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Effect of Setback on Fundamental Period of RC Framed Buildings

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***Abstract*: The ground motion during earthquake doesn't damage the building by impact or by any external force, rather it affects the building by creating an internal inertial force created 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 depict the ground motion and structural behaviour, design codes provide a Response spectrum. Response spectrum suitably 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 created by discontinuities in stiffness, strength or mass between adjacent storeys. A common type of vertical geometrical irregularity in building structures is known as the setback building. This study presents the design code perspective of this building category. Almost all the major international design codes recommend dynamic analysis for design of setback buildings for estimation of the fundamental period. However, the empirical equations of fundamental period given in these codes are a function of building height, which is vague 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 the same. Based on modal analysis of 36 setback buildings with varying irregularity and height, the goal of this research is to investigate the accuracy of existing code-based equations for estimation of the fundamental period of setback buildings. This study shows that it is difficult to quantify the irregularity in a setback building with any single parameter. The way design codes define setback irregularity by only geometry is found to be not adequate. Period of setback buildings are found to be always less than that of similar regular building. Fundamental period of a framed building depends not only on the height of the building but also on the bay width, irregularity and other structural and geometric parameters.**

***Keywords*: fundamental period, geometric irregularity, setback building**

1. 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. The determination of the fundamental period of structures is essential to earthquake design and assessment. Masonry infill panels have been used in Reinforced Concrete (RC) frame structures as interior and exterior partition walls. Since they are usually considered as non-structural elements, their interaction with the bounding frame is often ignored in design. If the properties of the infill wall like density and modulus elasticity of brick masonry is considered in structural design, it will help to improve the strength and stiffness of the structure. But in India infill wall is not considered as a structural element due to this, stiffness of infill wall is not estimated and not considered in design of structure. The setback affects the mass, strength, stiffness, centre of mass and centre of stiffness of setback building. Dynamic characteristics of setback 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.

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 than buildings with irregular configurations. The applicability of code based empirical formulas for calculation of fundamental period of setback buildings was nowhere discussed in the literature. Though much of the literature is available and many researchers have dealt with analysis in investigating the seismic behaviour of vertically irregular buildings as per governing earthquake codes of respective countries, but less work has been done on the dynamic analysis of buildings with setbacks and infill walls. Hence, the present study aims to perform a parametric study on irregular buildings to find fundamental period of different types of reinforced concrete moment resisting frames (MRF) with varying number of stories, number of bays and configuration using Modal analysis. These results were then compared with the code provided empirical formulae.

2. Methodology

1. 3D RC buildings with varying heights and widths were considered for the study. 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. Similarly, three different height categories were considered for the study, ranging from 6, 18 and 30 storeys, with a uniform storey height of 3m. Altogether 36 building frames with different amount of setback irregularities due to the reduction in width and height were selected.
2. There are altogether four different building geometries, one regular and three irregulars, for each height category are considered in the present study. Fig. 1 presents the elevation of all four different geometries of a typical six storey building. 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 T1, T2 and T3 depending on the percentage reduction of floor area and height as shown in the Fig. – 1. The regular frame is named as R. The exact nomenclature of the buildings considered are expressed in the form of T-XF-Y, where T represents the type of irregularity (i.e., T1 to T3 or R). X represents the number of storeys and Y represents the bay width in both the horizontal direction. For example, T3-18F-6 represents the building with S3 type of irregularity, having 18 numbers of stories and bay width of 6m in both the horizontal direction. For all the other setback buildings the reduction in height and reduction of width will be consistent with reductions as explained in Fig. – 1. The setbacks are considered in one horizontal direction only; the building is made three dimensional by repeating these bays in other horizontal direction.
3. 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.
4. The slab thickness is considered to be 120mm for all the buildings. Infill walls in the exterior faces of all the buildings are assumed as of 230mm thickness and of 120mm thickness for all the inner infill walls. The parapet wall is assumed to be of 230 mm thickness and of 1000mm height for all the selected buildings.
5. The structures are modelled by using computer software SAP-2000 as explained earlier. Modal analyses were performed to check if the selected frames represent realistic building models.

