ANALYZING THE EFFECTS OF SETBACK ON REINFORCE CONCRETE FRAMED STRUCTURE

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Abstract- 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 behavior, 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. 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.. 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. This study presents the design code perspective of this building category.

Keywords- geometric irregularity, setback building, fundamental period, regularity index, correction factor.

OBJECTIVES

A detailed literature review is carried out to define the objectives of the thesis. This is discussed in detail in Chapter 2 and briefly summarized here. Design codes have not given particular attention to the setback building form. 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 buildings. The higher modes significantly contribute to the response quantities of structure. There are a few literatures (Karavasilis et. al. 2008 and Sarkar et. al. 2010) on the definition and quantification of irregularity in setback buildings. This is an important parameter for estimation of fundamental period of setback buildings. There is a study (Sarkar et. al. 2010) on estimation of fundamental period of setback building frames. This study is limited only to plane frames and the formulation proposed in the study is difficult to be used for the actual three-dimensional setback buildings. Based on the literature review presented later, the salient objectives of the present study have been identified as follows:

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 and Rayleigh methods with fundamental period based on modal analysis.

RESULT AND DISCUSSION

All the selected building models with different setback irregularities are analyzed for linear dynamic behaviour using commercial software SAP2000 (v12). This chapter presents the analysis results and relevant discussions. According to the objectives of the present study, the results presented here are focussed on fundamental time period of selected setback buildings. The details of the selected buildings and the outline of the analysis procedure followed in this study are outlined in Chapter 3.

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 Chapters. 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

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.

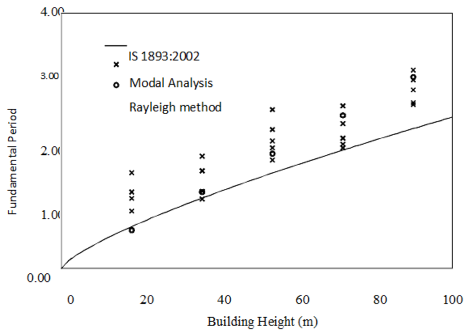

Fig. 4.1: Comparison of fundamental period of setback buildings with that obtained from IS 1893:2002 equations.

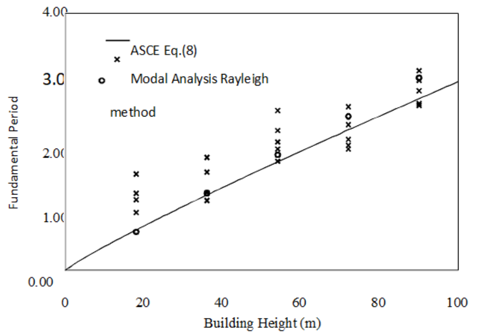

Fig. 4.2: Comparison of fundamental period of setback buildings with that obtained from ASCE 7:2010 Eq (2.8).

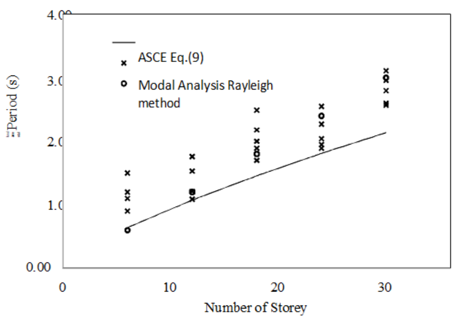

Fig. 4.3: Comparison of fundamental period of setback buildings with that obtained from ASCE 7:2010 Eq (2.9).

Figures 4.2 and 4.3 present the comparison of fundamental period of setback buildings with that obtained from Eqs. 2.8 and 2.9 of ASCE 7:2010 respectively. A similar conclusions to that of IS 1893:2002 can be made from the results presented in Figs. 4.2 - 4.3. This is to be noted that 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 the Fig. 4.3 shows that this approach is most conservative among other code equations. It is instructive to note from these three figures that the fundamental period in a framed building is not a function of building height only. These three figures clearly show that buildings with same overall height may have different fundamental periods with a considerable variation which is not addressed in the code empirical equations.

