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SEISMIC EFFECT ON THE FUNDAMENTAL PERIOD OF RC FRAMED SETBACK BUILDINGS

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Abstract: This paper presents a design code perspective of 'Setback' building category. Almost all the major international design codes 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 only, which is ambiguous for a setback building. It has been seen from the analysis that the fundamental period of a setback building changes when the configuration of the building changes, even if the overall height remains same. Based on modal analysis of 15-three-dimensional setback building frames with varying irregularity, this study critically reviews the existing method of quantifying vertical geometric irregularity and discusses the effect of irregularity on the fundamental period of setback buildings.

Keywords: Geometric Irregularity, Setback Building, Fundamental Period, Regularity Index, Correction Factor.

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INTRODUCTION

The magnitude of lateral force due to an earthquake depends mainly on inertial mass, ground acceleration and the dynamic characteristics of the building. To characterize the ground motion and structural behaviour, design codes provide the Response spectrum. Response spectrum conveniently describes the peak responses of structure as a function of natural vibration period, damping ratio and type of founding soil. The determination of the fundamental period of structures is essential to earthquake design and assessment.

This setback affects the mass, strength, stiffness, centre of mass and centre of stiffness of setback building. Dynamic characteristics of such buildings differ from the regular building due to changes in geometrical and structural property. Design codes are not clear about the definition of building height for computation of fundamental period. The baywise variation of height in setback building makes it difficult to compute natural period of such buildings.

With this background it is found essential to study the effect of setbacks on the fundamental period of buildings. Also, the performance of the empirical equation given in Indian Standard IS 1893:2002 for estimation of fundamental period of setback buildings is matter of concern for structural engineers.

1.1 OBJECTIVES:

a) To perform a parametric study of the fundamental period of different types of reinforced concrete moment resisting frames (MRF) with varying number of stories, number of bays, configuration, and types of irregularity.

b) To compare the fundamental periods of each structure calculated using code empirical equations with fundamental period based on modal analysis.

1.2 SCOPE OF THE STUDY:

a) The present paper is limited to reinforced concrete (RC) multi-storeyed building frames with setbacks.

b) Infill stiffness is not considered in the present paper. However, associated mass and weight is assumed in the analysis.

c) Setback buildings from 6-storeys to 18-storeys with different degrees of irregularity are considered.

d) The buildings are assumed to have setback only in one direction.

e) Column ends are assumed to be fixed at the foundation.

2. DESIGN CODE PERSPECTIVE:

Most of the available design codes for earthquake resistant building including IS 1893:2002, ASCE 7:2010, Euro code 8 or New Zealand code of practice, recommends an empirical formula for the determination of fundamental time period of building. Also the design codes define different types of irregular structures.

2.1 Fundamental Time Period

As per IS 1893:2002 buildings having simpler regular geometry and uniformly distributed mass and stiffness in plan as well as in elevation, suffer much less damage then buildings with irregular configurations. Design code recommends dynamic analysis to obtain the design seismic force for all irregular buildings. ASCE 7:2010 and Euro Code 8 specify similar guidelines.

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

$$T_a = 0.075h^{0.75} \qquad (2.1)$$

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 94 recommends the formula as shown:

$$T = 0.0731(h_n)^{0.75} \qquad (2.2)$$

In a similar way as per ASCE 7:2010, 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:

$$T_a = 0.0446(h_n)^{0.9} \qquad (2.3)$$

ASCE 7:2010 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:

$$T_a = 0.1N \qquad (2.4)$$

All the above empirical equation of fundamental period mentioned in codes (Eq. 2.1, Eq. 2.2 and Eq. 2.3) are function of overall building height and does not account for the stepped variations in height, applicable for setback buildings.

