A STUDY ON EFFECT OF SETBACK ON FUNDAMENTAL PERIOD OF RC FRAMED BUILDING

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ABSTRACT: This paper summarizes various aspects of 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.
Keywords: Geometric Irregularity, Setback Building, Fundamental Period, Regularity Index, Correction Factor

I. 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.
Seismic analysis of most structures is carried out using Linear Static (Equivalent Static) and Linear Dynamic (Response Spectrum) methods. Lateral forces calculated as per Equivalent Static Method depends on structural mass and fundamental period of structure. The empirical equations of the fundamental period of buildings given in the design codes are function of building height and base dimension of the buildings. Theoretically Response Spectrum Method uses modal analysis to calculate the natural periods of the building to compute the design base shear. However, some of the international codes (such as IS 1893:2002 and ASCE 7:2010) recommend to scale up the base shear (and other response quantities) corresponding to the fundamental period as per the code specified empirical formula, so as to improve this base shear (or any other response quantity) for Response Spectrum Analysis to make it equal to that of Equivalent Ststic Analysis. Therefore, estimation of fundamental period using the code empirical formula is inevitable for seismic design of buildings.

II. RESEARCH ON SETBACK BUILDING

The seismic response of vertically irregular building frames, which has been the subject of numerous research papers, started getting attention in the late 1970s. Vertical irregularities are characterized by vertical discontinuities in the geometry, distribution of mass, stiffness and strength. Setback buildings are a subset of vertically irregular buildings where there are discontinuities with respect to geometry. However, geometric irregularity also introduces discontinuity in the distribution of mass, stiffness and strength along the vertical direction. Majority of the studies on setback buildings have focused on the elastic response. Following is a brief review of the work that has been done on the seismic response of setback structures. Humar et. al. (1977) studied the dynamic behaviour of multi-storey steel rigid-frame buildings with setback towers. The effects of setbacks upon the building frequencies and mode shapes were examined. Then the effects of setbacks on seismic response are investigated by analysing the response of a series of setback building frame models to the El Centro ground motion. Finally, the computed responses to the El Centro earthquake are compared with some code provisions dealing with the seismic design of setback buildings. The conclusions derived from the study include the following: The higher modes of vibration of a setback building can make a very substantial contribution to its total seismic response; this contribution increases with the slenderness of the tower. Some of the important response parameters for the tower portion of a setback building are substantially larger than for a related uniform building. For very slender towers, the transition region between the tower and the base may be subjected to very large storey shears. 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.

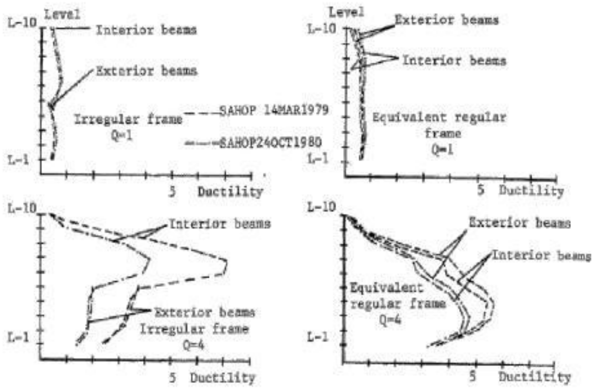


Fig. 1: Ductility Demands in Beams for the Selected RC Frames (Ref: Aranda,1984)

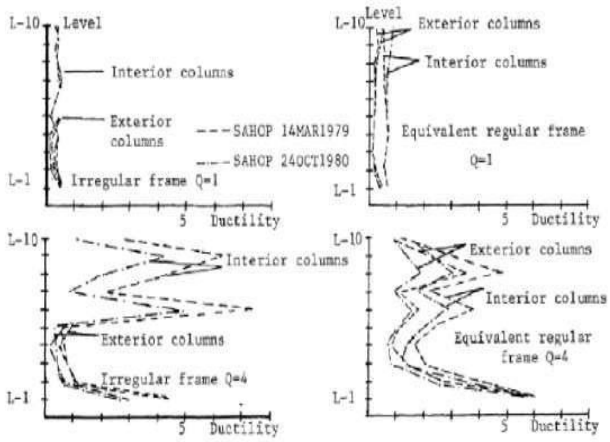


Fig. 2: Ductility Demands in Columns for the Selected RC Frames (Ref: Aranda, 1984)

2.1 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.

