STUDY OF FUNDAMENTAL PERIOD OF REINFORCED CONCRETE FRAMED STRUCTURAL BUILDING WITH FACTOR CONSIDERING SETBACK

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Abstract: *The magnitude of a tremor's parallel power is determined in large part by the dynamic characteristics of the structure, its inertial mass and the increase in ground speed. A Response spectrum is provided by design codes to describe not only the behavior of the structure but also the motion of the ground. The structure's peak responses in relation to the natural vibration period, damping ratio, and type of founding soil can be easily described using the response spectrum. For earthquake design and evaluation, it is necessary to determine the fundamental period of structures. The structural models of a few RC-framed structures are described in detail in this study. In addition, it illustrates the particular structure calculations utilized in this review. In addition, it explains the free vibration analysis method that was used in this study. The basic time of all selected building models was evaluated using the modular investigation, the Rayleigh strategy, and the experimental conditions of the plan codes.*

Keywords: *RC Buildings, Modal Analysis, Setback Buildings.*

1. Introduction

The building's dynamic characteristics, inertial mass, and ground acceleration all play major roles in determining the magnitude of an earthquake's lateral force. A Response spectrum is provided by design codes to describe the ground motion as well as the behaviour of the structure. The peak responses of the structure as a function of natural vibration period, damping ratio, and type of founding soil are conveniently described by response spectrum. For earthquake design and evaluation, it is essential to determine the fundamental period of structures. The design codes provide empirical equations for the fundamental period of buildings as a function of building height and base dimension. In order to calculate the design base shear, the Response Spectrum Method theoretically employs modal analysis to determine the building's natural periods. However, in order to improve this base shear (or any other response quantity) for Response Spectrum Analysis to make it equal to that of Equivalent Static Analysis, some international codes, such as IS 1893:2002 and ASCE 7:2010, recommend scaling up the base shear (and other response quantities) corresponding to the fundamental period in accordance with the code's specified empirical formula.

The mass, strength, stiffness, centre of mass, and centre of stiffness of the setback building are affected by this setback. These buildings' dynamic characteristics differ from those of regular buildings as a result of changes in their structural and geometrical properties. The definition of building height for the purpose of calculating fundamental period is unclear in design codes. It is challenging to calculate the natural period of setback buildings due to the bay wise variation in height. Structural engineers are also concerned about the performance of the empirical equation in Indian Standard IS 1893:2002 for estimating the fundamental period of setback buildings. This is the primary impetus for the current study.

Objectives

1. To study of the various reinforced concrete moment resisting frames with varying numbers of stories, bays, configurations and irregularity types.

2. To compare the fundamental time periods with the code empirical equations and Rayleigh methods for each structure.

2. Review of Literature

Chintanapakdee et al. (2004)

Utilize non-linear response history analysis to investigate the seismic demands of both regular and vertically irregular frames. The floor displacements are little affected by upper-story irregularities. On the other hand, the height-wise distribution of floor displacements is significantly influenced by irregularities in lower stories.

Athanassiadou et al. (2008)

Study the seismic response of multi-storey reinforced concrete frame building irregular in elevation, but regular in plan. Irregular frames along with the similar regular frames were analysed for the performance to both inelastic static pushover analysis and inelastic dynamic time history analysis for the same peak ground acceleration. To study the effect of design ductility the buildings were designed for high and medium ductility classes as per Euro code.

Karavasilis et al. (2008)

A study on the inelastic seismic response of plane steel moment resisting frames (MRF) with setbacks was presented in 2008. The created response databank's statistical analysis reveals that the height-wise distribution and amplitude of inelastic deformation demands are strongly influenced by the number of stories, beam-to-column strength ratio and geometrical irregularity and limit state.

Sarkar et al. (2010)

A novel approach to quantifying irregularities in stepped building frames that takes into account dynamic characteristics like mass and stiffness is proposed. The analysis and design of stepped buildings is the subject of this paper, which addresses a few key issues. They proposed a novel method for quantifying stepped building irregularities. It takes into account the frame's mass and stiffness distribution-related properties. The irregularity can be quantified more accurately using this method than the current methods. This study proposes a correction factor to the empirical code formula for fundamental period in order to make it applicable to stepped buildings.

The following is a mathematical representation of the regularity index:

$$\eta = \frac{\Gamma_1}{\Gamma_{1,ref}} \qquad \textbf{(1)}$$

Where Γ1 is the first mode participation factor for the setback building frame in question and Γref is the first mode support factor for the comparative customary structure outline without steps.