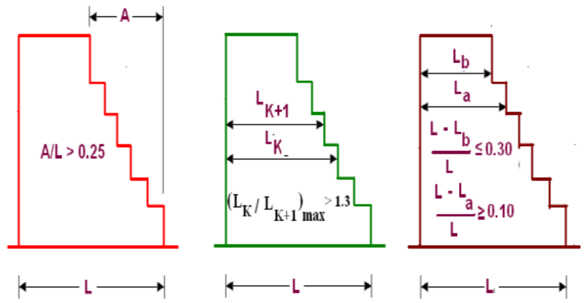


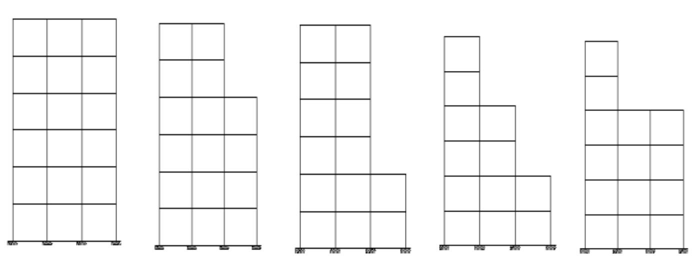
Fig. 2.1: Vertical geometric irregularity
(a) IS-1893:2002 (b) ASCE 7:2010
(c) EC 8 code

3. STRUCTURAL MODELLING

3.1 BUILDING GEOMETRY

The study is based on three dimensional 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. The bay width, i.e. 5m, 6m & 7m (in both the horizontal direction) with a uniform three number of bays at base were considered for this study.

The building geometries considered regular frame, without any setback, is also studied shown in Fig. 3.1.



Type-R Type-S1 Type-S2 Type-S3 Type-S4

Fig 3.1: Typical building elevations for six-storey building variants (R, S1 toS4)

The frames are designed with M-25 grade of concrete and Fe-415 grade of reinforcing steel as per prevailing Indian Standards. Gravity (dead and imposed) load and seismic load corresponding to seismic zone III of IS 1893:2002 are considered for the design. The cross sectional dimensions of beams and columns are taken as shown.

Table 3.1: Dimensions of beams & columns

Building Type	Column dimension (mm)	Beam dimension (mm)
Six-storey building	400 × 400	300 × 450
Twelve-storey building	600 × 600	450 × 600
Eighteen storey building	800 × 800	450 × 600

The structures are modelled by using computer software E-Tabs v.9.7.4

4. RESULTS AND DISCUSSIONS

The fundamental time periods of all the 15 selected setback buildings were calculated using different methods available including code based empirical equations such as IS 1893:2002 (Eq. 2.1), UBC 94 (Eq. 2.2), ASCE 7 (Eqs. 2.3 and 2.4) and period obtained from modal analysis.

Table 4.1: Fundamental period (s) of setback buildings with 5m, 6m & 7m bay

Building	Height (m)	$T_{IS\ 1893}$ (Eq. 2.1)	$T_{UBC.94}$ (Eq. 2.2)	$T_{ASCE.7}$ (Eq. 2.3 & 2.4)		T_{Modal}
R-6-5	18	0.66	0.64	0.63	0.6	1.23
S1-6-6	18	0.66	0.64	0.63	0.6	1.39
S2-6-6	18	0.66	0.64	0.63	0.6	1.38
S3-6-7	18	0.66	0.64	0.63	0.6	1.48
S4-6-7	18	0.66	0.64	0.63	0.6	1.50
R-12-5	36	1.10	1.07	1.17	1.20	1.43
S1-12-6	36	1.10	1.07	1.17	1.20	1.59
S2-12-6	36	1.10	1.07	1.17	1.20	1.58
S3-12-7	36	1.10	1.07	1.17	1.20	1.69
S4-12-7	36	1.10	1.07	1.17	1.20	1.70
R-18-5	54	1.49	1.46	1.69	1.8	2.03
S1-18-6	54	1.49	1.46	1.69	1.8	2.24
S2-18-6	54	1.49	1.46	1.69	1.8	2.24
S3-18-7	54	1.49	1.46	1.69	1.8	2.37
S4-18-7	54	1.49	1.46	1.69	1.8	2.39

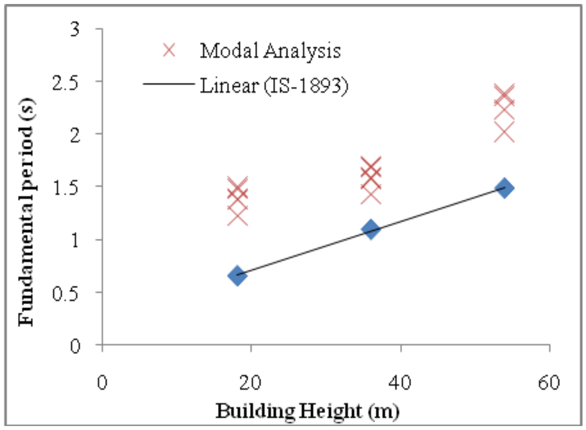


Fig. 4.1: Comparison of fundamental period of setback buildings from Modal Analysis with that obtained from IS 1893:2002 Eq.

