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EFFECT OF SETBACK ON FUNDAMANTAL PERIOD OF RC FRAMED BUILDINGS

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ABSTRACT

The unbalanced load effects can be further exacerbated by non-alignment of center of stiffness of the structural system and center of mass of the floor plates, which result in three-dimensional (3D), coupled mode shapes and experience coupled responses when exposed to wind & Earthquake loads. A structure can be classified as irregular if it contains irregular distributions of mass, stiffness and strength or due to irregular geometrical configurations. Different codes prescribe different limits for these irregularities like as per IS 1893:2002, a storey in a building is said

to contain mass irregularity if its mass exceeds 200% than that of the adjacent storey. If stiffness of a storey is less than 60% of the adjacent storey; in such a case the storey is termed as „weak storey", and if stiffness is less than 70 % of the storey above, then the storey is termed as „soft storey". In reality, many existing buildings contain irregularity due to functional and aesthetic requirements. However, past earthquake records show the poor seismic performance of these structures. This is due to ignorance of the irregularity aspect in formulating the seismic design methodologies by the seismic codes (IS 1893:2002, EC8:2004, UBC 1997, NBCC 1989, NBCC 2005 etc.).

Seismic Behaviour of asymmetric building may cause interruption of force flow and stress concentration. Due to this, there is produce of torsion in the building which leads to increase in shear force, lateral deflection and ultimately causes failure. Asymmetry can be reason for a buildings poor performance under sever seismic loading. The building with vertical setbacks and L, H, U or T shaped in plans which built as unit are more affected during seismic event. There is horizontal torsional effect on each arm arising from the differential lateral displacement of two ends of each arm. In this paper, inelastic seismic behaviour of multi-storeyed building with vertical setbacks are analysed by IS code approach. The effect of torsion on building are analysed. Designs of asymmetric multi-storeyed building are studied. Study shows that there is increase in shear force due to torsion in column and increase in area of steel reinforcement in column particularly at the edge member of the 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.

Here an attempt has been made to study the behaviour of different structures of reinforced concrete with different heights with and without shear walls. Coupled shear walls have also been studied to understand the comparative merit or demerit of framed structures with shear wall structures. Studies have been carried out on sample model structures and analysis has been carried out by ETABS software. It has been ensured to consider sample models that represent the current practices in structural design to include different structural configurations. Models having varied structural configurations like framed, shear wall, coupled shear wall, central core shear wall, core in core etc. have been taken into consideration. The inherent asymmetry present in the structures have also been dealt

KEYWORDS: Response spectrum, fundamental period, Building Performance, Story drift, Design Basis, Earthquake (DBE), Storey drift, lateral displacement, time period and base shear, inertial force.

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 behavior, 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 Static Analysis. Therefore, estimation of fundamental period using the code empirical formula is inevitable for seismic design of 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

II. OBJECTIVES

A detailed literature review is carried out to define the objectives of the thesis. This is discussed in detail in Chapter 2 and briefly summarised here. Design codes have not given particular attention to the setback building form. The research papers on setback buildings conclude that the displacement demand is dependent on the geometrical configuration of frame and concentrated in the neighbourhood of the setbacks for setback buildings. The higher modes significantly contribute to the response quantities of structure. There are a few literatures (Karavasilis et. al. 2008 and Sarkar et. al. 2010) on the definition and quantification of irregularity in setback buildings. This is an important parameter for estimation of fundamental period of setback buildings. There is a study (Sarkar et. al. 2010) on estimation of fundamental period of setback building frames. This study is limited only to plane frames and the formulation proposed in the study is difficult to be used for the actual three-dimensional setback buildings. Based on the literature review presented later, the salient objectives of the present study have been identified as follows:

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

III. 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 of 25 storeys with different degrees of irregularity are considered.
d. The buildings are assumed to have setback in both the orthogonal directions.
e. The setbacks have been assumed in X direction, Y direction and in both the directions.
f. Soil-structure interaction effects are not considered in the present study. Column ends are assumed to be fixed at the foundation.