They characterized a rectification factor k for the experimental recipe of IS 1893:2002 and altered it, as displayed:

$$T = 0.075h^{0.75} \times k$$

(2)

$$k = \frac{T}{T_{ref}} = [1-2(1-\eta)(2\eta-1)] \quad \text{For } 0.6 \le \eta \le 1.0$$

(3)

Where h is the total meter height of the building.

They characterized two inconsistency lists for ventured structures, Φ_s, and Φ_b

$$\Phi_s = \frac{1}{n_s - 1}\sum_{1}^{n_s-1}\frac{L_i}{L_{i+1}}$$

(4)

$$\Phi_b = \frac{1}{n_b - 1}\sum_{1}^{n_b-1}\frac{H_i}{H_{i+1}}$$

(5)

Where n_s is the number of frame storeys and n_b is the number of bays on the first frame storey.

Young (2011)

Present a study on how to determine the fundamental vibrational period of geometrically irregular structures. The fundamental periods of three distinct steel earthquake-resistant building structures were examined in this study: frames with varying degrees of geometric irregularities, such as moment resisting frames (MRF), concentrically braced frames (CBF), and eccentrically braced frames (EBF). ETABS v.9.7.2 is used to design and analyse 24 MRFs, 12 CBFs, and 12 EBFs.

Fundamental Time Period

According to IS 1893:2002, buildings with irregular configurations are more susceptible to damage than buildings with simpler regular geometry and uniformly distributed mass and stiffness in plan and elevation. For all irregular buildings, the design code calls for dynamic analysis to determine the design seismic force.

According to IS 1893:2002, the fundamental natural period of vibration, Ta (in seconds) of a RC moment resisting frame with an overall height of h (in meters) and no brick infill is as follows:

$$\mathbf{T_a=0.075\ h^{0.75}} \qquad \textbf{(6)}$$

The following formula is suggested by Uniform Building Code 94 for determining the fundamental natural period of vibration, T (in seconds), of a RC moment resisting frame with an overall height of h_n (in meters):

$$\mathbf{T=0.0731\ (h_n)^{0.75}} \qquad \textbf{(7)}$$

The approximate fundamental period T_a (in second) of a structure with an overall height of h_n (in meters) for a RC moment resisting frame building is given by, in a manner that is analogous to ASCE 7:2010:

$$\mathbf{T_a=0.0466\ (h_n)^{0.9}} \qquad \textbf{(8)}$$

According to ASCE 7:2010, the following equation can be used to calculate the fundamental period T_a (in seconds) of RC buildings for structures with a height of no more than 12 stories, provided that the storey height is at least 3 m, where N is the number of stories.

$$\mathbf{T_a=0.1\ N} \qquad \textbf{(9)}$$

The code says that an alternative substantiated analysis like normal mode analysis or Rayleigh's method can be used to figure out the fundamental period. Both of these methods require a computer program, so the majority of practicing engineers find these theory-based methods difficult to use. The Rayleigh condition is based on underlying properties and deformational qualities. The following is Rayleigh's formula for calculating fundamental period T (in seconds):

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

(10)

Where w_i is the portion of the total seismic dead load that is assigned to or located at level i,

d_i is the lateral force-induced horizontal shift at level i in relation to the base,

g is the gravitational acceleration,

f_i is the lateral force at level i.

3. Methodology

This study is based on an examination of a group of structural models that depict multi-story buildings with a setback that is vertically irregular. A summary of the various parameters that define the computational models, the fundamental assumptions, and the building geometries considered for this study are presented in the first section of this chapter. All of the buildings that were chosen were built to Indian standards. The current study's design process is briefly described in the second half of this chapter. The methods of free vibration analysis of the building system were taken into consideration in the study.

Material Properties

The entire frame models used in this study is made of concrete that is grade M-20 and reinforcing steel that is grade Fe-415. These materials' elastic properties are taken from the Indian Standard, IS 456 (2000). Concrete's short-term modulus of elasticity (Ec) is defined as:

$$E_C= 5000\sqrt{f_{ck}} \text{ MPa} \qquad (3.1)$$

Where f_{ck} = compressive strength of a concrete cube in MPa at 28 days.

According to IS 456 (2000), yield stress (f_y) and modulus of elasticity (E_s) are used for steel rebar.

Structural Elements

2D frame elements are used to model beams and columns. The bending moments and forces at the faces of the beam and column are used to model the joints between the beam and column by giving the frame elements end offsets. It is assumed that the beam-column joints are rigid (Figure 1). All of the models in this study were considered to have a fixed column end at the foundation.

