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SETBACK ANALYSIS OF REINFORCED CONCRETE FRAMED BUILDING

[1]Mohd. Ali Taj, [2]Prof. Dharmendra Singh
[1]Scholar M.tech (Structure), [2]Guide & HOD
Department of Civil Engineering, RNTU, Bhopal (M.P).

Abstract: Due to earthquake, the magnitude of the lateral force depends mainly on the root mass, ground acceleration and dynamic characteristics of the building. To represent ground motion and structural behavior, design codes provide a response spectrum. The reaction spectrum easily describes the top reactions of the structure in the form of a natural vibration duration, moisture ratio and founder soil type. It is necessary to determine the fundamental duration of the structures for earthquake design and evaluation. Seismic analysis of most structures is done using linear static (linear) static and linear dynamic (reaction spectrum) methods. The lateral power calculated according to the equivalent static method depends on the structural mass and the basic structure of the structure. The empirical equation of the fundamental period of the buildings given in the design code is the work of height and base dimensions of buildings. Theoretically the reaction spectrum method uses model analysis to calculate the natural period of the building, calculate the base shear. 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 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, 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 the same. Based on modal analysis of 90 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 and provide suggestions to improve their accuracy.
Keywords: Geometric Irregularity, Setback building, Fundamental period, Regularity index, Correction factor

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 and Rayleigh methods with fundamental period based on modal analysis.

2. SCOPE OF THE STUDY

a) The present study is limited to reinforced concrete (RC) multi-storeyed building frames with setbacks.
b) Infill stiffness is not considered in the present study. However, associated mass and weight is assumed in the analysis.
c) Setback buildings from 6 storeys to 30 storeys with different degrees of irregularity are considered.
d) The buildings are assumed to have setback only in one direction.
e) Soil-structure interaction effects are not considered in the present study. Column ends are assumed to be fixed at the foundation.

3. MODAL ANALYSIS

When free vibration is under consideration, the structure is not subjected to any external excitation (force or support motion) and its motion is governed only by the initial conditions. There are occasionally circumstances for which it is necessary to determine the motion of the structure under conditions of free vibration. However, the analysis of the structure in free motion provides the most important dynamic properties of the structure which are the natural frequencies and the corresponding modal shapes.
By considering the fact that the damping levels are usually very small in structural systems, the equation of free vibration can be written as:

$$MvKv0 \qquad 3.1$$

Looking for a solution in the formofvi

time and that on space variables can be separated. Substituting for v, the equation of motion changes to the following form:

$$M\,q\,t\,K\,q\,t0 \qquad 3.2$$

This is a set of N simultaneous equations of the type

$$m_{ijj}\ q\ tk_{ijj}\ q\ t\ 0;i1,2,\ ....,N \quad \text{(N, j1)}$$

3.3

Where the separation of variables leads to:

$$qt\ \ \frac{k^{N}_{ijj}\ (j1)}{m^{N}_{ijj}\ (j1)}\ ;i1,2,...N$$

3.4

As the terms on either side of this equation is independent of each other, this quantity can hold good only when each of these terms are equal to a positive constant, say 2.Thus we have,

$$qt\ \ qt\ 0 \quad (3.6^{N}$$

$$k_{ij}\ \ ^{2}m_{ijj}\ \ 0;i1,2,...N \quad (3.7) \quad j1$$

The solution of Eq. 3.6 is qt sint a harmonic of frequency. Hence the motion of all coordinates is harmonic with same frequency and same phase difference. The above equation is a set of N simultaneous linear homogenous equations in unknowns of j. The problem of determining constant 2 for which the Eq. 3.7 has a non-trivial solution is known as the characteristic value or Eigen value problem. The Eigen value problem may be rewritten, in matrix notations as,

$$K^{2}M0 \quad 3.8$$

A non-trivial solution for the Eq. 3.8 is feasible when only the determinant of the coefficient matrix vanishes, i.e.

