International Journal For Technological Research In Engineering
Volume 7, Issue 12, August-2020 *ISSN (Online): 2347 - 4718*

ANALYSIS OF SETBACK ON FUNDAMENTAL PERIOD OF REINFORCE CONCRETE BUILDINGS

Keerti Dohare[1], Prof Dharmendra Singh[2]
[1]M. Tech Research Scholar, [2]Asst Professor,
Department of Civil Engineering, RNTU, Bhopal (M.P)

***ABSTRACT:** The motion of the ground during earthquake do not damage the building by impact or by any external force, rather it impacts the building by creating an internal inertial forces which is due to vibration of building mass. 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 a Response spectrum. Response spectrum conveniently describes the peak responses of structure as a function of natural vibration period. Therefore it is necessary to study of natural vibration period of building to understand the seismic response of building. The behaviour of a multi-storey framed building during strong earthquake motions depends on the distribution of mass, stiffness, and strength in both the horizontal and vertical planes of the building. In multi-storeyed framed buildings, damage from earthquake ground motion generally initiates at locations of structural weaknesses present in the lateral load resisting frames. In some cases, these weaknesses may be created by discontinuities in stiffness, strength or mass between adjacent storeys. Such discontinuities between storeys are often associated with sudden variations in the frame geometry along the height. There are many examples of failure of buildings in past earthquakes due to such vertical discontinuities. A common type of vertical geometrical irregularity in building structures arises from abrupt reduction of the lateral dimension of the building at specific levels of the elevation. This building category is known as the setback building. Setback buildings with geometric irregularity (both in elevation and plan) are now increasingly encountered in modern urban construction. Setback buildings are characterised by staggered abrupt reductions in floor area along the height of the building, with consequent drops in mass, strength and stiffness. Height-wise changes in stiffness and mass render the dynamic characteristics of these buildings different from the 'regular' building. Many investigations have been performed to understand the behaviour of irregular structures as well as setback structures and to ascertain method of improving their performance.*

***KEYWORDS:** geometric irregularity, setback building, fundamental period, regularity index, correction factor.*

I. 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 a 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.

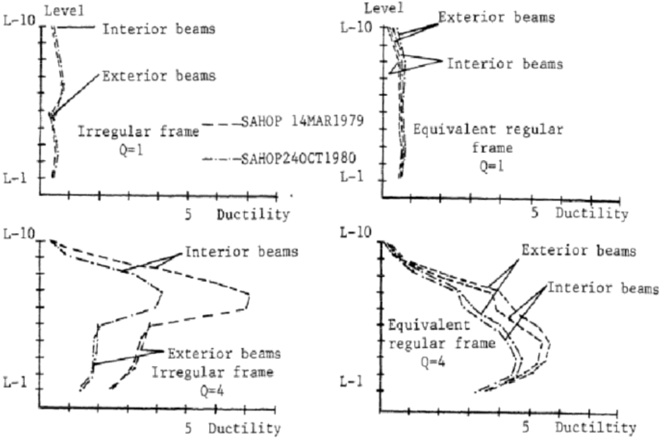


Fig. : Ductility demands in beams for the selected RC frames (Ref: Aranda,1984)

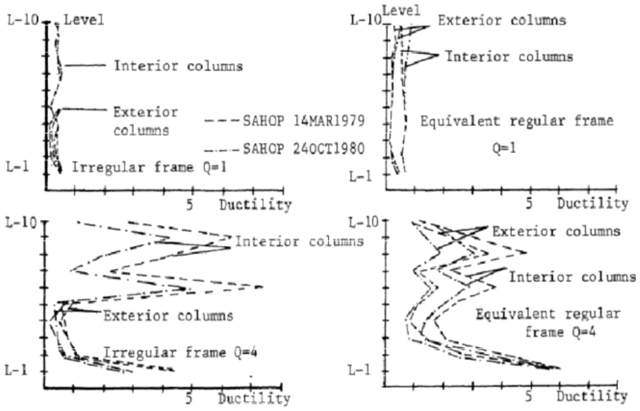
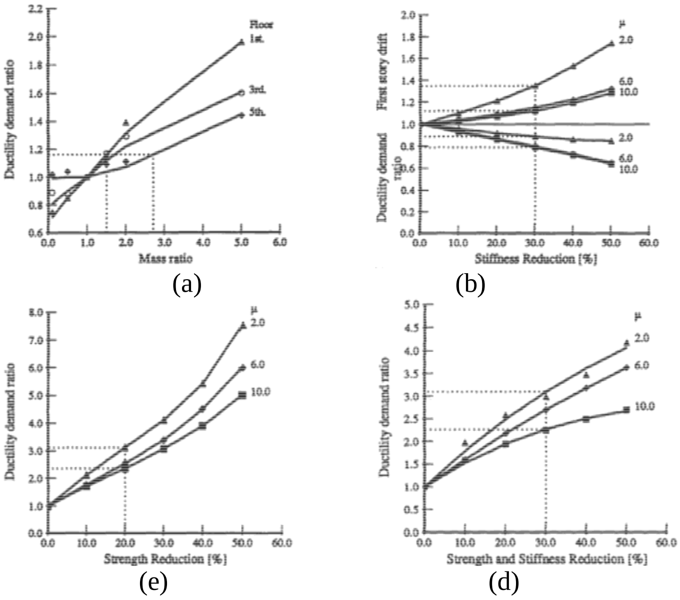


Fig. : Ductility demands in Columns for the selected RC frames (Ref: Aranda, 1984)

It was concluded that for both the models the ductility demand in the exterior beams are larger than Valmundsson et. al. (1997) studied the two dimensional building frames with 5, 10 and 20 storey. They studied the earthquake response of these structures with non uniform mass, stiffness and strength distributions. Response from time history and equivalent lateral force methods are being compared. Based on this comparison they evaluated the requirements under which a structure can be considered regular and ELF procedure are applicable.



