EFFECT OF SETBACK ON 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. 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.

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. This study shows that it is difficult to quantify the irregularity in a setback building with any single parameter. Also, 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. 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.

Keyword: -Geometric Irregularity, Setback building, Fundamental period, Regularity index, Correction factor .

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1. INTRODUCTION

Response of setback buildings under seismic loading, effect of vertical irregularity on fundamental period of building and the quantification of setback and 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.

Setback in buildings introduces staggered abrupt reductions in floor area along the height of the 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 storey in an urban locality with closely spaced tall buildings.
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.

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 (Ec) of concrete is
taken as:

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

Where fck characteristic compressive strength of concrete cube in MPa at 28-day
(20 MPa in this case). For the steel rebar, yield stress (fy) and modulus of elasticity (Es) is
taken as per IS 456 (2000).
Structural Elements
Beams and columns are modelled by 2D frame elements. The beam-column joints are modelled by giving end-offsets to the frame elements, to obtain the bending moments and forces at the beam and column faces. The beam-column joints are assumed to be rigid (Fig. 3.1). The column end at foundation was considered as fixed for all the models in this study.

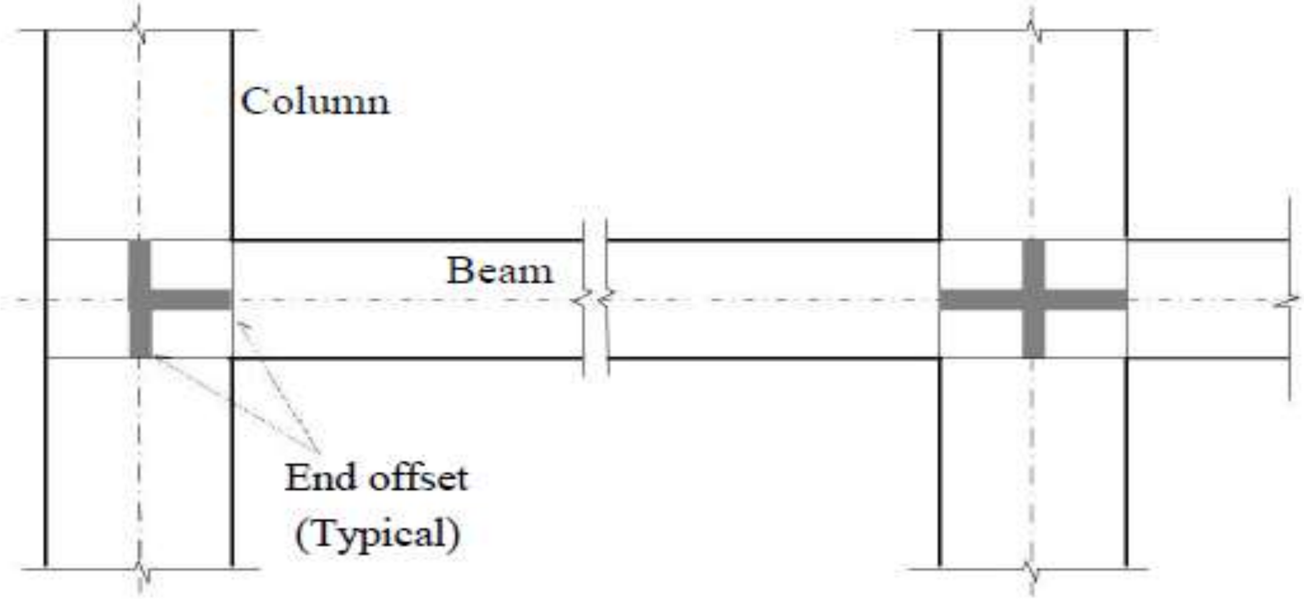

Fig. 3.1: Use of end offsets at beam-column joint

The structural effect of slabs due to their in-plane stiffness is taken into account by assigning 'diaphragm' action at each floor level. The mass/weight contribution of slab is modelled separately on the supporting beams.