The amounts of setback irregularity present in the selected buildings are calculated as per IS 1893:2002 code.

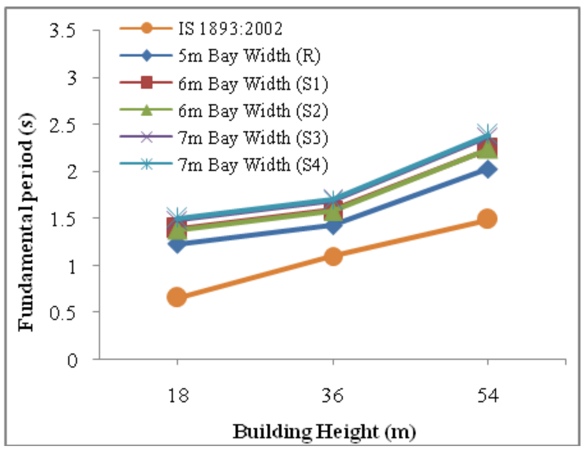


Fig. 4.2: Fundamental period (Modal) versus height of setback buildings.

Fig.4.2 presented above show that the buildings with same maximum height may have different period depending on the amount of irregularity present in the setback buildings.

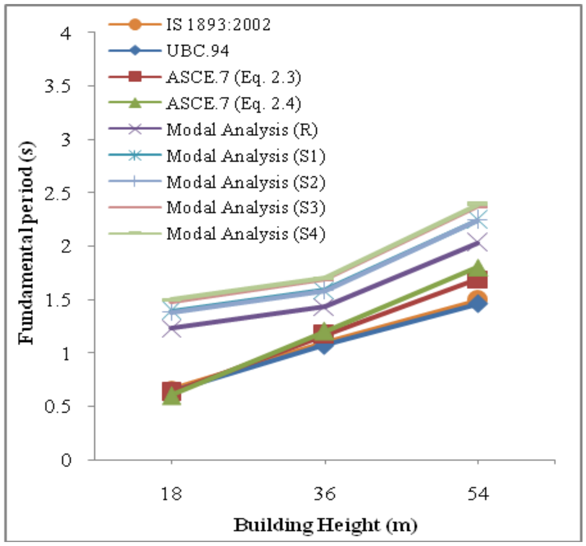


Fig. 4.3: Fundamental period (Modal & Empirical Eq.) versus height of buildings.

All the major international design codes including IS 1893:2002 does not specify bay width or plan dimension as a parameter which affects the fundamental period of RC framed building without considering brick infill. However, it is observed that the bay width or the plan dimension affects the fundamental period of such type of buildings.

Therefore it is concluded that the bay width or the plan dimension of the building affects the fundamental period of building, and it should be accounted for in the code based empirical equations for the calculation of fundamental period of RC frame buildings without infill also.

5. CONCLUSIONS

Based on the work presented in this paper following point-wise conclusions can be drawn:

1) Period of setback buildings are found to be always less than that of similar regular building. Fundamental period of setback buildings are found to be varying with irregularity even if the height remain constant.

2) The code (IS 1893:2002) empirical formula gives the lower-bound of the fundamental periods obtained from Modal Analysis. Therefore, it can be concluded that the code (IS 1893:2002) always gives conservative estimates of the fundamental periods of setback buildings with 6 to 18 storeys.

3) Unlike other available equations, Eq. 2.4 from ASCE 7: 2010 does not consider the height of the building but it considers only the number of storeys. Although this is not supported theoretically this approach is found to be most conservative among other code equations.

4) It is found that the fundamental period in a framed building is not a function of building height only.

5) This study indicates that 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 design codes.

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