(a) (b)

(e) (d)

Fig. : (a) Maximum ductility demand for 5-story structure with mass irregularity and design ductility = 2; (b) Maximum ductility demand and first story drift for 20-story structure with stiffness irregularity; (c) Maximum ductility demand for 20-story structure with strength irregularity; (d) Maximum ductility demand for 20-story structure with strength and stiffness irregularities (Ref. Valmundsson, 1997)

They concluded that with the 50 % increase in the mass of one floor the ductility demand increases maximum by 20% as shown in Fig 2.3(a) depending on the design ductility. Reducing the stiffness of the first story by 30%, while keeping the strength constant, increases the first story drift by 20-40%, depending on the design ductility as shown in Fig 2.3(b).On reducing the strength of the first story by 20% the ductility demand increases by 100-200% as shown in Fig 2.3(c). Reducing the first story strength and stiffness proportionally by 30% increases the ductility demand by 80-200% as shown in Fig 2.3(d), depending on the design ductility. Thus strength criterion results in large increases in response quantities and is not consistent with the mass and stiffness requirement

Through statistical comparison, it was found that a 3-variable power model which is able to account for irregularities resulted in a better fit to the Rayleigh data than equations which were dependent on height only. The proposed equations were validated through a comparison of available measured period data. For braced frames, the proposed equations were also compared with a database of examples from literature.

II. FUNDAMENTAL TIME PERIOD FOR SETBACK BUILDINGS

The fundamental time periods of all the 90 selected setback buildings were calculated using different methods available in literature including code based empirical formulas. These methods are explained in Chapter 2. Fundamental period of these buildings were also calculated using modal analysis. Modal analysis procedure is explained in Chapter 3.

The fundamental periods for all the selected setback buildings as obtained from different methods available in literature are tabulated in Tables 4.1 - 4.3. Table 4.1 presents the results of buildings with 5m bay width, Table 4.2 presents the results of buildings with 6m bay width whereas the Table 4.3 presents the results of buildings with 7m bay width. The fundamental periods presented here are computed as per different code empirical equations such as IS 1893:2002 (Eq. 2.6), UBC 94 (Eq. 2.7), ASCE 7 (Eqs. 2.8 and 2.9) as well as Rayleigh Method (Eq. 2.10), and period obtained from modal analysis.

Results

Table : Fundamental period (s) of setback buildings with 5 m bay width

Building Designation	Height (m)	TIS1893 (Eq. 2.6)	TUBC.94 (Eq. 2.7)	TASCE.7 (Eq. 2.8)	TASCE.7 (Eq. 2.9)	TRayleigh (Eq. 2.10)	TModal
R-6-5	18	0.66	0.64	0.63	0.60	1.1	1.17
S1-6-5	18	0.66	0.64	0.63	0.60	1.02	1.05
S2-6-5	18	0.66	0.64	0.63	0.60	1.02	1.09
S3-6-5	18	0.66	0.64	0.63	0.60	0.9	0.95
S4-6-5	18	0.66	0.64	0.63	0.60	0.93	0.97
S5-6-5	18	0.66	0.64	0.63	0.60	0.94	1.01
R-12-5	36	1.10	1.07	1.17	1.20	1.32	1.49
S1-12-5	36	1.10	1.07	1.17	1.20	1.21	1.37
S2-12-5	36	1.10	1.07	1.17	1.20	1.29	1.4
S3-12-5	36	1.10	1.07	1.17	1.20	1.09	1.24
S4-12-5	36	1.10	1.07	1.17	1.20	1.11	1.24
S5-12-5	36	1.10	1.07	1.17	1.20	1.21	1.40
R-18-5	54	1.49	1.46	1.69	1.80	1.89	2.18
S1-18-5	54	1.49	1.46	1.69	1.80	1.73	2.00
S2-18-5	54	1.49	1.46	1.69	1.80	1.86	2.08
S3-18-5	54	1.49	1.46	1.69	1.80	1.73	1.84
S4-18-5	54	1.49	1.46	1.69	1.80	1.70	1.82
S5-18-5	54	1.49	1.46	1.69	1.80	1.95	2.16
R-24-5	72	1.85	1.81	2.19	2.40	2.04	2.44
S1-24-5	72	1.85	1.81	2.19	2.40	1.98	2.29
S2-24-5	72	1.85	1.81	2.19	2.40	2.10	2.43
S3-24-5	72	1.85	1.81	2.19	2.40	1.95	2.16
S4-24-5	72	1.85	1.81	2.19	2.40	1.89	2.09
S5-24-5	72	1.85	1.81	2.19	2.40	2.19	2.72
R-30-5	90	2.19	2.14	2.67	3.00	2.57	3.18
S1-30-5	90	2.19	2.14	2.67	3.00	2.34	2.89
S2-30-5	90	2.19	2.14	2.67	3.00	2.51	3.12
S3-30-5	90	2.19	2.14	2.67	3.00	2.20	2.76
S4-30-5	90	2.19	2.14	2.67	3.00	2.12	2.63
S5-30-5	90	2.19	2.14	2.67	3.00	2.8	3.55