As discussed in Section 2.3.1 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. Therefore, there is a need to define the irregularity for a setback building and relate the empirical equation of fundamental period of the setback building with its irregularity. Some of the previous works addressed this issue of defining irregularity and proposed some measure of quantifying the irregularity in setback buildings. Section 2.2 discusses these literatures in detail. Design codes do not directly quantify the irregularity in setback buildings but it gives a parameter to distinguish the regular and setback irregular buildings. These are discussed in Section 2.3.1 of Chapter 2.

The amounts of setback irregularity present in the selected buildings are calculated as per the definition given in the available literature as well as the international design codes and are presented in Tables 4.4 – 4.6.

Table 4.4: Characteristics of setback buildings with 5 m bay width

Building Designation	Height (m)	T_{Modal} (s)	$\frac{A}{L}$ (IS 1893)	$\frac{L_{i1}}{L_i}$ (ASCE 7)	Karavasilis et.al. 2008		(Sarkar et.al. 2010)
					s	b	
R-6-5	18	1.17	0.00	1.00	1.00	1.00	1.00
S1-6-5	18	1.05	0.33	1.50	1.25	1.25	0.75
S2-6-5	18	1.09	0.33	1.50	1.25	2.00	0.70
S3-6-5	18	0.95	0.66	2.00	1.75	1.75	0.65
S4-6-5	18	0.97	0.66	3.00	2.00	1.25	0.72
S5-6-5	18	1.01	0.66	3.00	2.00	2.00	0.55
R-12-5	36	1.49	0.00	1.00	1.00	1.00	1.00
S1-12-5	36	1.37	0.33	1.50	1.10	1.25	0.94
S2-12-5	36	1.4	0.33	1.50	1.10	2.00	0.85
S3-12-5	36	1.24	0.66	2.00	1.30	1.75	0.79
S4-12-5	36	1.24	0.66	3.00	1.40	1.25	0.88
S5-12-5	36	1.4	0.66	3.00	1.40	2.00	0.65
R-18-5	54	2.18	0.00	1.00	1.00	1.00	1.00
S1-18-5	54	2.00	0.33	1.50	1.03	1.25	0.94
S2-18-5	54	2.08	0.33	1.50	1.03	2.00	0.85
S3-18-5	54	1.84	0.66	2.00	1.09	1.75	0.78
S4-18-5	54	1.82	0.66	3.00	1.18	1.25	0.88
S5-18-5	54	2.16	0.66	3.00	1.18	2.00	0.64
R-24-5	72	2.44	0.00	1.00	1.00	1.00	1.00
S1-24-5	72	2.29	0.33	1.50	1.02	1.25	1.16
S2-24-5	72	2.43	0.33	1.50	1.02	2.00	1.01
S3-24-5	72	2.16	0.66	2.00	1.07	1.75	0.80
S4-24-5	72	2.09	0.66	3.00	1.09	1.25	1.07
S5-24-5	72	2.72	0.66	3.00	1.09	2.00	0.78
R-30-5	90	3.18	0.00	1.00	1.00	1.00	1.00
S1-30-5	90	2.89	0.33	1.50	1.02	1.25	0.94
S2-30-5	90	3.12	0.33	1.50	1.02	2.00	0.84
S3-30-5	90	2.76	0.66	2.00	1.05	1.75	0.76
S4-30-5	90	2.63	0.66	3.00	1.07	1.25	0.86
S5-30-5	90	3.55	0.66	3.00	1.07	2.00	0.62