IV. METHODOLOGY

The steps undertaken in the present study to achieve the above-mentioned objectives are as follows:

a) Carry out extensive literature review, to establish the objectives of the research work.
b) Select an exhaustive set of setbacks building frame models with different heights (2 to 25 storeys), Bay width in both horizontal direction (4m, 3.5m) and different irregularities (limit to 16 setbacks building models).
c) Perform free vibration analysis, dynamic analysis and wind load analysis for each of the 16 building models.
d) Analysing the results of free vibration analysis

V. LITERATURE REVIEW

Al-Ali et. al. (1998) they studied the seismic response of buildings with vertical irregularity. They discussed on the quantification of effects of irregularity in mass, stiffness, strength and their combinations for seismic demands. Deformation demand i.e. roof drift and storey drift are also being studied. The analysis considered in the study is both elastic and inelastic dynamic analysis. Two dimensional, single bay, 10 story frame MDOF models designed according to strong beam weak column philosophy.They found that seismic response due to mass irregularity is least, whereas the effect of strength irregularity is larger than the effect of stiffness irregularity. The seismic response was seen to be affected severely when the combined stiffness and strength irregularity is studied.

Chintanapakdee et. al. (2004) studied the seismic demands for vertically irregular and regular frames by non linear response history analysis. 48 irregular frames of 12 story height were designed and tested as per strong column weak beam philosophy. Three types of irregularities is considered for the study: Stiffness irregularity (KM), strength irregularity (SM), and combined stiffness- and-strength irregularity (KS). The effect of vertical irregularity on storey drift and floor displacement were studied. They concluded the following point.

The all the three types of irregularities KM, SM and KS influence the height-wise variation of story drifts, with the effects of strength irregularity being larger than stiffness irregularity, and the effects of combined- stiffness-and-strength irregularity being the largest among the three. Introducing a soft and/or weak story increases the story drift demands in the modified and neighbouring stories and decreases the drift demands in other stories.

Sarkar et. al. (2010) proposes a new method of quantifying irregularity in stepped building frames, which accounts for dynamic characteristics i.e. mass and stiffness. This paper discusses some of the key issues regarding analysis and design of stepped buildings. They proposed a new approach for quantifying the irregularity in stepped building. It accounts for properties associated with mass and stiffness distribution in the frame. This approach is found to perform better than the existing measures to quantify the irregularity. Based on free vibration analysis of 78 stepped frames with varying irregularity and height, this study proposes a correction factor to the empirical code formula for fundamental period, to render it applicable for stepped buildings They proposed a measure of vertical irregularity, called ‘regularity index’, accounting for the changes in mass and stiffness along the height of the building as a ratio. is the 1st mode participation factor for the setback building frame under consideration the 1st mode participation factor for the similar regular building frame without stepIS 1893:2002

1. 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.

2. Fundamental Time Period

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 then buildings with irregular configurations. Design code recommends dynamic analysis to obtain the design seismic force for all irregular buildings. ASCE 7:2010 and Euro Code 8 specify similar guidelines. This chapter discusses about the analysis and design considerations of setback buildings only.

All design code recommends performing dynamic analysis on setback buildings to obtain design seismic forces, and its distribution to different levels along the height of the building. Codes recommend modifying the response quantities (such as base shear) to be scaled up to a factor if the response from dynamic analysis is less than the response calculated using the empirical equation of fundamental time period. The response quantity is to be scaled up by a factor which is the ratio of base shear using empirical equations to the base shear using dynamic analysis.

