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Effect of Plan Area of the Building on Period of Vibration of RC Framed Structures

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ABSTRACT: Fundamental natural period of vibration *T* of the building is an important parameter for evaluation of seismic base shear. Empirical equations given in the Indian seismic code for the calculation of the fundamental period of a framed structure, primarily as a function of height, and do not consider the effect of stiffness of the structure, base dimensions of the structure, number of panels in both the directions, plan are of the building and amount of infill as well as properties of the infill.

The fundamental natural period can be evaluated using simplified expressions found in codes, which are based on earthquake recordings in existing buildings, laboratory tests, numerical or analytical computations. These technical codes provide expressions which depend on basic parameters such as building height or number of stories. Building periods predicted by these expressions are widely used in practice although it has been observed that there is a scope for further improvement in these equations, since the height alone is inadequate to explain period variability. It is also known that the period of a RC frame structure differs depending on whether the longitudinal or transverse direction of the structure is considered.

The aim of this study is to find the effects of plan area of the building to predict the fundamental natural period of vibration of reinforced concrete buildings with moment resisting frames (MRF). A few examples of dynamic analysis are presented in this study in order to show that the effect of plan area of the structure in calculating the time period of the structure.

Key Words*: Plan Area; Dynamic Analysis; Natural Period of Vibration; Stiffness*

1. INTRODUCTION

Estimation of seismic base shear requires the fundamental natural period of vibration T of the building. Hence, empirical formulae obtained through experimentally observed behavior of buildings are utilized [1- 3]. The stiffness contribution of many non structural elements, such as in-fill masonry panels [4 & 5], also considered to derive period formula in different countries. For this reason, the empirical expression for *T* may be specific to each country. The approximate fundamental natural period of vibration (Ta) in second of a moment resisting frames building without brick infill panels may be estimated by empirical expression given in Indian seismic code IS1893 (Part-1)-2002 [6]

$T_a = 0.075h^{0.75}$ for R.C. frame building (1.1)

$= 0.085h^{0.75}$ for steel frame building (1.2)

$T_a = 0.09\,h / \sqrt{d}$ for all other buildings. (1.3)

Where *h* is the height of the building in m and *d* is the base dimension of the building in m.

Recent Indian seismic design code IS1893 (Part-1)-2002 allows the estimation of T by any of the following methods:

- Experimental observations on similar buildings,
- Any rational method of analysis (referring to dynamic analysis), or
- Using the empirical expressions prescribed in the code IS1893 (Part-1)-2002.

The fundamental period can be evaluated using simplified expressions 1.1 to 1.3 found in Indian seismic codes, which are based on earthquake recordings in existing buildings, laboratory tests, numerical or analytical computations. These technical codes provide expressions which depend on basic parameters such as building height or number of storeys. Building periods predicted by these expressions are widely used in practice although it has been pointed out by Amanat and Hoque (2006) [7] and Verderame, Iervolino and Manfredi (2010) [8] that there is scope for further improvement in these equations since the height alone is inadequate to explain period variability. It is also known that the period of a reinforced concrete (RC) frame structure differs depending on whether the longitudinal or transverse direction of the structure is considered.

The aim of this study is to find the effect of plan area of the structure in order to predict the fundamental natural period of vibration of reinforced concrete buildings with moment resisting frames. A few examples of dynamic analysis are presented in this study in order to show that the plan area should also be incorporated in the formula to evaluate period of vibration.

2. LITERATURE STUDY

The value of the fundamental natural period needs to be as accurate as possible in earthquake resistant designs, as lower the value of time period, higher will be the base shear and vice versa, with a special emphasis on designs which are based on either linear static (or lateral force) methods or performance level. Buildings are usually designed for seismic resistance using elastic analysis, but most will experience significant inelastic deformations under large earthquakes.

Thus, building codes extract seismic loads of inelastic designs from a linear spectrum, which is dependent on the fundamental natural period of structure, and ground zone type. In other words, in current seismic code provisions, seismic forces estimation using design spectra requires either implicitly the use of empirical equations for the fundamental period determination or more specifically detailed dynamic analysis.

Since the predicted fundamental natural period is used to obtain the expected seismic load affecting the structure, a precise estimation of it, is important for the safety of the applied procedure in the design steps and consequently in the future performance of the structure after it is constructed. The fundamental natural period of vibration required for the earthquake resistant design of RC structures has been calculated for many years using a simplified formula relating the period to the height of the building. One of the first formulae of this type was presented over 30 years ago in ATC3-06 (ATC, 1978) [9] given as

$$T = C_t H^{0.75} \qquad (2.1)$$

where:

H – height of the structure [m] and

C_t – constant depending on the structure type.

The coefficient C_t is calibrated in order to achieve the best fit to experimental data.