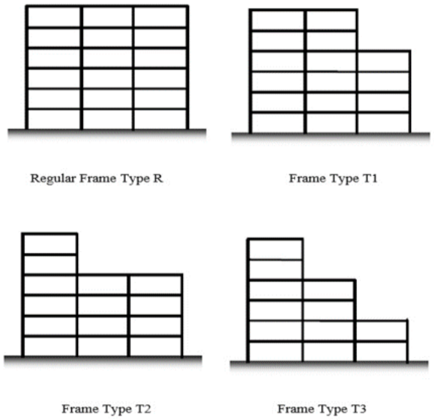

Fig. 1. Typical Building Elevations for 6-storey Building Frames

3. Results and discussions

- The fundamental time periods of all the 36 selected setback buildings were calculated using different methods available in literature including code based empirical formulas. Fundamental period of these buildings was also calculated using modal analysis.
- It was found that the IS code 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 30 storeys.
- Fig. 2 – 4, presented 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. These figures show that the fundamental period is indeed very sensitive to the building height.
- Fig. 5 – 8 present the fundamental periods of different building variants as a function of bay width keeping the building height same. 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. It is observed from these figures that, the change in bay width affects the fundamental period of the setback building considerably.
- Fig. 9 – 11 presents the variation in fundamental period with the change in bay width of the setback

building. 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.

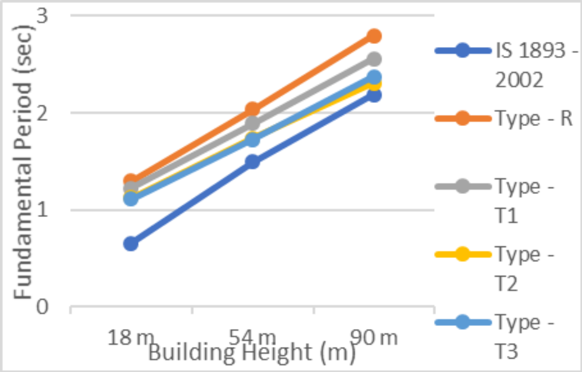

Fig. 2. Fundamental Period (Modal) vs. Height of Setback Buildings of 5m bay width

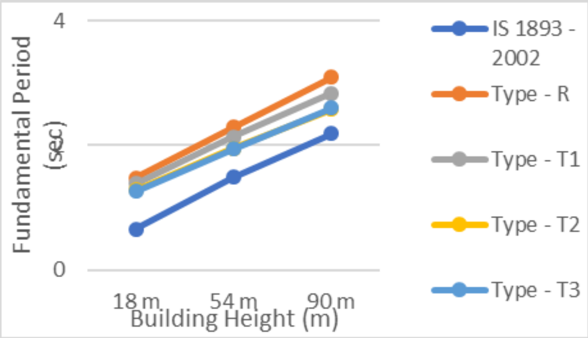

Fig. 3. Fundamental Period (Modal) vs. Height of Setback Buildings of 6m bay width

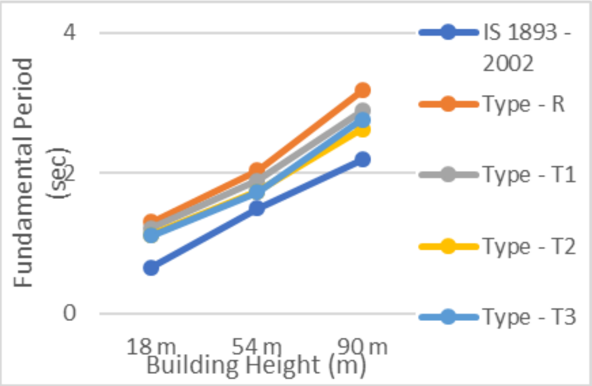

Fig. 4. Fundamental Period (Modal) vs. Height of Setback Buildings of 7m bay width

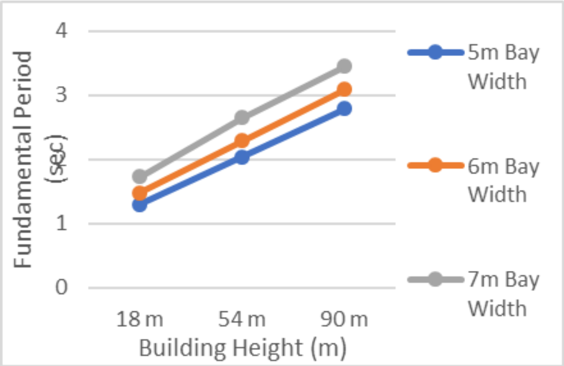

Fig. 5. Variation of Fundamental Period (Modal) with Bay Width for Setback Building Type – R