3. VERTICAL GEOMETRIC IRREGULARITY

All design codes define plan irregularity and vertical irregularity as two major types of irregularity. Vertical geometric irregularity or Setback building is one among the vertical irregularity defined in all codes. As per IS 1893:2002, such building is to be considered as setback buildings where the horizontal direction of the lateral force resisting system in any story is more than 150 percent of that in its adjacent storey, as shown in Fig.2.5 (a). As per ASCE 7:2010, setback building is defined as, when the horizontal direction of the seismic force resisting system in any story is more than 130 percent of that in its adjacent storey, as shown in Fig.2.5(b). Design codes consider this ratio of lateral dimension of two adjacent stores as criteria to define vertical geometric irregularity. Design codes do not quantify the amount of irregularity in any setback building; it merely is a rule to distinguish regular and irregular building.

VI. STRUCTURAL MODELS

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.25 storey height were considered for the study.
With a uniform storey height of 3m. Altogether 15 building frames with different amount of setback irregularities due to the reduction in width and height were selected.

There are altogether three different building geometries, one setback in X direction (SX1), setback in Y direction (SY1) and setback in both directions (SD1) are considered in the present study. Fig 3.1 TO 3.3 presents the elevation of all three different geometries of a typical 25 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 SD1, SD2, SD3, SD4 and SD5 depending on the percentage reduction of floor area and height as shown in the Fig. 3.3.
The exact nomenclature of the buildings considered are expressed in the form of S-X-Y, where S represents the type of irregularity (i.e., S1 to S5 or R). X represents the number of storeys and Y represents the bay width 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