Table 4.5: Characteristics of setback buildings with 6 m bay width

Building Designation	Height (m)	T_{Modal} (s)	$\frac{A}{L}$ (IS 1893)	$\frac{L_{i1}}{L_i}$ (ASCE 7)	Karavasilis et.al. 2008		(Sarkar et.al. 2010)
					s	b	
R-6-6	18	1.37	0.00	1.00	1.00	1.00	1.00
S1-6-6	18	1.23	0.33	1.50	1.25	1.25	0.79
S2-6-6	18	1.28	0.33	1.50	1.25	2.00	0.73
S3-6-6	18	1.11	0.66	2.00	1.75	1.75	0.67
S4-6-6	18	1.13	0.66	3.00	2.00	1.25	0.75
S5-6-6	18	1.17	0.66	3.00	2.00	2.00	0.57
R-12-6	36	1.72	0.00	1.00	1.00	1.00	1.00
S1-12-6	36	1.57	0.33	1.50	1.10	1.25	0.95
S2-12-6	36	1.60	0.33	1.50	1.10	2.00	0.85
S3-12-6	36	1.41	0.66	2.00	1.30	1.75	0.79
S4-12-6	36	1.42	0.66	3.00	1.40	1.25	0.88
S5-12-6	36	1.56	0.66	3.00	1.40	2.00	0.66
R-18-6	54	2.45	0.00	1.00	1.00	1.00	1.00
S1-18-6	54	2.28	0.33	1.50	1.03	1.25	0.96
S2-18-6	54	2.35	0.33	1.50	1.03	2.00	0.86
S3-18-6	54	2.08	0.66	2.00	1.09	1.75	0.78
S4-18-6	54	2.06	0.66	3.00	1.18	1.25	0.89
S5-18-6	54	2.37	0.66	3.00	1.18	2.00	0.66
R-24-6	72	2.68	0.00	1.00	1.00	1.00	1.00
S1-24-6	72	2.52	0.33	1.50	1.02	1.25	0.69
S2-24-6	72	2.65	0.33	1.50	1.02	2.00	0.62
S3-24-6	72	2.35	0.66	2.00	1.07	1.75	0.56
S4-24-6	72	2.3	0.66	3.00	1.09	1.25	0.64
S5-24-6	72	2.84	0.66	3.00	1.09	2.00	0.47
R-30-6	90	3.45	0.00	1.00	1.00	1.00	1.00
S1-30-6	90	3.19	0.33	1.50	1.02	1.25	0.96
S2-30-6	90	3.32	0.33	1.50	1.02	2.00	0.86
S3-30-6	90	2.94	0.66	2.00	1.05	1.75	0.78
S4-30-6	90	2.84	0.66	3.00	1.07	1.25	0.88
S5-30-6	90	3.64	0.66	3.00	1.07	2.00	0.64

Table 4.6: Characteristics of setback buildings with 7 m bay width

Building Designation	Height (m)	T_{Modal} (s)	$\frac{A}{L}$ (IS 1893)	$\frac{L_{i1}}{L_i}$ (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

Table 4.4 presents the results of buildings with 5m bay width, Table 4.5 presents the results of buildings with 6m bay width whereas the Table 4.6 presents the results of buildings with 7m bay width. The height of the building presented here are maximum height of the buildings. The fundamental periods presented here are obtained from modal analysis.

It can be seen from these tables that the parameter given in IS 1893 and ASCE 7 to distinguish setback irregularity are quite similar yielding similar results except for few buildings. One of the two indices (b) given by Karavasilis et. al., 2008 is an improved version of that presented in

ASCE 7 where it considers the summation of variation of building width along its height instead of variation of building width in one adjacent floor. Sarkar et. al. (2010) defined the irregularity in terms of the modal parameters. This procedure is based on two-dimensional plane frame analysis. While calculating the regularity index using this method, it is found to be not suitable for a three dimensional building. Fundamental mode vibration of a setback building and a similar regular building may not be in the same horizontal direction for a three dimensional building and it is difficult to use this method for such buildings. Also, it is clear from these three tables presented above that the change in period due to the setback irregularity is not consistent with any of these parameters discussed here.

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.