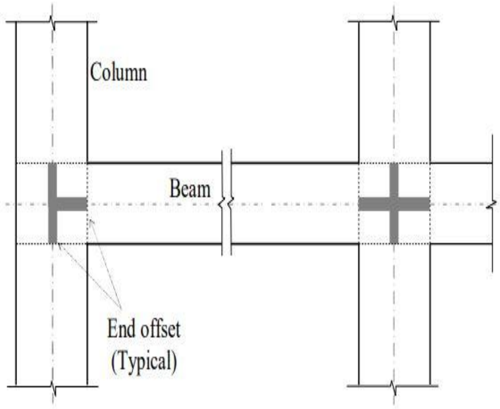

Figure 1: Use of end offsets at beam column joint

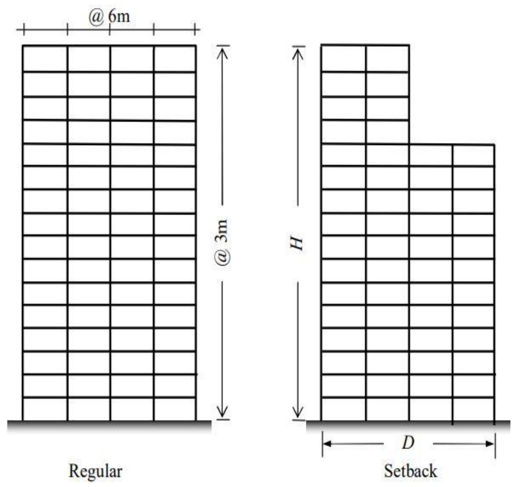

Figure 2: Structural Models

Building Geometrical Standards

The various degrees of irregularity or setback represented by these building geometries are varied. For the purpose of this investigation, three distinct bay widths—5 m, 6 m, and 7 m—all with the same number of bays at the base were taken into consideration. It is important to note that bay widths of 4 to 7 meters are typical, particularly in Indian and European practice. In a similar vein, the study took into account five distinct height categories, ranging from 6 to 30 storeys, with a common storey height of 3 meters. Ninety building frames total were chosen, each with a different amount of setback irregularities as a result of the reduced width and height.

Linear Dynamic Analysis

Even structures with uniform mass and solidness dissemination act in a reasonably unsurprising way, while structures that are with areas of intermittence or anomaly don't. Significant response characteristics like. Dynamic analyses can be done in two ways:

(1) An examination of the response spectrum and

(2) An examination of the elastic or inelastic time history.

Due to its simplicity, the response spectrum analysis is the method of choice. When calculating the structure's dynamic response, the time history method is utilized if it is essential to represent inelastic response characteristics or to incorporate time-dependent effects.

4. Result and Discussions

The findings of the analysis and pertinent discussions are presented in this chapter. The results presented here are focused on the fundamental time period of selected back buildings, which aligns with the study's goals. Previous chapter provides an overview of the analysis method used in this study as well as the specifics of the buildings chosen.

Tables 1 present a tabulation of the fundamental periods for all of the selected setback buildings, as determined by various published methods. The outcomes for buildings with a bay width of 5 meters are shown in Table 1, the outcomes for buildings with a bay width of 6 meters are shown in Table 2, and the outcomes for buildings with a bay width of 7 meters are shown in Table 3. Different code empirical equations, such as IS 1893:2002 are used to calculate the fundamental periods presented here UBC 94 (Eq. 7 and ASCE 7, 8 and 9), and the Rayleigh Method (Equation 10), and the modal analysis-derived duration.

Buildin	**Hei**	**TIS1**	**TUBC**	**TASC**	**TASC**	**TRa**	**TM**
R-6-	18	0.6	0.6	0.6	0.6	1.1	1.
S1-	18	0.6	0.6	0.6	0.6	1.0	1.
S2-	18	0.6	0.6	0.6	0.6	1.0	1.
S3-	18	0.6	0.6	0.6	0.6	0.8	0.