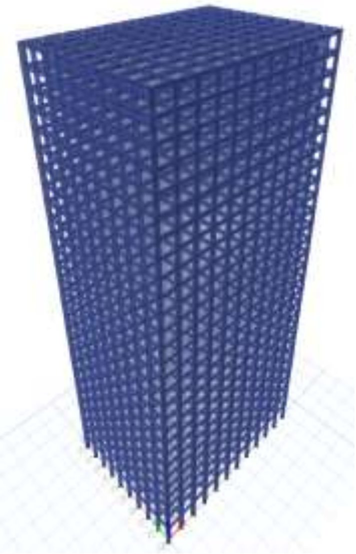


Fig:1 SX1

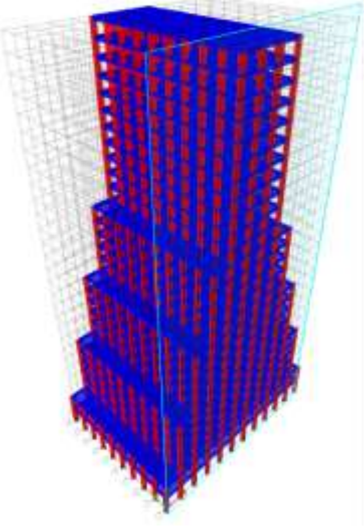


Fig:2 SX2

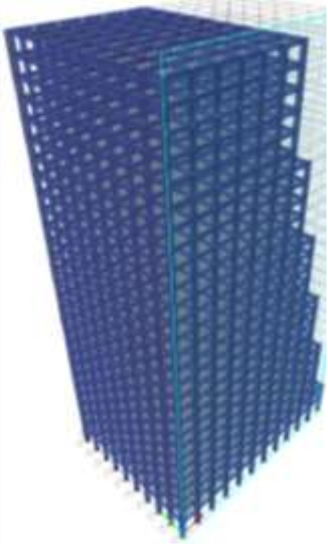


Fig:3 SX3

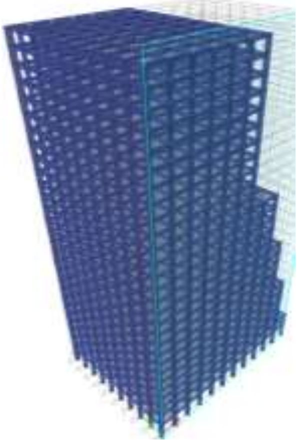


Fig:*4 SX4*

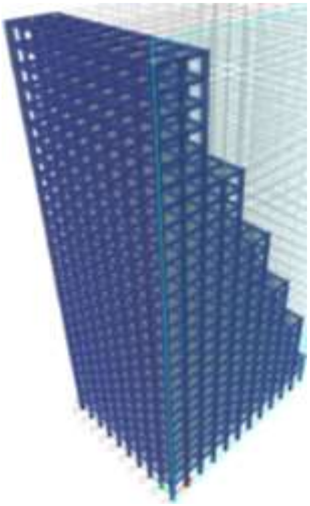


Fig:5 SX5

VII. MODEL PARAMETERS

Seismic Parameters				
Seismic Zone (Z)		IV	Soil Type (S)	Medium
Response Reduction Factor (R)		4	Importance Factor (I)	1.2
Seismic Weight (W)		591216.85	Zone Factor	0.24
Total Height (m)		102.5	Length along X (m)	40
Basement Height (m)		8	Width along Y (m)	40
Height of Mumty (m)		3.5	Effective Height (m)	99
Acceleration, g (mm/s^2)		9806.65	Default Scale Factor	1470.9975
EQX	-12259.78	4.40E-06	Scale X	**1.73**
EQY	-2.9E-06	-1.23E+04		2541.01
SPECX	7097.2307	9.83E+00	Scale Y	**1.63**
SPECY	9.8338	7.53E+03		2395.57

Sl.	Description	Value	Reference
01	Terrain category.	4	IS-875
02	Class of structure.	C	IS-875
03	Probability factor, k1.	1.0	IS-875
04	Terrain, height and structure size factor, k2.	As/Height	IS-875
05	Topography factor, k3.	1.0	IS-875
06	Importance factor, k4 for the cyclonic region	1.0	IS-875

VIII. RESULTS AND DISCUSSIONS

1. VARIATION OF TIME PERIOD WITH RESPECT TO CHANGE IN COLUMN SIZE

Different buildings were analysed for their fundamental time period by changing their column sizes, while keeping all other parameters as same. And the variation of Time Period with respect to change in Column size was plotted in Fig: 6. Here we see the structure having same Plan area and Height shows a change in time period. With the decrease in the column size, the stiffness of the structure decreases; hence the building becomes more flexible and the time period increases. And thus the base shear decreases.

Fig.6: Variation of Time Period With Respect to Change in Column Size

2. Variation of Time Period with Infill and Without Infill

The structure is modelled with and without considering infill in two different set of models and the results are plotted in Fig. 7. We observe here that the structure gets additional stiffness when infill is modelled hence the time period is much lower when modelled with infill than that with no infill. The base shear is higher for the model in which infill is considered, but this difference of base shear goes on decreasing with the change in height.

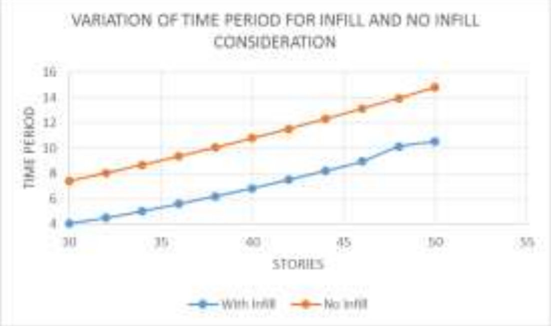


Fig.7: Variation of Time Period with infill and without infill.

3. Variation of Time Period with Building Asymmetry

Symmetrical buildings with uniform mass and stiffness distribution behave in a fairly predictable manner, whereas buildings that are asymmetrical or with areas of discontinuity.Static method specified in building codes are based on single-mode response with simple corrections for including higher mode effects.

Table 1: Change in Time Period with respect to geometric irregularities

Type	**Height**	**Time Period**		
		Modal Analysis	**IS1893**	**UBC 97**
No Irregularities	30	1.782038	0.961396	0.93704
1	30	1.691982	0.961396	0.93704
2	30	1.589424	0.961396	0.93704
3	30	1.551101	0.961396	0.93704
4	30	1.490155	0.961396	0.93704

The fundamental periods for all the selected setback buildings as obtained from different methods available as tabulated above show that the buildings with same height and width may have different period depending on the amount of irregularity present in the setback buildings.