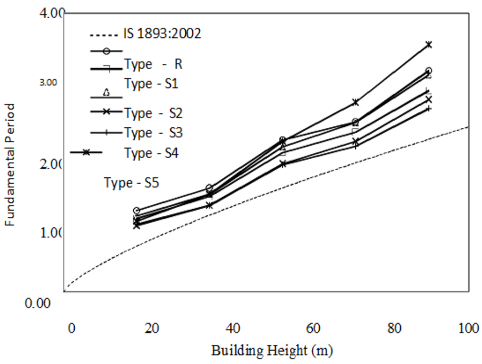

Fig. 4.4: Fundamental period (Modal) versus height of setback buildings of 5m bay width

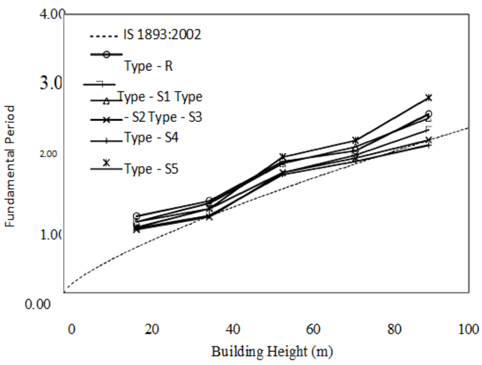

Fig. 4.5: Fundamental period (Rayleigh) versus height of setback buildings of 5m bay width

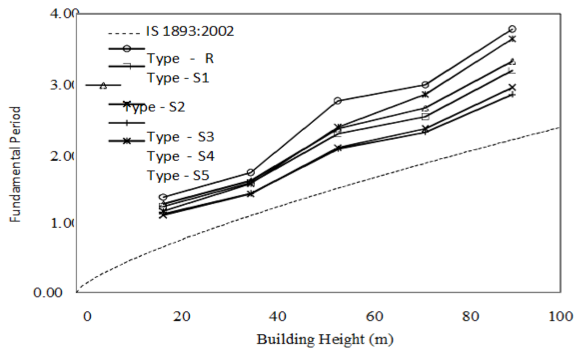

Fig. 4.6: Fundamental period (Modal) versus height of setback buildings of 6m bay width

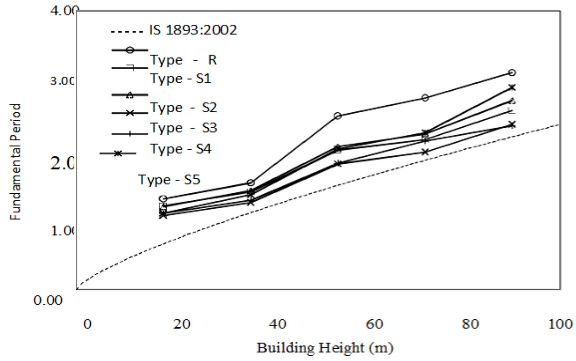

Fig. 4.7: Fundamental period (Rayleigh) versus height of setback buildings of 6m bay width

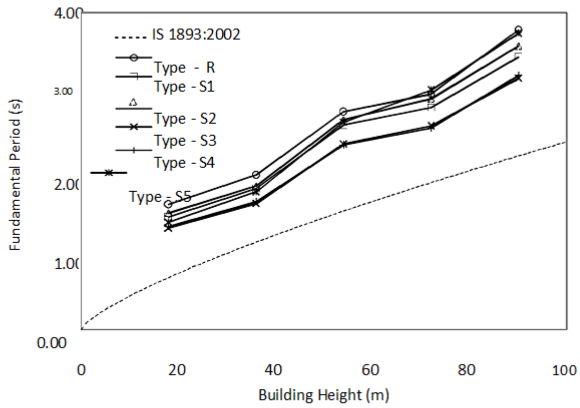

Fig. 4.8: Modal analysis time period versus height of setback buildings of 7m bay width

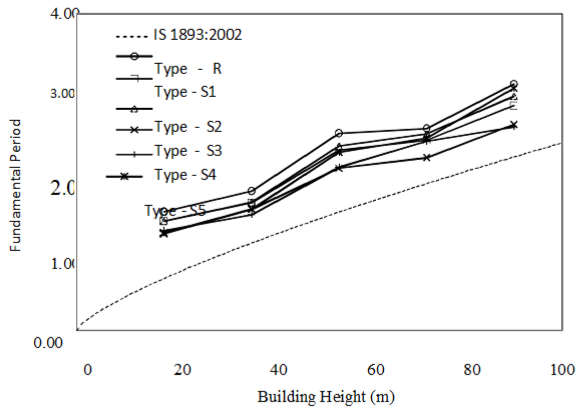

Fig. 4.9: Rayleigh analysis time period versus height of setback buildings of 7m bay width

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.