$$\left| K\ \ ^{2}M \right|\ \ 0 \quad 3.9$$

The expansion of the determinant in Eq. 3.9 yields an algebraic equation of nth order in 2, which is known as the characteristic equation. The roots of characteristic equation are known as the Eigen values and the positive square roots of these Eigen values are known as the natural frequencies of the MDOF system. It is only at these N frequencies that the system admits synchronous motion at all coordinates. For stable structural systems with symmetric and positive stiffness and mass matrices the Eigen values will always be real and positive. For each Eigen values the resulting synchronous motion has a distinct shape and is known as natural/normal mode shape or eigenvector. The normal modes are as much a characteristic of the system as the Eigen values are.

They depend on the inertia and stiffness, as reflected by the coefficients mijand kij. These shapes correspond to those structural configurations, in which the inertia forces imposed on the structure due to synchronous harmonic vibrations are exactly balanced by the elastic restoring forces (3.2) within the structural system. These eigenvectors are determined as the non-trivial solution of Eq. 3.8.

MODE PARTICIPATION FACTOR

The forced vibration of MDOF system excited by support motion is described by the coupled system of differential equation as:

$$MvCv\ \ KvMrv_{g} \quad 3.10$$

Where vg denotes ground acceleration, v is the vector of structural displacements relative to the ground displacements, and r is a vector of influence coefficients. The ith element of vector r represents the displacement of ith degree of freedom due to a unit displacement of the base. The nature of this equation is similar to that of standard forced vibration problem. Hence this can be solved using mode-superposition method and the equation can be decoupled as:

$$,r\ 1,2,...N \quad (3.11)\text{here}, {}_{r}$$

$$\frac{{}^{r\ T}Mr}{{}_{r}^{T}M_{r}}$$

is known as the *mode – participation* Factor for the *r*

4. SUMMARY

This chapter presents details of the structural models of selected RC framed buildings. It also describes the selected building geometries used in the present study. The selected buildings are representing the realistic three dimensional buildings of 6-30 storeys. Free vibration analysis method used in the present study is also explained in this chapter.

RESULT SUMMARY

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 analyzed 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 a single or multiple parameters to accurately define the irregularity in a three dimensional set back buildings.

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 analyze 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.

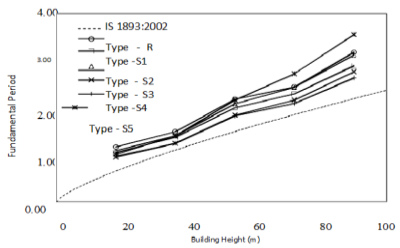


Fig. 4.4: Fundamental period (Modal) versus height of setback buildings of 5m bay width

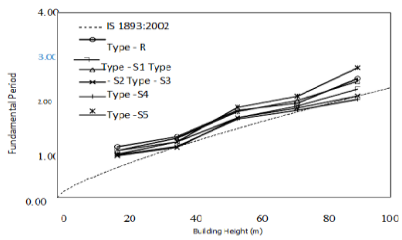


Fig. 4.5: Fundamental period (Rayleigh) versus height of setback buildings of 5m bay width

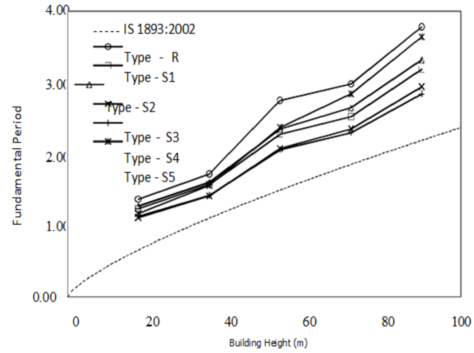


Fig. 4.6: Fundamental period (Modal) versus height of Setback buildings of 6m bay width