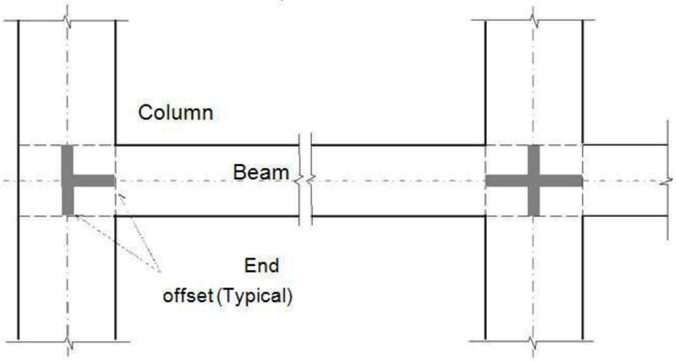
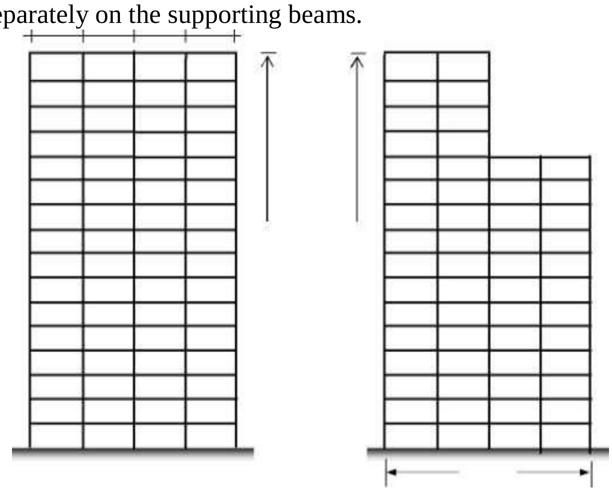


Fig. 3 Use of end Offsets at Beam-Column Joint

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.



Regular Setback

Fig. 4 Typical Structural Models used in the Present Study

III. 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 shown in Fig. 4. There are altogether six different building geometries, one regular and five irregular, for each height category are considered in the present study. Fig 5 presents the elevation of all six 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 S1, S2, S3, S4 and S5 depending on the percentage reduction of floor area and height as shown in the Fig. 5.

Type - R **Type – S1**

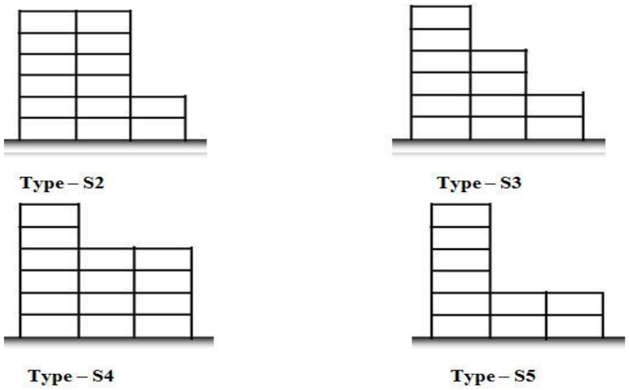


Fig 5 Typical Building Elevations for Six-Storey Building Variants (R, S1 to S5)

Table 1: Dimensions of Beams and Columns for Different Buildings

Building Type according to number to stories	Column dimension	Beam dimension
Six-storey building	400 mm × 400 mm	300 mm × 450 mm
Twelve-storey building	600 mm × 600 mm	450 mm × 600 mm
Eighteen storey building	800 mm × 800 mm	450 mm × 600 mm
Twenty four-storey building	1000 mm × 1000 mm	450 mm × 750 mm
Thirty-storey building	1200 mm × 1200 mm	600 mm × 750 mm

The structures are modelled by using computer software SAP-2000 (v12) as explained in Section 3.2. Modal analyses were performed to check if the selected frames represent realistic building models. It is found that the selected buildings cover a wide fundamental period range of 0.95s – 3.78s. It may be noted that the fundamental period versus overall height variation of all the selected frames are consistent with the empirical relationships presented by Goel and Chopra (1997) as shown in Fig. 6. This shows that the models selected for this study can be interpreted as being representative of general moment resisting RC frame behaviour for six to thirty-storey buildings, as established by Goel and Chopra (1997).