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

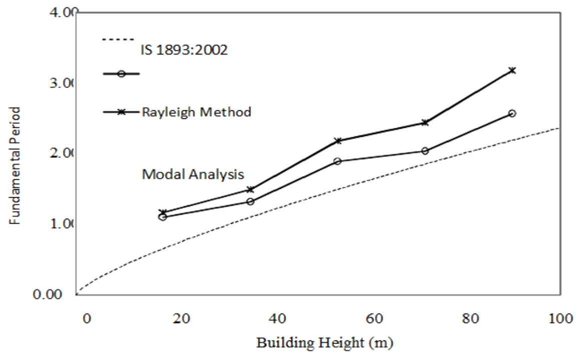

Fig. 4.10: Fundamental time period vs. height of Type - R building with 5 m bay width

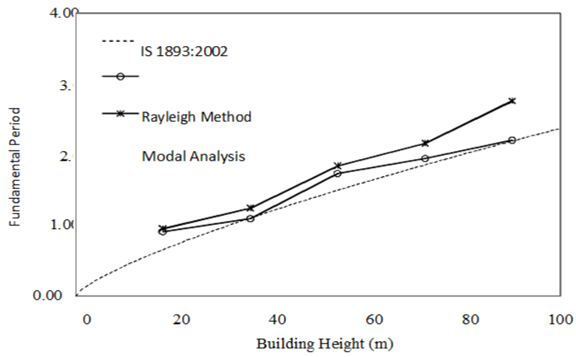

Fig. 4.11: Fundamental time period vs. height of Type–S3 setback building with 5 m bay width

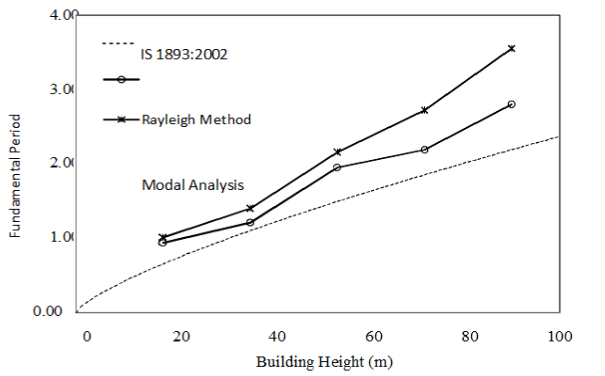

Fig. 4.12: Fundamental time period vs. height of Type–S5 setback building with 5 m bay width

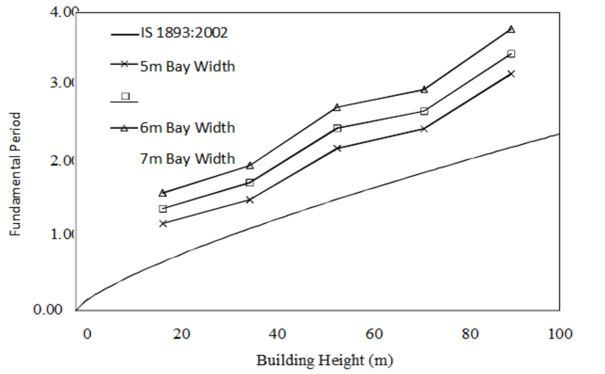

Fig. 4.13: Variation of fundamental time period with bay width for Type – R building