Crowley and Pinho [10] used a computer solution SeismoStruct (Seismosoft Ltd | Via Panoramica 1910, 98100 Messina, Italy) to model RC frames corresponding to actual buildings (three to eight stories) from five different European countries exposed to earthquake action (Greece, Italy, Portugal, Romania, and ex-Yugoslavia). The two dimensional RC frames were modeled as bare frames, fully infilled frames and infilled frames with openings, and a weighted average of the period of vibration of these types of frames was then calculated by taking into account their frequency of occurrence within the building stock. The equations for calculating the period of uncracked infilled buildings using a weighted mean period of vibration for each frame was represented as

$$T = 0.038H \qquad (2.2)$$

To derive period formula for fully infilled frames and the infilled frames with openings, the same models with reduced member stiffness were used. The study results in a simplified period-height equation for use in the assessment of existing RC buildings, taking due account of the presence of infill panels.

$$T = 0.055H \qquad (2.3)$$

M. Hadzima et. al [11] have proposed seven different equations in their study. In order to determine more accurate expressions for the elastic period, they considered seven basic expressions which, in addition to the number of floors, take into consideration each of the following:

- The number of bays parallel to the considered direction;
- The ratio between the number of bays in the longitudinal and transversal directions;
- The product between the number of bays in the longitudinal and transversal directions.

Following are the expressions proposed to evaluate period of vibration:

$$T = C_1 N^{C2} \qquad (2.4)$$

$$T = C_1 N^{C2} B^{C3} \qquad (2.5)$$

$$T = C_1 N^{C2} + C_3 B^{C4} \qquad (2.6)$$

$$T = C_1 N^{C2} \left(\frac{B_x}{B_y} \right)^{KC3} \qquad (2.7)$$

$$T = C_1 N^{C2} \left(B_x . B_y \right)^{C3} \qquad (2.8)$$

$$T = C_1 N^{C2} + C_3 \left(B_x . B_y \right)^{C4} (2.1) \qquad (2.9)$$

$$T = C_1 N^{C2} + C_3 \left(\frac{B_x}{B_y} \right)^{C4} \qquad (2.10)$$

Where, N is the number of storeys, B is the number of bays of the building parallel to the considered direction, B_x is the number of bays in longitudinal direction, B_y is the number of bays in transversal direction, k is a constant which has a value of 1 when the period in the longitudinal direction is to be determined and a value of -1 when the period in the transversal direction is to be determined and C_1, C_2, C_3 and C_4 are (unknown) parameters that need to be determined. The parameters of the expressions are determined by performing nonlinear regression analysis.

Goel and Chopra (1997) [12] collected data measured from eight Californian earthquakes, from 1971 (San Fernando earthquake) until 1994 (Northridge earthquake) and different formulas were proposed resulting from semi empirical analysis, with the best-fit plus 1 standard deviation recommended for displacement-based assessment, whilst the best-fit minus 1 standard deviation recommended for conservative force-based design (Chopra and Goel, 1997):

$$T_U = 0.067\,H^{0.9} \qquad (2.11)$$

$$T_L = 0.0466\,H^{0.9} \qquad (2.12)$$

where H is the height of the structure [m].

Gerardo M. 2010 [8] evaluated fundamental natural period for both main directions of the buildings of the considered sample, and regression analysis is employed to capture the dependency of the elastic dynamic properties of the structures as a function of mass and stiffness. Based on the results of the analyses a power-law regression was carried out as a function of height. In the comparison with Eurocode 8 formulas existing buildings show systematically larger periods for those herein analyzed. In particular, gravity loads designed buildings, featuring a 3D structural system, seems to require a twofold definition of period referring to the two directions. Therefore, height alone seems inadequate to explain period variability and the results of his study suggested that a global parameter (e.g., plan area) should be added in simplified relationships for rapid period evaluation. Therefore, an expression which includes also the plan area is considered in the following equations.

$$T = \alpha H^{\beta} S^{\gamma} \qquad (2.13)$$

where S is the product of the two principal plan dimensions of the building L_x and L_y.

In the literature review it has been observed the most of the research work has been carried out by considering height of the building or number of stories of the building as the only parameter to evaluate the fundamental natural period of the building, only Garerdo (2010) proposed the period equation considering plan area along with the height of the building. It is therefore required to find out the effect of the plan area on fundamental natural period.