Table : Fundamental period (s) of setback buildings with 6 m bay width

Building Designation	Height (m)	TIS1893 (Eq. 2.6)	TUBC.94 (Eq. 2.7)	TASCE.7 (Eq. 2.8)	TASCE.7 (Eq. 2.9)	TRayleigh (Eq. 2.10)	TModal
R-6-6	18	0.66	0.64	0.63	0.60	1.30	1.37
S1-6-6	18	0.66	0.64	0.63	0.60	1.20	1.23
S2-6-6	18	0.66	0.64	0.63	0.60	1.19	1.28
S3-6-6	18	0.66	0.64	0.63	0.60	1.06	1.11
S4-6-6	18	0.66	0.64	0.63	0.60	1.09	1.13
S5-6-6	18	0.66	0.64	0.63	0.60	1.09	1.17
R-12-6	36	1.10	1.07	1.17	1.20	1.53	1.72
S1-12-6	36	1.10	1.07	1.17	1.20	1.4	1.57
S2-12-6	36	1.10	1.07	1.17	1.20	1.42	1.60
S3-12-6	36	1.10	1.07	1.17	1.20	1.25	1.41
S4-12-6	36	1.10	1.07	1.17	1.20	1.28	1.42
S5-12-6	36	1.10	1.07	1.17	1.20	1.36	1.56
R-18-6	54	1.49	1.46	1.69	1.80	2.18	2.45
S1-18-6	54	1.49	1.46	1.69	1.80	2.00	2.28
S2-18-6	54	1.49	1.46	1.69	1.80	2.05	2.35
S3-18-6	54	1.49	1.46	1.69	1.80	1.80	2.08
S4-18-6	54	1.49	1.46	1.69	1.80	1.81	2.06

S5-18-6	54	1.49	1.46	1.69	1.80	2.02	2.37
R-24-6	72	1.85	1.81	2.19	2.40	2.27	2.68
S1-24-6	72	1.85	1.81	2.19	2.40	2.15	2.52
S2-24-6	72	1.85	1.81	2.19	2.40	2.23	2.65
S3-24-6	72	1.85	1.81	2.19	2.40	1.97	2.35
S4-24-6	72	1.85	1.81	2.19	2.40	2.13	2.30
S5-24-6	72	1.85	1.81	2.19	2.40	2.25	2.84
R-30-6	90	2.19	2.14	2.67	3.00	2.82	3.45
S1-30-6	90	2.19	2.14	2.67	3.00	2.57	3.19
S2-30-6	90	2.19	2.14	2.67	3.00	2.71	3.32
S3-30-6	90	2.19	2.14	2.67	3.00	2.37	2.94
S4-30-6	90	2.19	2.14	2.67	3.00	2.35	2.84
S5-30-6	90	2.19	2.14	2.67	3.00	2.80	3.64

Table : Fundamental period (s) of setback buildings with 7 m bay width

Building Designation	Height (m)	TIS1893 (Eq. 2.6)	TUBC.94 (Eq. 2.7)	TASCE.7 (Eq. 2.8)	TASCE.7 (Eq. 2.9)	TRayleigh (Eq. 2.10)	TModal
R-6-7	18	0.66	0.64	0.63	0.60	1.50	1.58
S1-6-7	18	0.66	0.64	0.63	0.60	1.35	1.42
S2-6-7	18	0.66	0.64	0.63	0.60	1.38	1.47
S3-6-7	18	0.66	0.64	0.63	0.60	1.20	1.28
S4-6-7	18	0.66	0.64	0.63	0.60	1.26	1.30
S5-6-7	18	0.66	0.64	0.63	0.60	1.23	1.35
R-12-7	36	1.10	1.07	1.17	1.20	1.76	1.95
S1-12-7	36	1.10	1.07	1.17	1.20	1.61	1.78
S2-12-7	36	1.10	1.07	1.17	1.20	1.62	1.81
S3-12-7	36	1.10	1.07	1.17	1.20	1.53	1.59
S4-12-7	36	1.10	1.07	1.17	1.20	1.46	1.61
S5-12-7	36	1.10	1.07	1.17	1.20	1.53	1.74
R-18-7	54	1.49	1.46	1.69	1.80	2.49	2.73
S1-18-7	54	1.49	1.46	1.69	1.80	2.28	2.58
S2-18-7	54	1.49	1.46	1.69	1.80	2.33	2.65
S3-18-7	54	1.49	1.46	1.69	1.80	2.05	2.35
S4-18-7	54	1.49	1.46	1.69	1.80	2.06	2.33
S5-18-7	54	1.49	1.46	1.69	1.80	2.25	2.62
R-24-7	72	1.85	1.81	2.19	2.40	2.55	2.97
S1-24-7	72	1.85	1.81	2.19	2.40	2.40	2.80
S2-24-7	72	1.85	1.81	2.19	2.40	2.48	2.91
S3-24-7	72	1.85	1.81	2.19	2.40	2.18	2.57
S4-24-7	72	1.85	1.81	2.19	2.40	2.39	2.54
S5-24-7	72	1.85	1.81	2.19	2.40	2.43	3.02
R-30-7	90	2.19	2.14	2.67	3.00	3.11	3.78
S1-30-7	90	2.19	2.14	2.67	3.00	2.84	3.44
S2-30-7	90	2.19	2.14	2.67	3.00	2.96	3.58
S3-30-7	90	2.19	2.14	2.67	3.00	2.60	3.17
S4-30-7	90	2.19	2.14	2.67	3.00	2.57	3.21
S5-30-7	90	2.19	2.14	2.67	3.00	3.06	3.74