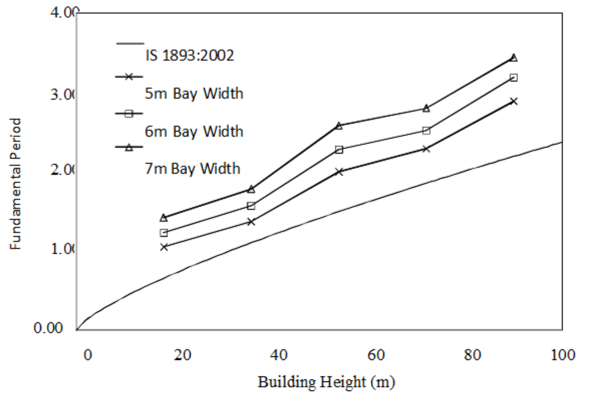

Fig. 4.14: Variation of fundamental time period with bay width for Type – S1 setback building.

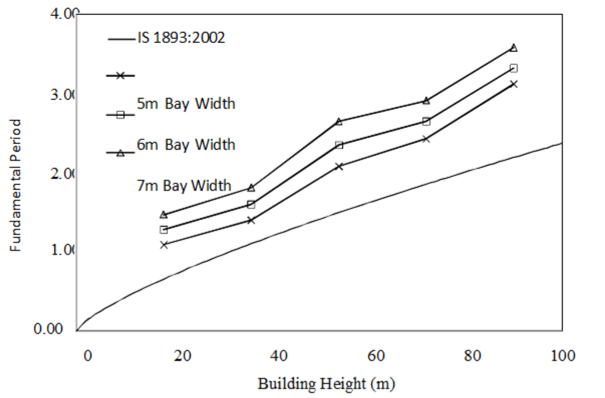

Fig. 4.15: Variation of fundamental time period with bay width for Type – S2 setback building

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.

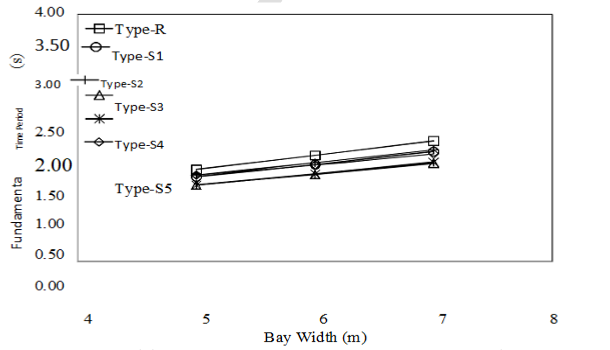

Fig. 4.16: Variation of fundamental time period with bay width for 12-storey setback buildings

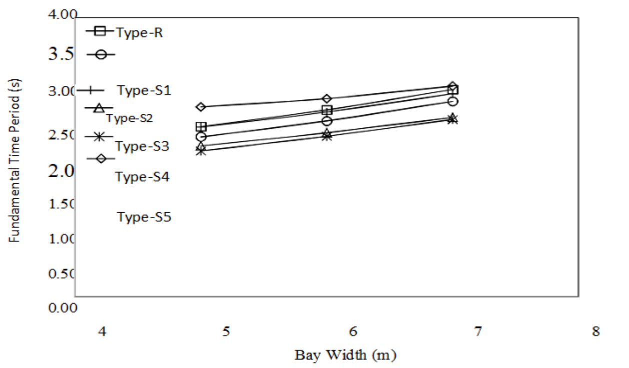

Fig. 4.17 Variation of fundamental time period with bay width for 24-storey setback buildings

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 normalized average height or width of the buildings. Fig. 4.16 presents the fundamental period scatter of the setback buildings against the normalized average height/width of the buildings. This figure clearly shows that there is hardly any correlation between normalized average height/width and the fundamental period of setback buildings

CONCLUSIONS

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. 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.

SCOPE OF FUTURE STUDY

This study could not conclude on the appropriate parameter defining the irregularity in three-dimensional multi-storeyed setback buildings. There is a scope to investigate different parameters either geometrical or structural or combination of both to define the setback irregularity. The present study is limited to reinforced concrete (RC) multi-storeyed building frames with setbacks only in one direction. There is a future scope of study on three dimensional building models having setbacks in both of the horizontal orthogonal directions.

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