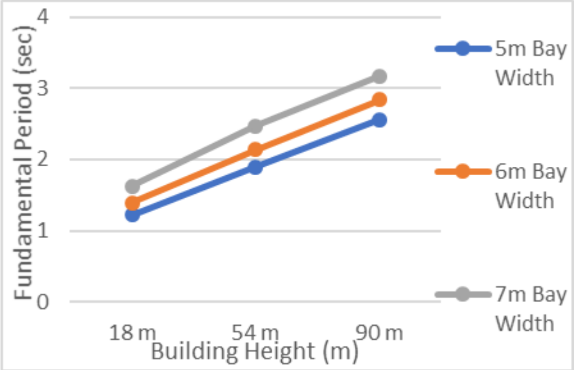

Fig. 6. Variation of Fundamental Period (Modal) with Bay Width for Setback Building Type – T1

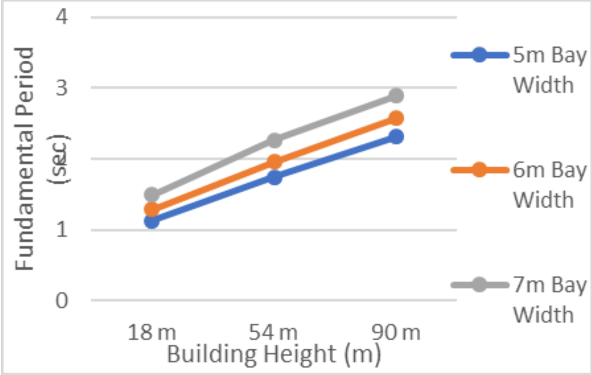

Fig. 7. Variation of Fundamental Period (Modal) with Bay Width for Setback Building Type – T2

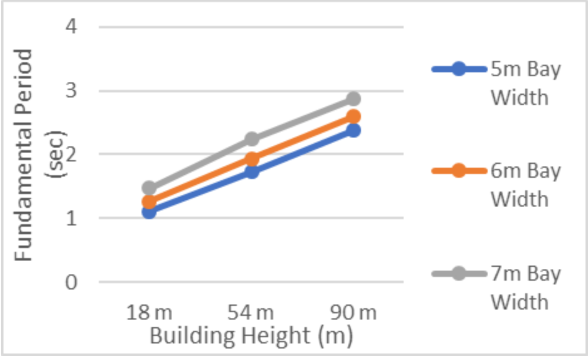

Fig. 8. Variation of Fundamental Period (Modal) with Bay Width for Setback Building Type – T3

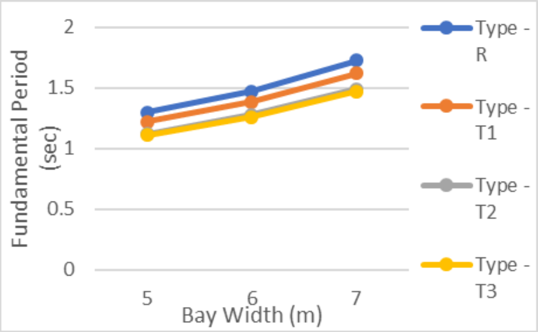

Fig. 9. Variation of fundamental time period with bay width for 6-storey setback buildings

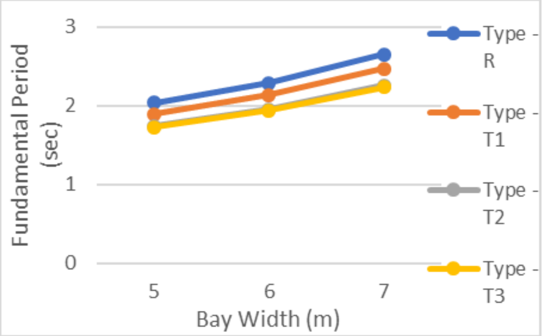

Fig. 10. Variation of fundamental time period with bay width for 18-storey setback buildings

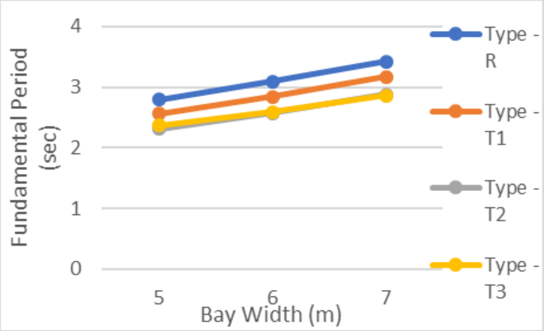

Fig. 11. Variation of fundamental time period with bay width for 30-storey setback buildings

4. Conclusions

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 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 30 storeys.
- Unlike other available equations, Eq. 3.4 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.
- 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.
- 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.

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