

# Effect of Setback on Fundamental Period of RC Framed Buildings

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## 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.

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## INTRODUCTION

The magnitude of lateral force due to an earthquake depends mainly on inertial mass, ground acceleration and the dynamic characteristics of the building. To characterize the ground motion and structural behaviour, design codes provide 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. 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. This is the primary motivation underlying the present study.

## LITERATURE REVIEW

The literature review is conducted 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 first part of this chapter is devoted to a review of published literature related to response of irregular buildings under seismic loading. The response quantities include ductility demand, inter-story drift, lateral displacement, building frequencies and mode shapes. The second half of this chapter is devoted to a review of design code perspective on the estimation of fundamental period of setback building. This part describes different empirical formulas used in different design codes for the estimation of fundamental period, and the description and quantification of irregular buildings.

Aranda et. al. (1984) studied the ductility demands of RC Frames irregular in height. The study focuses in inelastic behavior of RC Frames irregular in height when subjected to earthquake motion. For the numerical analysis static methods with

different ductility factors were used. Two RC buildings of 30 m overall height was studied. One is the regular building with three bays of 5m each in both the horizontal direction. And the other one is irregular building with a tower of 5m bay width in both horizontal directions starting at mid height of the building and located centrally. Wood et. al. (1992) investigated the seismic behavior of reinforced concrete frames with setbacks using the response of two small scale models. She studied the displacement, acceleration and shear response of setback frames during earthquake simulation. She found that the first mode dominates the displacement and shear response of setback buildings however the acceleration response is governed mainly by higher modes. She concluded that, the response of setback structure is no different than that of the regular structure and hence it does not require different design considerations.

### Structural Modelling

The study in this thesis is based on analysis of a family of structural models representing vertically irregular multi-storeyed setback buildings. The first part of this chapter presents a summary of various parameters defining the computational models, the basic assumptions and the building geometries considered for this study. All the selected buildings were designed as per Indian Standards.

### Computational Model

Modelling a building involves the modelling and assemblage of its various load-carrying elements. The model must ideally represent the mass distribution, strength, stiffness and deformability. Modelling of the material properties and structural elements used in the present study is discussed below.

### Material Properties

M-20 grade of concrete and Fe-415 grade of reinforcing steel are used for all the frame models used in this study. Elastic material properties of these materials are taken as per

Indian Standard IS 456 (2000). The short-term modulus of elasticity ( $E_c$ ) of concrete is taken as:

$$E_c = 5000 f_{ck} \text{ MPa} \quad (3.1)$$

Where  $f_{ck}$  = characteristic compressive strength of concrete cube in MPa at 28-day

(20 MPa in this case). For the steel rebar, yield stress ( $f_y$ ) and modulus of elasticity ( $E_s$ ) is taken as per IS 456 (2000).

### Linear Dynamic Analysis

Symmetrical buildings with uniform mass and stiffness distribution behave in a fairly predictable manner, whereas buildings that are asymmetrical or with areas of discontinuity or irregularity do not. For such buildings, dynamic analysis is used to determine significant response characteristics such as (1) the effect of the structure's dynamic characteristics on the vertical distribution of lateral forces; (2) the increase in dynamic loads due to Torsional motions; and (3) the influence of higher modes, resulting in an increase in story shears and deformations.

## RESULTS AND DISCUSSIONS

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.

### 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.

## SUMMARY

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.

## 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:

- i) 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.
- ii) 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.
- iii) 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.

## SCOPE OF FUTURE STUDY

- i) 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.
- ii) 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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