3. BUILDING CONFINGURATION

Here in this paper a 25 story RC frame buildings square shaped in plan is analyzed using computerized solution STAAD V8i [13] with the following assumptions:

1	Type of structure	Multistory rigid jointed plane frames
2	No of storey	G+24, Twenty five stories
3	Seismic Zones	III
4	Floor height	3.6 m.
5	Depth of foundation	2.0 m
6	Building height	92.0 m (90.0+2.0)
7	Building Details	As per Table No 1 & Figure 1 & 3.
8	Size of beams	0.30 m x 0.6 0m
9	Walls- (a) External-	200 mm (outer periphery of the building)
	(b) Internal	100 mm (internal walls as partitions)
10	Thickness of slab	150 mm
11	Imposed load [14]	4.00 kN/ m^2
12	Floor finish	1.00 kN/ m^2
13	Water proofing	2.500 kN/ m^2
14	Specific wt. of RCC	25.00 kN/ m^3
15	Specific wt of infill	20.00 kN/ m^3
16	Materials used	Concrete M-25 and Reinforcement Fe-415.
17	Earthquake load	As per IS1893(Part-1)-2002
18	Type of soil	Type -II, Medium soil as per IS-1893
19	Ec	5000√fck N/ mm^2 (Ec is short term static modulus of elasticity in N/ mm^2)
20	Fck	0.7√fc k N/ mm^2(Fck is characteristic cube strength of concrete in N/ mm^2)
21	Static analysis	Equivalent static lateral force method.
22	Dynamic analysis	Using Response spectrum method
23	Software used	STAAD-Pro for both static and dynamic analysis
24	Fundamental natural period of building	As per IS1893 (Part-1)-2002
25	Zone factor Z	as per IS1893 (Part-1)-2002 for different zones as per clause 6.4.2

As mentioned in Table 1, total 36 numbers of square shaped building in plan and 92.00 m in height i.e. 25 (G+24) storied buildings with the different base dimensions (L x B in fig 1) ranging from 24 m x 24 m to 72 m x 7 2 m having 6 panels of bay width (a in Fig. 1) 4 m to 12 m each are analyzed in this study to examine the effect of plan area in the period of vibration of the building, for mentioned building geometries of the building each building configuration is again analyzed by changing the size of the columns from 1.0 m x 1.0 m, 0.75 m x 0.75 m 0.6 m x 0.6 m and 0.5 m x0.5 m. Various building configurations were modeled using computer solution

STAAD-V8i, in which beams and columns are modeled and load from the slabs, which includes floor finish and waterproofing, are assigned as a floor load whereas the brick masonry loads are assigned as a member load on the beams. Nodes at the foundation level are assigned as a fixed support. Soil structure interaction has not been taken into consideration in the analysis. Building plans considered here in this study are assumed with specific dimensions only and model so created in the computer solution are validated using standard problem and response quantities were compared. It is found that results of the software and solved problem are almost matching.