The results presented in Tables 4.1 – 4.3 are also shown graphically in Figs 4.1 - 4.3 for better understanding. The fundamental periods of 6 to 30 story setback buildings are plotted against number of stories. Fig. 4.1 presents the comparison of fundamental period of setback buildings with that obtained from IS 1893:2002 equation. This figure shows that the code empirical formula gives the lower-bound of the fundamental periods obtained from Modal Analysis and Raleigh Method. 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 30 storeys. It can also be seen that Raleigh Method underestimates the fundamental periods of setback buildings slightly which is also conservative for the selected buildings.

Table : Characteristics of setback buildings with 7 m bay width

Building Designation	Height (m)	TModal (s)	$\frac{A}{L}$ (IS 1893)	$\frac{L_{11}}{L_{\iota}}$ (ASCE 7)	Karavasilis *et.al.* 2008		(Sarkar *et.al.* 2010)
					s	*b*	
R-6-7	18	1.58	0.00	1.00	1.00	1.00	1.00
S1-6-7	18	1.42	0.33	1.50	1.25	1.25	0.86
S2-6-7	18	1.47	0.33	1.50	1.25	2.00	0.80
S3-6-7	18	1.28	0.66	2.00	1.75	1.75	0.74
S4-6-7	18	1.30	0.66	3.00	2.00	1.25	0.82
S5-6-7	18	1.35	0.66	3.00	2.00	2.00	0.63
R-12-7	36	1.95	0.00	1.00	1.00	1.00	1.00
S1-12-7	36	1.78	0.33	1.50	1.10	1.25	0.94
S2-12-7	36	1.81	0.33	1.50	1.10	2.00	0.85
S3-12-7	36	1.59	0.66	2.00	1.30	1.75	0.79
S4-12-7	36	1.61	0.66	3.00	1.40	1.25	0.88
S5-12-7	36	1.74	0.66	3.00	1.40	2.00	0.66
R-18-7	54	2.73	0.00	1.00	1.00	1.00	1.00
S1-18-7	54	2.58	0.33	1.50	1.03	1.25	0.97
S2-18-7	54	2.65	0.33	1.50	1.03	2.00	0.88
S3-18-7	54	2.35	0.66	2.00	1.09	1.75	0.81
S4-18-7	54	2.33	0.66	3.00	1.18	1.25	0.91
S5-18-7	54	2.62	0.66	3.00	1.18	2.00	0.67
R-24-7	72	2.97	0.00	1.00	1.00	1.00	1.00
S1-24-7	72	2.80	0.33	1.50	1.02	1.25	0.92
S2-24-7	72	2.91	0.33	1.50	1.02	2.00	0.83
S3-24-7	72	2.57	0.66	2.00	1.07	1.75	0.76
S4-24-7	72	2.54	0.66	3.00	1.09	1.25	0.85
S5-24-7	72	3.02	0.66	3.00	1.09	2.00	0.63
R-30-7	90	3.78	0.00	1.00	1.00	1.00	1.00
S1-30-7	90	3.44	0.33	1.50	1.02	1.25	0.94
S2-30-7	90	3.58	0.33	1.50	1.02	2.00	0.84
S3-30-7	90	3.17	0.66	2.00	1.05	1.75	0.76
S4-30-7	90	3.21	0.66	3.00	1.07	1.25	0.86
S5-30-7	90	3.74	0.66	3.00	1.07	2.00	0.62

Fundamental period for different setback buildings are shown in Figs.4.4 - 4.9 as a function of maximum building height. Fundamental periods obtained from Modal analyses and Rayleigh analyses are plotted separately and are compared with that obtained from IS 1893:2002 empirical equation. Fundamental period of all the setback types (S1 to S5) along with regular (R) buildings are shown in a single plot so as to analyse the pattern of variation of fundamental period. The results obtained from ASCE 7: 2010 are found to be similar to those obtained from IS 1893:2002 hence not shown separately.