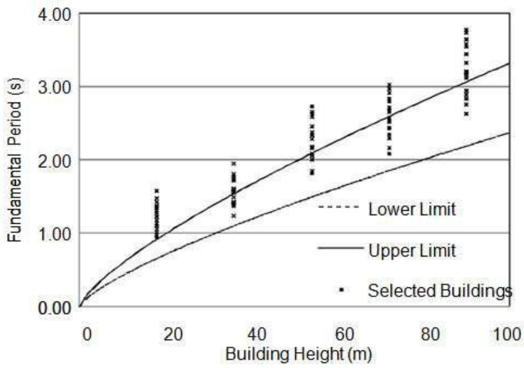


Fig. 6: Fundamental Period Versus Overall Height Variation of all the Selected Frames

IV. MODE PARTICIPATION FACTOR

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

$$Mv \;\; Cv \quad Kv \;\; Mrv_q \qquad (3.10)$$

Where v_g denotes ground acceleration, v is the vector of structural displacements relative to the ground displacements, and r is a vector of influence coefficients. The i^{th} element of vector r represents the displacement of i^{th} 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:

$$q_r \;\; 2_{r\,r} q_r \quad {}_r^{2} \quad q_r \;{}_r v_g \qquad , \; r \;\; 1,2,\ldots N$$

$${}_r{}^T Mr \qquad\qquad th$$

Where, ${}_r$ $\quad r^T{}_{Mr}$ is known as the *mode – participation* Factor for the *r* $\quad$ mode.

V. 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. 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. 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.

VI. 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.

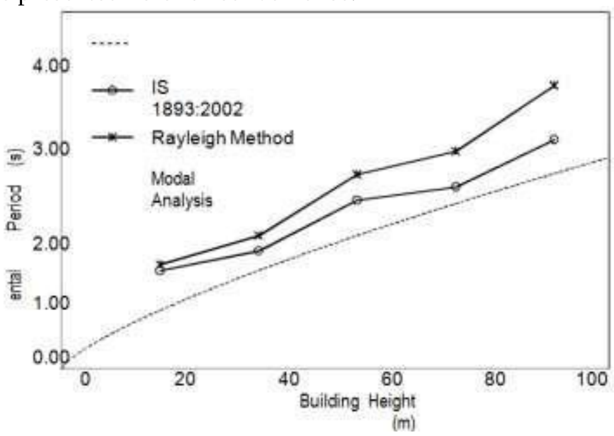


Fig. 7: Fundamental time period vs. height of Type - R building with 5 m bay width

VII. DESIGN CODE PERSPECTIVE

Most of the available design codes for earthquake resistant building including IS 1893:2002, ASCE 7:2010, Euro code 8 or New Zealand code of practice, recommends an empirical formula for the determination of fundamental time period of building. Also the design codes define different types of irregular structures. The forthcoming sections discusses about the different approaches for calculating fundamental time period and the definition of irregularity as per available design codes. 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. A common type of vertical geometrical irregularity in building structures arises is the presence of setbacks, i.e. the presence of abrupt reduction of the lateral dimension of the building at specific levels of the elevation. This building category is known as „setback 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 storeys in an urban locality with closely spaced tall buildings. This type of building form also provides for compliance with building bye-law restrictions related to „floor area ratio‟ (practice in India). 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. 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. To get a clear idea about the dynamic performance of setback buildings a detailed literature review is carried out 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 research papers on setback buildings conclude that the displacement demand is dependent on the geometrical configuration of frame and concentrated in the neighborhood of the setbacks for setback structures.

VIII. 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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