S4-	18	0.6	0.6	0.6	0.6	0.9	0.
S5-	18	0.6	0.6	0.6	0.6	0.9	1.
R-	36	1.1	1.0	1.1	1.2	1.3	1.
S1-	36	1.1	1.0	1.1	1.2	1.2	1.
S2-	36	1.1	1.0	1.1	1.2	1.2	1.
S3-	36	1.1	1.0	1.1	1.2	1.0	1.
S4-	36	1.1	1.0	1.1	1.2	1.1	1.
S5-	36	1.1	1.0	1.1	1.2	1.2	1.
R-	54	1.4	1.4	1.6	1.8	1.8	2.
S1-	54	1.4	1.4	1.6	1.8	1.7	1.
S2-	54	1.4	1.4	1.6	1.8	1.8	2.
S3-	54	1.4	1.4	1.6	1.8	1.7	1.
S4-	54	1.4	1.4	1.6	1.8	1.7	1.
S5-	54	1.4	1.4	1.6	1.8	1.9	2.
R-	72	1.8	1.8	2.1	2.4	2.0	2.
S1-	72	1.8	1.8	2.1	2.4	1.9	2.
S2-	72	1.8	1.8	2.1	2.4	2.1	2.
S3-	72	1.8	1.8	2.1	2.4	1.9	2.
S4-	72	1.8	1.8	2.1	2.4	1.8	2.
S5-	72	1.8	1.8	2.1	2.4	2.1	2.
R-	90	2.1	2.1	2.6	3.0	2.5	3.
S1-	90	2.1	2.1	2.6	3.0	2.3	2.
S2-	90	2.1	2.1	2.6	3.0	2.5	3.
S3-	90	2.1	2.1	2.6	3.0	2.1	2.
S4-	90	2.1	2.1	2.6	3.0	2.1	2.
S5-	90	2.1	2.1	2.6	3.0	2.7	3.

Table 4.1: Fundamental periods of setback buildings with 5 m bay width

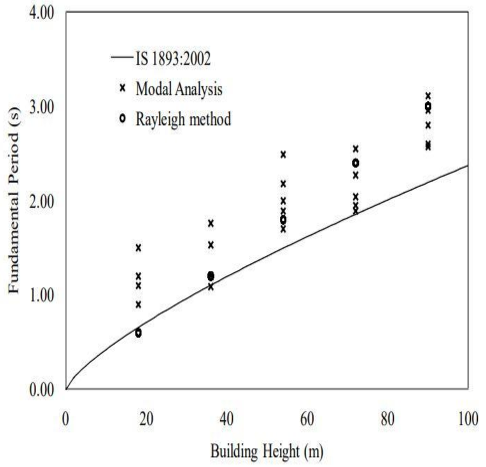

Figure 3: Comparison of fundamental period of setback buildings with that obtained from IS 1893:2002 equation

Figures 4 to 5 depict the fundamental period for various setback buildings as a function of the maximum building height. Separately, the fundamental periods from Modal and Rayleigh analyses are plotted and compared to those from the IS 1893:2002 empirical equation. In order to examine the pattern of variation in fundamental period, all setback types and regular (R) buildings' fundamental periods are plotted together. The outcomes of ASCE 7 are as follows: 2010 are not shown separately because they were found to be comparable to those obtained from IS 1893:2002.

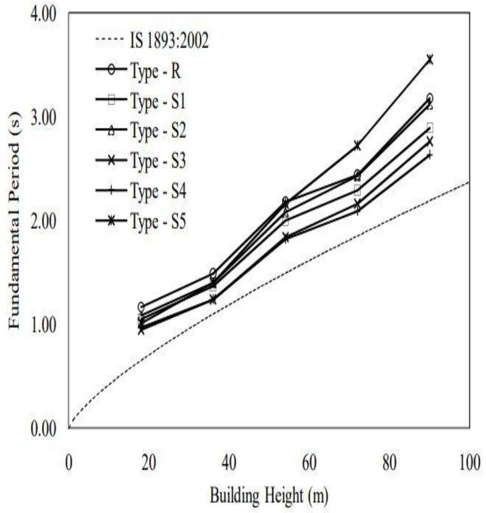

Figure 4: Fundamental period (Modal)

versus height of setback buildings of 5m bay width

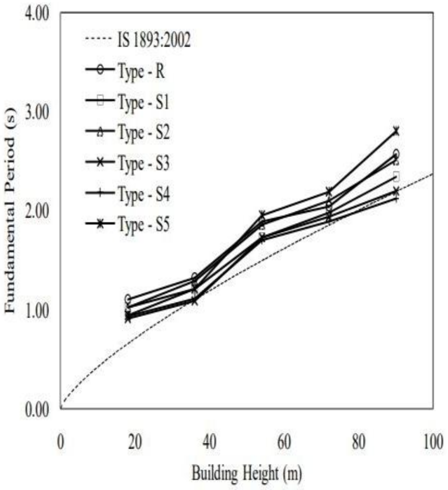

Fig. 5: Fundamental period (Rayleigh) versus height of setback buildings of 5m bay width

All of the selected buildings' normalized average height and width are detailed in Tables. The major time of the comparing building likewise introduced to associate them. The fact that the normalized average height and normalized average width for any setback building are the same is interesting to note from Tables. Likewise, these tables show that principal time of the customary structure is in every case more than that of mishap structures.