4. Variation of Time Period with Foundation System Type

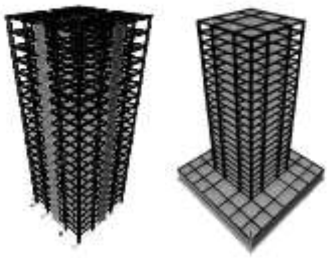


Fig.8: Structural foundation systems.

Modelling of the base foundation system affects the fundamental time period. Here we compare two different approaches to model the same superstructure as shown in Fig. 4.

a) Structure A - Fixed support at the base (not considering SSI)
b) Structure B - Flexible Support at the base (considering SSI)

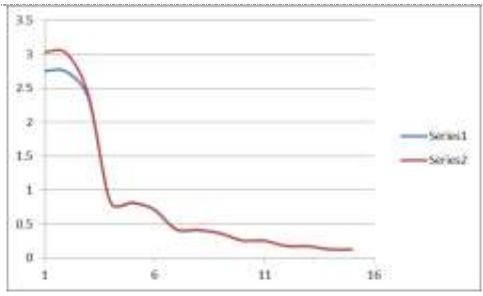


Fig.9: Variation of Time Period with foundation system type

Natural Period of Vibration (for the first 15 modes) of the example structures were compared in the graph as shown in Fig. 5 illustrates that the natural period of the Structure A is much less than that of the Structure B. And the difference in the natural period for lower modes was more significant compared to that of the higher modes. It can be explained that the rotation of column bases occurring in the first and second mode shape is larger than that of the higher modes.

5. Experimental Investigation For Low Rise Buildings

Low rise stiff buildings exhibit smaller time periods and vibrate predominantly in its fundamental mode. The important parameters that determine the fundamental time period of such buildings are plan dimension, member sizes and structural configuration. Height does not play a significant role, as dictated by the IS1893:2002 formula. Here an attempt have been made to model 108 different models with different storey height, different spans and different number of storeys.

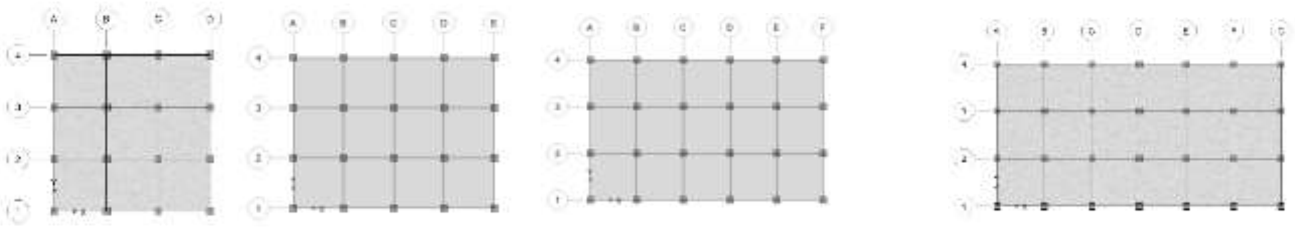

Type A Type B Type C Type D

Fig.10: Types of Low Rise Building Models Considered

Table 4.3: Types of Low Rise Building Models Considered

Structure Type	No. of Storeys	Size of Span (m)	Storey Height (m)
Type A	3,4,6	3,4,5	3,4,5
Type B	3,4,6	3,4,5	3,4,5
Type C	3,4,6	3,4,5	3,4,5
Type D	3,4,6	3,4,5	3,4,5

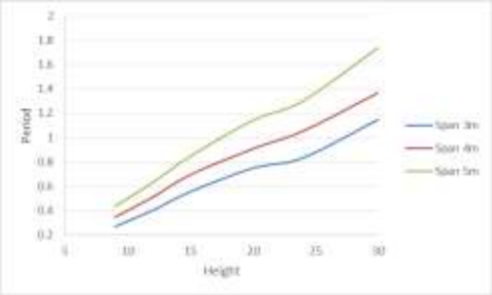


Fig.11: Variation of Period with Beam Spans

6. Variation Of Period With Beam Spans

If the column beam configuration remains same and the span of the beam increases the natural period of the building increases as shown in Fig. 7. This is due to the reduction on the overall stiffness of the floor.