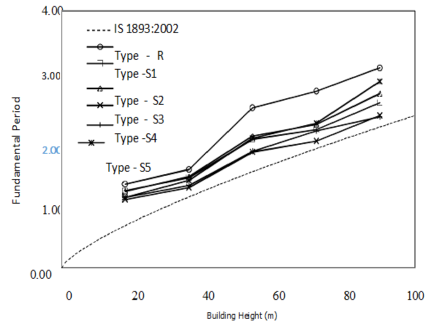


Fig. 4.7: Fundamental period (Rayleigh) versus height of setback buildings of 6m bay width

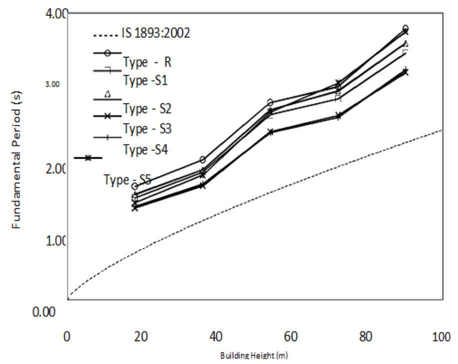


Fig. 4.8: Modal analysis time period versus height of setback buildings of 7m bay width

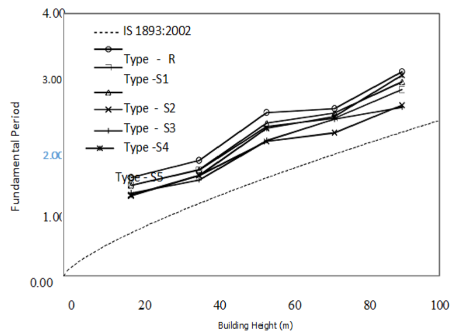


Fig. 4.9: Rayleigh analysis time period versus height of setback buildings of 7m bay width

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.

5. PARAMETERS AFFECTING FUNDAMENTAL TIMEPERIOD

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

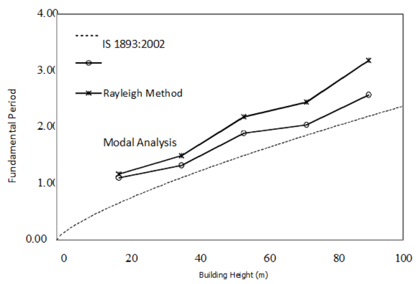


Fig. 4.10: Fundamental time period vs. height of Type - R building with 5 m bay width

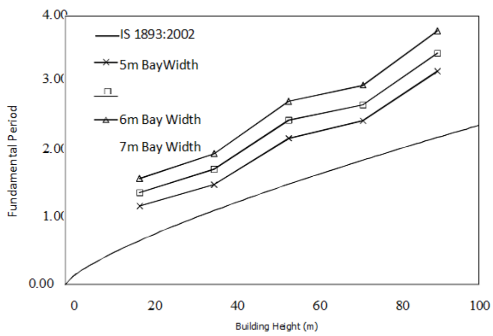


Fig. 4.13: Variation of fundamental time period with bay width for Type – R building.

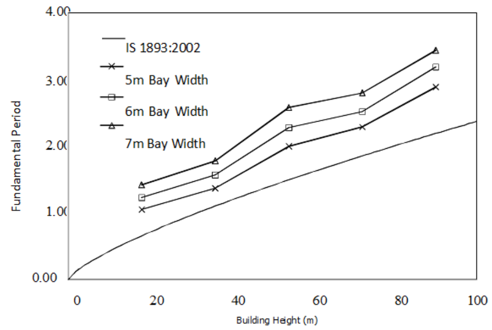
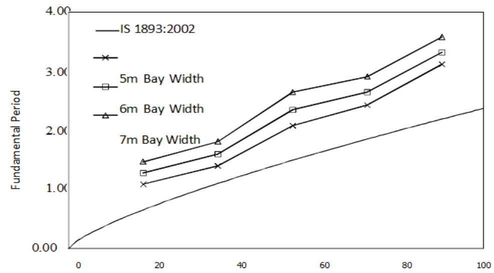


Fig. 4.14: Variation of fundamental time period with bay width for Type – S1 setback building



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.

6. 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. 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 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.

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