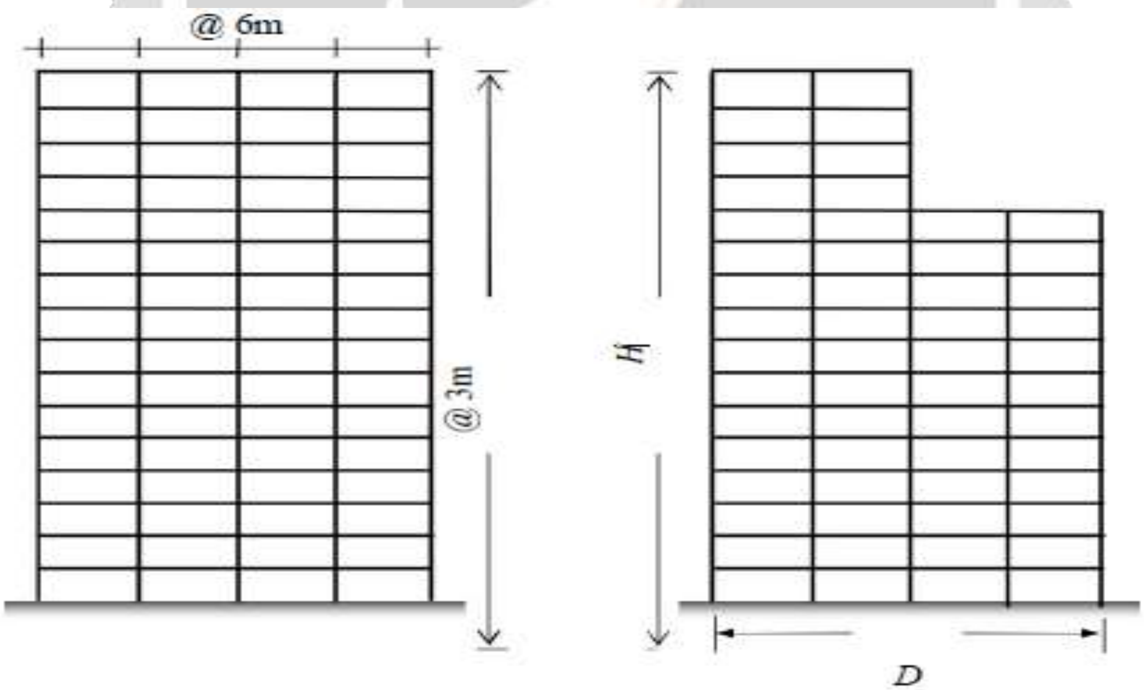

Fig. 3.2: Typical structural models used in the present study

BUILDING GEOMETRY

The study is based on three dimensional RC building with varying heights and widths. 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

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 deformationsStatic method specified in building codes are based on single-mode response with simple corrections for including higher mode effects. While appropriate for simple regular structures, the simplified procedures do not take into account the full range of seismic behaviour of complex structures. Therefore, dynamic analysis is the preferred method for the design of buildings with unusual or irregular geometry.

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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:

$$Mv \;\; Kv \;\; 0 \qquad (2)$$

Looking for a solution in the form of vi q(t) i ,i 1,2,....N , where the dependence on time and that on space variables can be separated. Substituting for v, the equation of motion changes to the following form:

$$M \;\; q\,t \;\; K \;\; q\,t \;\; 0 \qquad (3)$$

This is a set of N simultaneous equations of the type N

$$\sum_{j\,1}^{N} m_{ij} \; {}_j q\, t k_{ij} \qquad \sum_{j\,1}^{N} \; {}_j q \; t \quad 0; i \;\; 1,2,\ldots, N \qquad (4)$$

Where the separation of variables leads to:

$$\frac{q\,t}{q\,t} = \frac{\sum_{j\,1}^{N} k_{ij\ j}}{\sum_{j\,1}^{N} m_{ij\ j}} \;;i\;\;1,2,\ldots N$$

(5)

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,

q t 2 q t 0 (6)

$$\sum_{j\,1}^{N} k_{ij} \quad {}^{2}\, m_{ij\ \ j} \quad 0;i\;\;1,2,\ldots N$$

(7)

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. 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 (8)

Results and Discussion

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 a single or multiple parameters to accurately define the irregularity in a three dimensional 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.

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.*

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.

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.

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