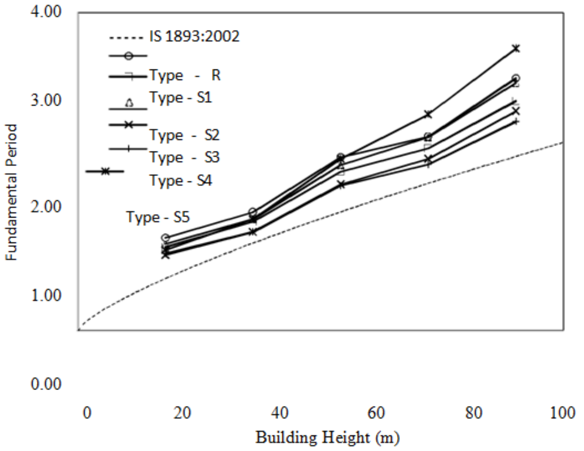


Fig. : Fundamental period (Modal) versus height of setback buildings of 5m bay width

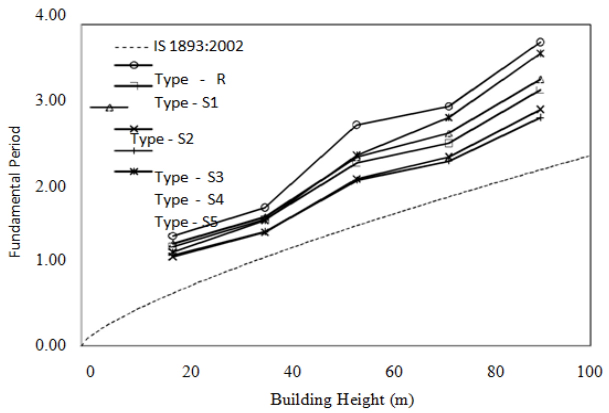


Fig. : Fundamental period (Modal) versus height of setback buildings of 6m bay width

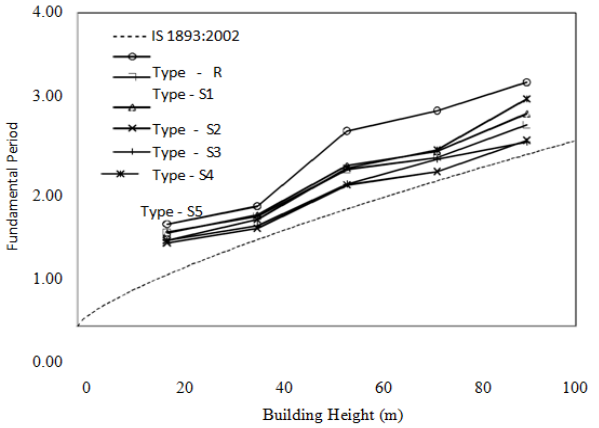


Fig. : Fundamental period (Rayleigh) versus height of setback buildings of 6m bay width

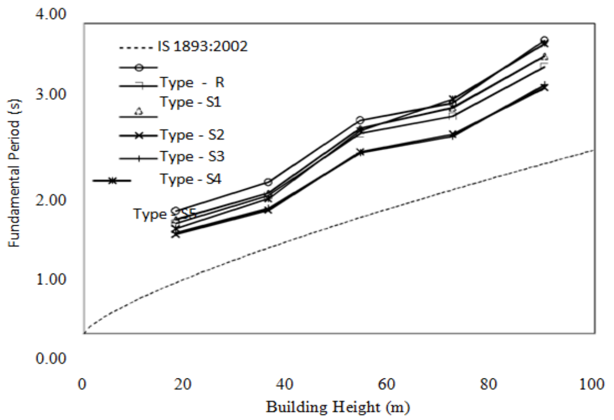


Fig. : Modal analysis time period versus height of setback buildings of 7m bay width

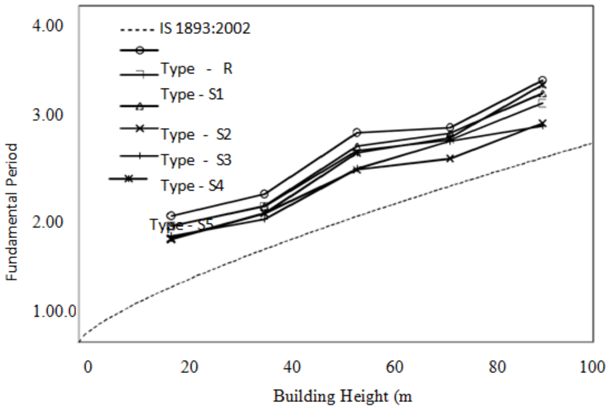


Fig. : Rayleigh analysis time period versus height of setback buildings of 7m bay width

Figs.4.4 - 4.9 presented above show that 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. This observation is valid for the periods calculated from both modal and Rayleigh analysis. It is found that variation of fundamental periods calculated from modal analysis and Rayleigh method are quite similar.

