varadharajan et al. [13] the effect of irregularity increases with increase in building height, i.e. variation of fundamental time period due to variation in irregularity is more for multistoried buildings.

## VIII. PROPOSED EQUATIONS

The proposed equation is developed by nonlinear regression analysis, i.e., Power regression analysis. Regression analysis was carried out to understand the relationship between fundamental time period and various parameters affecting it. Regression analysis was carried out using IBM SPSS Statistics V20 [14] and Microsoft Excel softwares for finding out a modified empirical equation for calculating fundamental time period of setback buildings with the values obtained from modal analysis using ETABS 2015 [12]. Regression analysis was done for each irregularity (R, S1, S2, S3, S4 and S5). Regression analysis considering base dimension and building height was done separately. However, the equations should be formulated based on the total results of all the building models for better accuracy, power regression analysis was performed on total 90 results obtained from the modal analysis. Separate equations were obtained corresponding to each regression analysis conducted for each irregularity considering fundamental time period as a function of building height and base dimension. Finally, by correlating all the equations, modified empirical equations were obtained for determining the approximate fundamental time period.

In the present study, buildings with a height less than 50m is considered as low rise buildings and those with more than 50m is considered as high rise buildings. According to this study there are two types of equations were derived, one is for low rise buildings and other one is for high rise (multistoried) buildings.

### 1) Low Rise Buildings:

$$T = [0.11 h^{0.58} + 0.05d^{0.7}] \quad (9)$$

Where, T is the fundamental time period, h is the building height and d is the base dimension.

### 2) High Rise Buildings:

For multistoried buildings, this equation was not satisfied. It's already clear from previous section that effect of irregularity increases with increase in building height. Variation of fundamental time period due to variation in irregularity is more for multistoried buildings. Hence, the above equation is not satisfied for buildings above 50 m. For such buildings, irregularity should be considered in finding fundamental time period of the building. Relating this amount of setback irregularity with the results obtained from regression analysis, the best-fit equation for finding fundamental time period of multistoried buildings having height more than 50m low with setback in two directions was obtained as

$$T = \lambda [0.11 h^{0.58} + 0.05d^{0.7}] \quad (10)$$

Where, T =fundamental time period, h=building height, d=base dimension and  $\lambda$  is the correction factor. Here,  $\lambda = 4.4032\eta_{ir}^2 - 10.582\eta_{ir} + 7.2936$  (Varadharajan et al. [13]). Where,  $\eta_{ir} = \text{Regularity index} = \frac{\omega_i}{\omega_r}$  (Varadharajan et al [13]). Here,  $\omega_i$  and  $\omega_r$  are the modal combinations of frequency of vibration of the irregular and regular building frames.



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The percentage error was calculated for fundamental time period using estimated equation and IS 1893:2002 [3] from fundamental time period obtained from modal analysis and it is observed the expression suggested for buildings are found closer to the values obtained by modal analysis than those calculated using IS 1893:2002 [3]. The fundamental time period predicted for setback buildings with suggested modified expression is found to be approximate 0-15% error for low rise buildings to IS 1893:2002 [3] where the error is up to 65%. For multistoried buildings, the error is 0-21%. Therefore, height alone seems inadequate to evaluate period of vibration and the results of this study suggest that height of the building, base dimension and irregularity index should also be added in simplified relationships for the evaluation of time period of vibration in seismic analysis

## IX. CONCLUSION

Based on the work presented in this thesis, the conclusions can be summarized as follows:

1. Period of setback buildings is found to be always less than that of similar regular building. It is found that the fundamental period in a framed building is not a function of building height only. This study shows that buildings with same overall height may have different fundamental periods with a considerable variation which is not addressed in the code empirical equations.
2. The code (IS 1893:2002 [3]) empirical formula gives the lower-bound of the fundamental periods obtained from Modal Analysis and Rayleigh's Method. Therefore, it can be concluded that the code (IS 1893:2002 [3]) always gives conservative estimates of the fundamental periods of setback buildings with 6 to 30 stories.
3. In the empirical equation of fundamental period, the height of the building is not defined in the design code adequately. For a regular building there is no ambiguity as the height of the building is same throughout both the horizontal directions. However, this is not the case for setback buildings where building height is not constant
4. The buildings with same maximum height and same maximum width may have different period depending on the amount of irregularity present in the setback buildings. This variation of the fundamental periods due to variation in irregularity is found to be more for taller buildings and comparatively less for shorter buildings. It is found that variation of fundamental periods calculated from modal analysis and Rayleigh's method are quite similar.
5. Based on the obtained results Separate expressions are suggested as the best-fit equation for determining fundamental time period for buildings below 50m and buildings above 50m.
6. The results obtained from the proposed equation of the fundamental period of vibration is compared with the results of dynamic analysis for all the building models with different location of setbacks. For buildings below 50m, an error of 0-15% was observed for the expression obtained for setback buildings by regression analysis and an error of 0-21% was observed for setback buildings above 50m. This can be further improved with analysis of large sampling data.

## X. SCOPE FOR FUTURE WORK

1. The present study is limited to reinforced concrete (RC) multi-storeyed building frames with setbacks. Another study could be done on steel-framed multi-storey buildings with setbacks.
2. Soil-structure interaction effects are not considered in the present study. Further studies could be extended by considering Soil-structure interaction effect.
3. In this work column size has been kept constant throughout the building height. One may go for the variation of sizes for the different levels as per the actual design consideration.
4. Column ends are assumed to be fixed at the foundation. Study may further be extended for different column supports like roller and pinned.
5. The models used to derive these equations fail to account for partition walls, structural walls like shear walls, and other structural elements which add to the stiffness of a structure. Further studies may be conducted which account for these elements. However, associated mass and weight is assumed in the analysis.
6. As more measured data becomes available like varying heights or configuration, further comparison should be conducted with refinement of the proposed equations as needed.

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