Building Designation	h_{av} /h	d_{av} /d	Fundamental Time Period
R-6-5	1.000	1.000	1.170
S1-6-5	0.887	0.887	1.045
S2-6-5	0.783	0.783	1.091
S3-6-5	0.666	0.666	0.945
S4-6-5	0.783	0.783	0.967
S5-6-5	0.555	0.555	1.010
R-12-5	1.000	1.000	1.485
S1-12-5	0.887	0.887	1.373
S2-12-5	0.783	0.783	1.400
S3-12-5	0.666	0.666	1.235
S4-12-5	0.783	0.783	1.235
S5-12-5	0.555	0.555	1.373
R-18-5	1.000	1.000	2.175
S1-18-5	0.887	0.887	2.000
S2-18-5	0.783	0.783	2.077
S3-18-5	0.666	0.666	1.835
S4-18-5	0.783	0.783	1.821
S5-18-5	0.555	0.555	2.155
R-24-5	1.000	1.000	2.437
S1-24-5	0.887	0.887	2.290
S2-24-5	0.783	0.783	2.425
S3-24-5	0.666	0.666	2.157
S4-24-5	0.783	0.783	2.087
S5-24-5	0.555	0.555	2.715
R-30-5	1.000	1.000	3.175
S1-30-5	0.887	0.887	2.887
S2-30-5	0.783	0.783	3.120
S3-30-5	0.666	0.666	2.757
S4-30-5	0.783	0.783	2.633
S5-30-5	0.555	0.555	3.550

Table 2: Normalised average height and width of the buildings with 5m bay width

5. Conclusion

The Rayleigh method, modal analysis, and empirical equations provided in the design codes were used to estimate the fundamental period of all of the selected building models. This chapter presents a critical analysis of the findings. The point of the examinations and conversations were to recognize a boundary that portrays the inconsistency of a misfortune fabricating and show up at a better observational condition to appraise the central time frame of difficulty structures with certainty. This study, on the other hand, demonstrates that it is challenging to quantify the irregularity in a setback building using just one parameter. According to the findings of this study, there is very little correlation between the fundamental periods of three-dimensional buildings and any of the parameters that previous researchers or design codes used to define the setback irregularity.

References

- *Chintanapakdee, C. and Chopra, A.K. (2004) "Seismic Response of Vertically Irregular Frames: Response History and Modal Pushover Analyses", Journal of Structural Engineering, ASCE, Vol. 130, No. 8, pp. 1177-1185*
- *Das, S. and Nau, J.M. (2003) "Seismic Design Aspects of Vertically Irregular Reinforced Concrete Buildings", Earthquake Spectra, Vol. 19, No. 3, pp. 455-477*
- *Eurocode 8. Design of structures for earthquake resistance, part-1: general rules, seismic actions and rules for buildings. Brussels: European Committee for Standardization (CEN); 2004*
- *Fragiadakis, M., Vamvatsikos, D. and Papadrakakis, M. (2006) "Evaluation of the Influence of Vertical Irregularities on the Seismic Performance of a NineStorey Steel Frame", Earthquake Engineering & Structural Dynamics, Vol. 35, No. 12, pp. 1489-1509*
- *Karavasilis, T.L., Bazeos, N. and Beskos, D.E. Seismic response of plane steel MRF with setbacks: Estimation of inelastic deformation demands. Journal of Constructional Steel Research, 2008, 64, pp. 644-654*
- *Sarkar, P., Prasad, A. M., and Menon, D., (2010) Vertical geometric irregularity in stepped building frames, Engineering Structures 32, pp. 2175–2182*
- *Valmundsson, E.V. and Nau, J.M. (1997) "Seismic Response of Building Frames with Vertical Structural Irregularities", Journal of Structural Engineering, ASCE, Vol. 123, No. 1, pp. 30-41*
- *Wong, C.M. and Tso, W.K. (1994) "Seismic Loading for Buildings with Setbacks", Canadian Journal of Civil Engineering, Vol. 21, No. 5, pp. 863-871*
- *Wood, S.L. (1992). "Seismic Response of R/C Frames with Irregular Profiles", Journal of Structural Engineering, ASCE, Vol. 118, No. 2, pp. pp. 545-566*
- *Young, K.C. (2011) "An Investigation of the Fundamental Period of Vibration of Irregular Steel Structures", Thesis for Master of Science in the Graduate School of the Ohio State University*