7. Variation Of Period With Plan Ratio

There is marginal variation in time periods if there is a difference in plan ratio as shown in Fig. 8. From this we can infer that while establishing a generalized formula for the fundamental time period we can ignore this aspect of the structure and limit our self to the plan area and height of the structure.

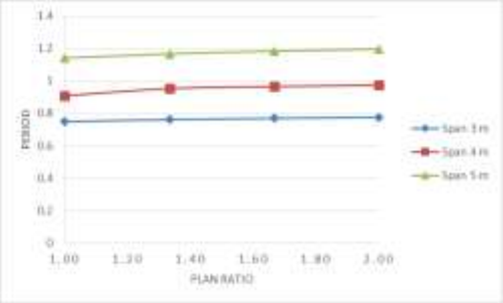


Fig.12: Variation of Period with Plan Ratio

8. Variation Of Period For 9 M Buildings

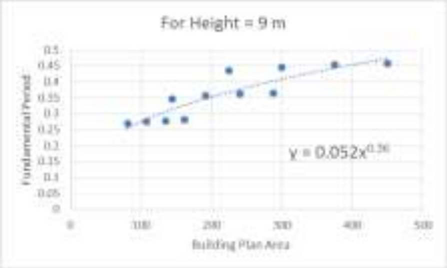


Fig.13: Variation of Period for 9 m buildings

For a building of 9 m height, from the curve fit given in Fig. 9 for the fundamental natural period, we can derive a power relationship as follows.

T = 0.052 (BD) 0.36 (10)

9. Variation Of Period For 15 M Buildings

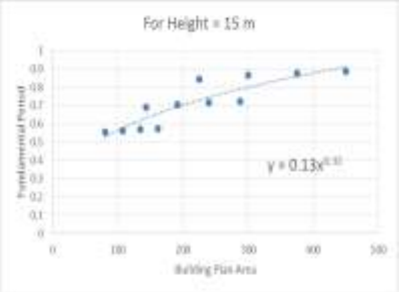
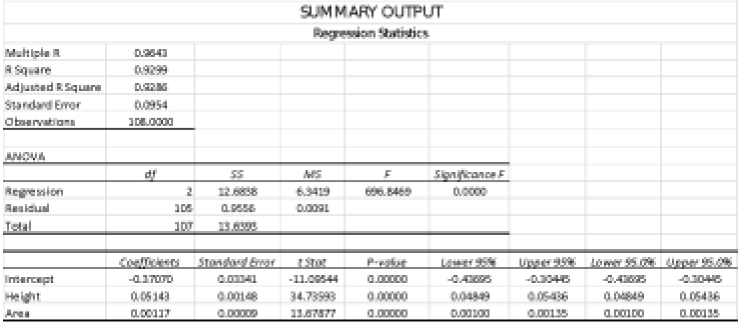


Fig.14: Variation of Period for 15 m buildings

This shows that the present study estimation of periods gives a variation of about-13% to 15% (Eq. 11) as shown in Table 5. Whereas the variation is -36% to 3% as per the without infill time period formula of IS 1893-2002.

10. Regression Analysis

The findings of the regression analysis has been presented here in Fig. 4.11.



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9643
R Square	0.9299
Adjusted R Square	0.9286
Standard Error	0.0954
Observations	108.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	12.6838	6.3419	696.8469	0.0000
Residual	105	0.9556	0.0091		
Total	107	13.6395			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.37070	0.03341	-11.09544	0.00000	-0.43695	-0.30445	-0.43695	-0.30445
Height	0.05143	0.00148	34.73593	0.00000	0.04849	0.05436	0.04849	0.05436
Area	0.00117	0.00009	13.67877	0.00000	0.00100	0.00135	0.00100	0.00135

Fig. 4.11: Regression Analysis

Based on the above analysis, the formula for fundamental time period can be suggested as,

$T_a = 0.05143h+0.00117A-0.3707$

Where,
h = Height of the building in meters.
A = Plan area of the building in square meters.