III. PARAMETERS AFFECTING FUNDAMENTAL TIME PERIOD

One of the main objectives of the present study was to formulate an improved empirical relation to evaluate fundamental period of setback buildings considering the vertical geometric irregularity. It is, therefore, required to know the important parameters which control the fundamental period of a setback building. This section analyses the fundamental period computed using the Rayleigh method and Modal analysis against different possible parameters. Although the results of all the selected buildings are considered for analysis, results of 15 building are presented here for convenience. Figs. 4.10-4.12 present the fundamental periods of three irregular building variants as a function of height keeping bay width same. This figure shows that the fundamental period is indeed very sensitive to the building height. Figs. 4.13 – 4.15 present the fundamental periods of three irregular building variants as a function of bay width keeping the building height same. Figs. 4.16

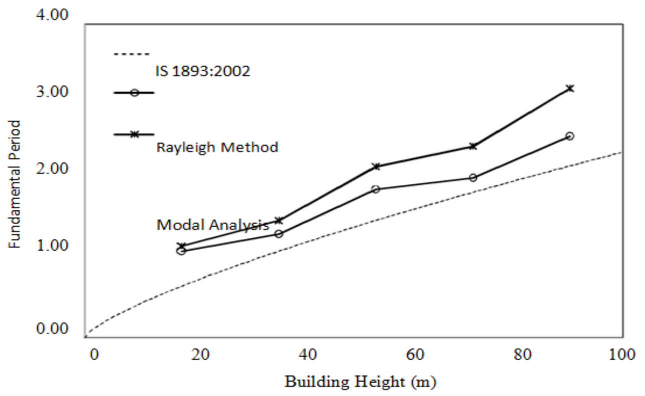


Fig. : Fundamental time period vs. height of Type - R building with 5 m bay width

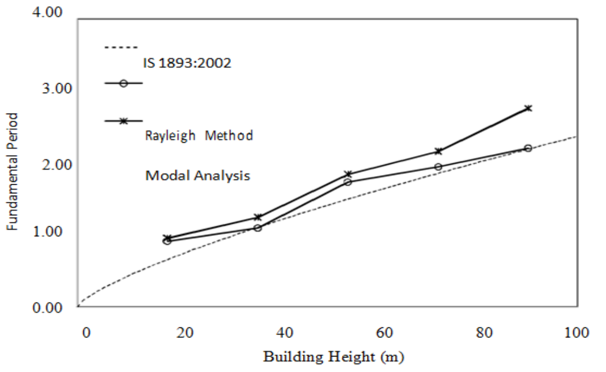


Fig. : Fundamental time period vs. height of Type–S3 setback building with 5 m bay width

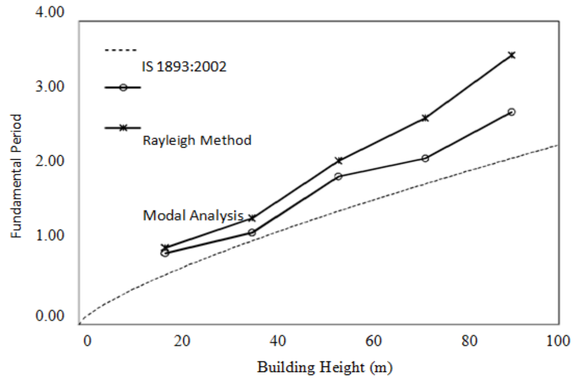


Fig. : Fundamental time period vs. height of Type–S5 setback building with 5 m bay width

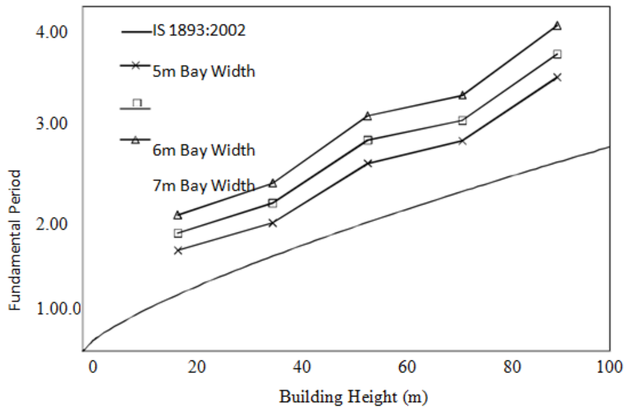


Fig. : Variation of fundamental time period with bay width for Type – R building.

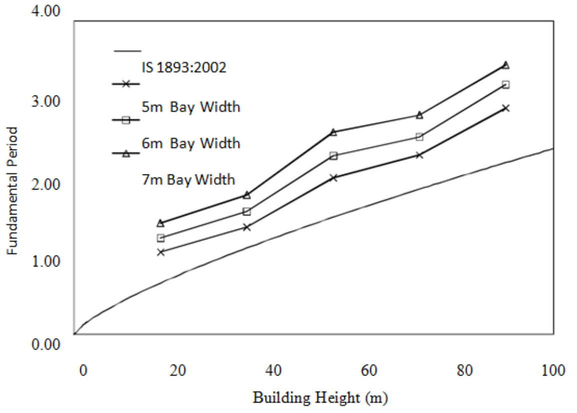


Fig. : Variation of fundamental time period with bay width for Type – S1 setback building.

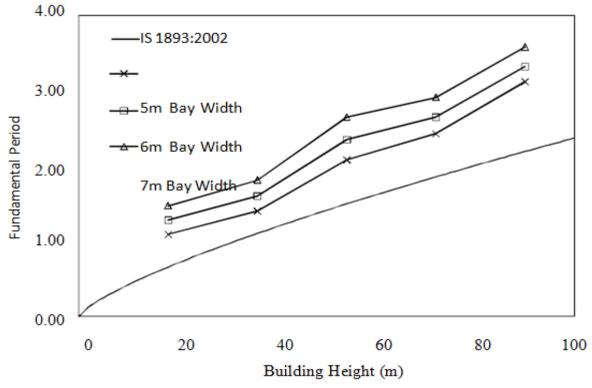


Fig. : Variation of fundamental time period with bay width for Type – S2 setback building

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. Figs.4.16 - 4.17 presents the variation in fundamental period with the change in bay width of the setback building, it is observed from these figures that, the change in bay width affects the fundamental period of the setback building considerably.

Fig 4.16 and 4.17 presents the variation of fundamental time period with bay width for 12 storey setback building and 24 storey setback buildings 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 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.

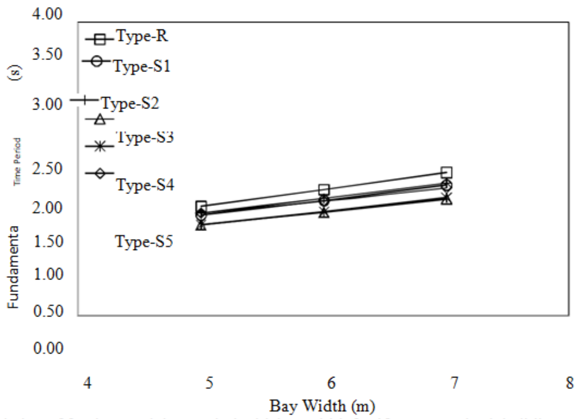


Fig. : Variation of fundamental time period with bay width for 12-storey setback buildings.

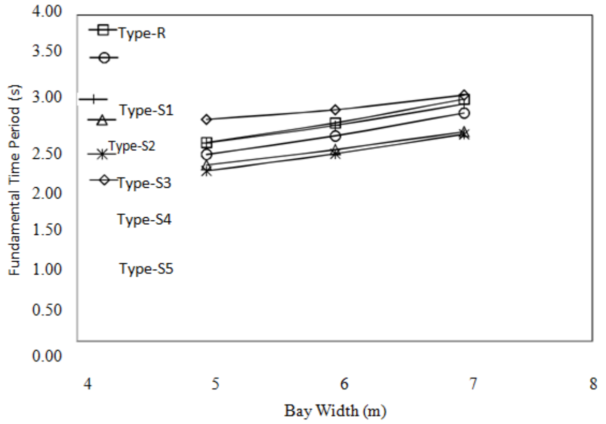


Fig. Variation of fundamental time period with bay width for 24-storey setback buildings

Section 4.2.1 explained that the fundamental period is also sensitive to the setback irregularity of the buildings. As explained earlier the measures to quantify the irregularity given in literatures are found to be not very efficient as a parameter for formulation. Therefore, a new approach of considering average height and average width of the setback buildings was tried to define the irregularity in line with Young (2011). The average height is calculated as the ratio of summation of the heights of individual bay to the number of bays. Similarly the average width is calculated as the ratio of summation of the width of the individual storey to the number of storeys. These average height and average width made non-dimensional with respect to maximum building height and maximum building width at base, respectively.

Tables 4.7 - 4.9 present the details of normalised average height and normalised average width of all the selected buildings. The fundamental period of the corresponding building also presented to correlate them. It is interesting to see from the Tables 4.7 - 4.9 that the normalised average height and normalised average width for any setback building is same. Also, these tables show that fundamental period of the regular building is always more than that of setback buildings. However, the fundamental periods of setback buildings are not consistent with the normalised average height or width of the buildings. Fig. 4.16 presents the fundamental period scatter of the setback buildings against the normalised average height/width of the buildings. This figure clearly shows that there is hardly any correlation between normalised average height/width and the fundamental period of setback buildings.

IV. SUMMARY AND CONCLUSIONS

SUMMARY OF THE WORK

The behaviour of a multi-storey framed building during strong earthquake motions depends on the distribution of mass, stiffness, and strength in both the horizontal and vertical planes of a building. In multi-storeyed framed buildings, damage from earthquake ground motion generally initiates at locations of structural weaknesses present in the lateral load resisting frames. Further, these weaknesses tend to accentuate and concentrate the structural damage through plastification that eventually leads to complete collapse. In some cases, these weaknesses may be created by discontinuities in stiffness, strength or mass between adjacent storeys. Such discontinuities between storeys are often associated with sudden variations in the frame geometry along the height. There are many examples of failure of buildings in past earthquakes due to such vertical discontinuities. Structural engineers have developed confidence in the design of buildings in which the distributions of mass, stiffness and strength are more or less uniform. But there is a less confidence about the design of structures having irregular geometrical configurations.

A common type of vertical geometrical irregularity in building structures arises is the presence of setbacks, i.e. the presence of abrupt reduction of the lateral dimension of the building at specific levels of the elevation. This building category is known as 'setback building'. This building form is becoming increasingly popular in modern multi-storey building construction mainly because of its functional and aesthetic architecture. In particular, such a setback form provides for adequate daylight and ventilation for the lower storeys in an urban locality with closely spaced tall buildings. This type of building form also provides for compliance with building bye-law restrictions related to 'floor area ratio' (practice in India). Setback buildings are characterised by staggered abrupt reductions in floor area along the height of the building, with consequent drops in mass, strength and stiffness. 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 bay-wise 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.