The above formula has an error range of -30% to 36% which is still better compared to -47% to 45% error given by the existing formula.

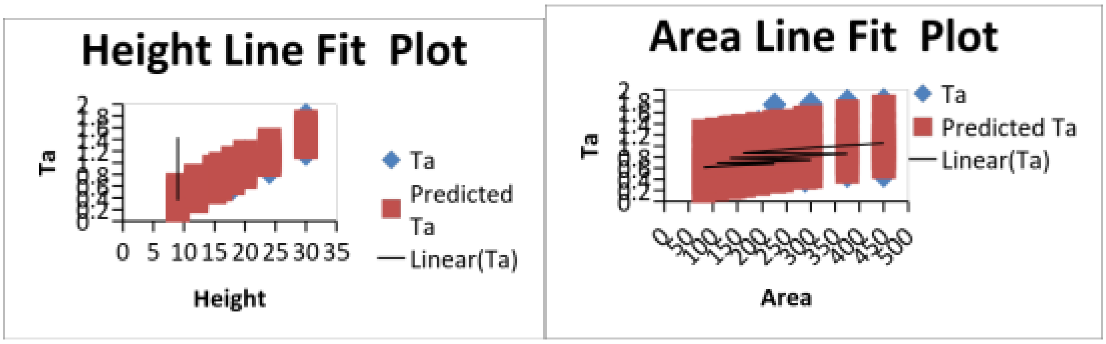


Fig. 4.12: Fundamental period with respect to Plan Area and Height at 30 m height.

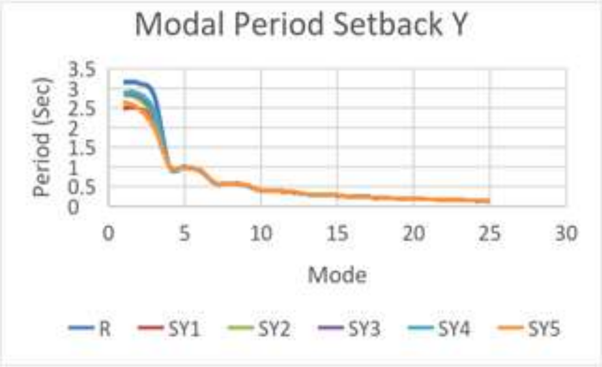
The formulae given by the plots in Fig. 12 suggests the following:

1. Area Line Fit Plot has an error range of -57% to 136%.
2. Height Line Fit Plot has an error range of -27% to 42%.
3. Therefore, as the height of the building increases above a certain range, the fundamental time period depends more on the height and less on its plan area.

11. Experimental Investigation For Medium Rise Buildings

Medium rise slightly flexible buildings exhibit larger time periods but still vibrate predominantly in its fundamental mode. The important parameters that determine the fundamental time period of such buildings are height, member sizes and structural configuration where height does play a crucial role, as dictated by the IS1893:2002 formula. But other parameters like presence of non-structural elements, stiffness irregularities in plan and elevation etc. can affect the dynamic behaviour of the structure significantly. Here an attempt have been made to model different buildings with different storey height, different spans and different number of storeys. Assumption of non-structural walls have also been made.

The present study estimation of periods gives a variation of about 0-5% (Eq. 13), whereas the variation is 0 to 70% as per the without infill time period formula of IS 1893-2002. The IS1893:2002 formula for time period predicts very lower values of time period, which indicates high stiffness in the structure and thereby higher value of base shear. This approach is though on the conservative side, but not accurate.



IX. CONCLUSION

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.

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) 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.

iv) 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.

v) 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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