To get a clear idea about the dynamic performance of setback buildings a detailed literature review is carried out in two major areas. These are: (i) Response of setback buildings under seismic loading, effect of vertical irregularity on fundamental period of building and the quantification of setback and (ii) the recommendations proposed by seismic design codes on setback buildings. The research papers on setback buildings conclude that the displacement demand is dependent on the geometrical configuration of frame and concentrated in the neighbourhood of the setbacks for setback structures. The higher modes significantly contribute to the response quantities of structure. Empirical equations used in design codes, such as IS 1893:2002, ASCE 7:2010, Euro code 8 and Rayleigh method for the estimation of Fundamental period are discussed with reference to setback buildings. The different code recommendations for the description and quantification of irregular buildings are also discussed briefly. The applicability of code based empirical formulas for calculation of fundamental period of setback buildings was no where mentioned in the literature, except Sarkar et. al. (2010). The procedure discussed in this literature is based on two-dimensional plane frame analysis and not suitable for a realistic three dimensional building. Therefore, it is essential to develop an improvement in the code based empirical equation to estimate the fundamental period of setback buildings.

To achieve the objective of the study altogether 90 building frames were selected for the study representing the realistic three dimensional buildings of 6-30 storeys. 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) with a uniform three number of bays at base 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 were considered for the study, ranging from 6 to 30 storeys, with a uniform storey height of 3m. Altogether 90 building frames with different amount of setback irregularities due to the reduction in width and height were selected. The building geometries considered in the present study are taken from literature (Karavasisis et. al., 2008). The regular frame, without any setback, is also studied.

There are altogether six different building geometries, one regular and five irregular, for each height category are considered in the present study. The buildings are three dimensional, with the irregularity in the direction of setback, in the other horizontal direction the building is just repeating its geometric configuration. Setback frames are named as S1, S2, S3, S4 and S5 depending on the percentage reduction of floor area and height. The frames are designed with M-20 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 II of IS 1893:2002 are considered for the design. All the selected building models with different setback irregularities are analyzed for linear dynamic behaviour using commercial software SAP2000 (v12) with a focus on fundamental time period.

V. CONCLUSIONS

Fundamental period of all the selected building models were estimated as per modal analysis, Rayleigh method and empirical equations given in the design codes. The results were critically analysed and presented in this chapter. The aim of the analyses and discussions were to identify a parameter that describes the irregularity of a setback building and arrive at an improved empirical equation to estimate the fundamental period of setback buildings with confidence. However, this study shows that it is difficult to quantify the irregularity in a setback building with any single parameter. 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 previous researchers or design codes. However, it requires further investigation to arrive at single or multiple parameters to accurately define the irregularity in a three dimensional setback buildings. Based on the work presented in this thesis following point-wise conclusions can be drawn:

- 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. The change in period due to the setback irregularity is not consistent with any of these parameters used in literature or design codes to define irregularity.
- The code (IS 1893:2002) empirical formula gives the lower-bound of the fundamental periods obtained from Modal Analysis and Raleigh Method. 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 30 storeys. It can also be seen that Raleigh Method underestimates the fundamental periods of setback buildings slightly which is also conservative for the selected buildings. However the degree of conservativeness in setback building is not proportionate to that of regular buildings.
- Unlike other available equations, Eq. 2.9 from ASCE 7: 2010 does not consider the height of the building but it considers only the number of storeys of the buildings. Although this is not supported theoretically this approach is found to be most conservative among other code equations.
- 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.
- 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 may change from one end to other.

REFERENCES

[1] Agrawal, P. and Shrikhande, M., Earthquake resistant design of structures, PHI learning pvt. ltd.

[2] Al-Ali, A.A.K. and Krawinkler, H. (1998). “Effects of Vertical Irregularities on Seismic Behavior of Building Structures”, Report No. 130, The John A. Blume Earthquake Engineering Center,Department of Civil and Environmental Engineering, Stanford University, Stanford, U.S.A

[3] Aranda, G.R. (1984). “Ductility Demands for R/C Frames Irregular in Elevation”, Proceedings of the Eighth World Conference on Earthquake Engineering, San Francisco, U.S.A., Vol. 4, pp. 559-566.

[4] ASCE 7 Minimum Design Loads for Buildings and Other Structures. American Society of Civil Engineers, 2010.

[5] Athanassiadou CJ. Seismic performance of R/C plane frames irregular in elevation. Eng Struct 2008;30, pp 1250-61.

[6] BIS (2002). “IS 1893 (Part 1)-2002: Indian Standard Criteria for Earthquake Resistant Design of Structures, Part 1 – General Provisions and Buildings (Fifth Revision)”, Bureau of Indian Standards, New Delhi

[7] 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 .

[8] Chopra,A. K. (2003). Dynamics of structures: theory and applications to earthquake engineering. Prentice – Hall, Englewood Cliffs,N.J.

[9] 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.

[10] Esteva, L. (1992). "Nonlinear Seismic Response of Soft-First-Story Buildings Subjected to Narrow-Band Accelerograms", Earthquake Spectra, Vol. 8, No. 3, pp. 373-389.