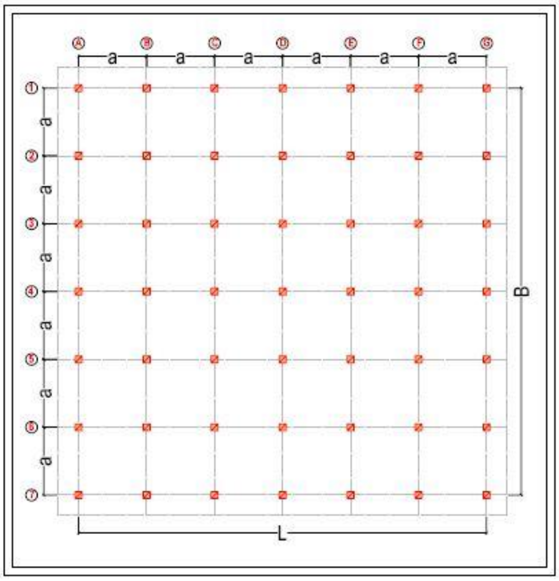

Figure1 Centre Line Plan of Building

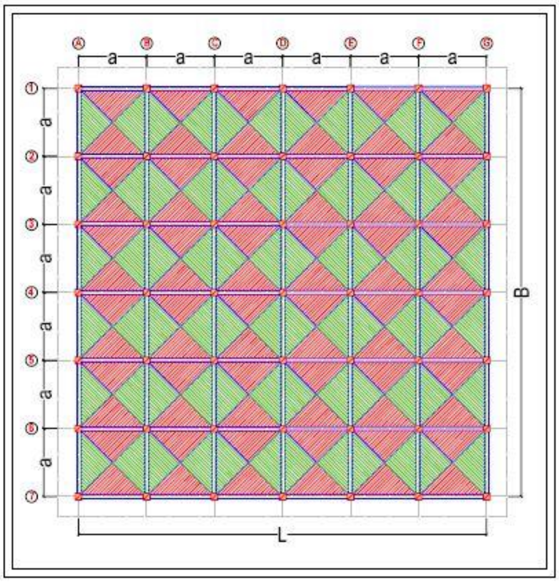

Figure 2 Load Distribution Diagram

Table 1 Building Dimensions

S. No.	Type	Base Dimension	Size of Column			
		m × m	m	m	m	m
1	B1	24.00 × 24.00	1.0×1.0	0.75×0.75	0.6×0.6	0.5×0.5
2	B2	30.00 × 30.00	1.0×1.0	0.75×0.75	0.6×0.6	0.5×0.5
3	B3	36.00 × 36.00	1.0×1.0	0.75×0.75	0.6×0.6	0.5×0.5
4	B4	42.00 × 42.00	1.0×1.0	0.75×0.75	0.6×0.6	0.5×0.5
5	B5	48.00 × 48.00	1.0×1.0	0.75×0.75	0.6×0.6	0.5×0.5
6	B6	54.00 × 54.00	1.0×1.0	0.75×0.75	0.6×0.6	0.5×0.5
7	B7	60.00 × 60.00	1.0×1.0	0.75×0.75	0.6×0.6	0.5×0.5
8	B8	66.00 × 66.0	1.0×1.0	0.75×0.75	0.6×0.6	0.5×0.5
9	B9	72.00 × 72.00	1.0×1.0	0.75×0.75	0.6×0.6	0.5×0.5

4. RESULTS

In this paper 36 buildings with different base dimensions are analyzed, keeping the height of the building same i.e. 92 m, it is observed in the analysis that, cut off modes required to be 20 to get the 90% participation. Here it can easily be observed that the time period of the building based on the code based formula comes out to be 2.1915 sec without considering infill walls, as the same are not modeled in the analysis. Period of the building so calculated by the code formula will remain same in all the 36 cases which are compared with the value of time period derived from the dynamic analysis, the value of time period for the first mode of vibration are compered in the succeeding tables.

Table 2 Comparison of Time Period with Base Dimension (Column Size 1.0m × 1.0m)

Plan	*T* Sec	Base Dimension L × B m	Percentage Variation in *T* %	Percentage Variation in Base Dimension %
B1	3.7348	24 × 24	**Base case**	
B2	4.5643	30 × 30	22.21	25.00
B3	5.5000	36 × 36	47.27	50.00
B4	6.5224	42 × 42	74.64	75.00
B5	7.6205	48 × 48	104.04	100.00
B6	8.7869	54 × 54	135.27	125.00
B7	10.0163	60 × 60	168.19	150.00
B8	11.3045	66 × 66	202.68	175.00
B9	12.6483	72 × 72	238.66	200.00

Table 3 Comparison of Time Period with Base Dimension (Column Size 0.75m × 0.75m)

Plan	*T* Sec	Base Dimension L × B m	Percentage Variation in *T* %	Percentage Variation in Base Dimension %
B1	3.8429	24 × 24	**Base case**	
B2	4.7107	30 × 30	22.58	25.00
B3	5.6980	36 × 36	48.27	50.00
B4	6.7816	42 × 42	76.47	75.00
B5	7.9487	48 × 48	106.84	100.00
B6	9.1915	54 × 54	139.18	125.00
B7	10.5042	60 × 60	173.34	150.00
B8	11.8825	66 × 66	209.21	175.00
B9	13.3229	72 × 72	246.69	200.00

Table 4 Comparison of Time Period with Base Dimension (Column Size 0.60m × 0.60m)

Plan	*T* Sec	Base Dimension L × B m	Percentage Variation in *T* %	Percentage Variation in Base Dimension %
B1	4.1774	24 × 24	**Base case**	
B2	5.0791	30 × 30	21.59	25.00
B3	6.1060	36 × 36	46.17	50.00
B4	7.2327	42 × 42	73.14	75.00
B5	8.4463	48 × 48	102.19	100.00
B6	9.7380	54 × 54	133.11	125.00
B7	11.1019	60 × 60	165.76	150.00
B8	12.5342	66 × 66	200.05	175.00
B9	14.0324	72 × 72	235.92	200.00

Table 5 Comparison of Time Period with Base Dimension (Column Size 0.50m × 0.50m)

Plan	*T* Sec	Base Dimension L X B m	Percentage Variation in *T* %	Percentage Variation in Base Dimension %
B1	4.72346	24 X 24	**Base case**	
B2	5.68307	30 X 30	20.32	25.00
B3	6.76691	36 X 36	43.26	50.00
B4	7.94961	42 X 42	68.30	75.00
B5	9.21853	48 X 48	95.16	100.00
B6	10.56505	54 X 54	123.67	125.00
B7	11.98386	60 X 60	153.71	150.00
B8	13.47086	66 X 66	185.19	175.00
B9	15.02332	72 X 72	218.06	200.00

Table 6 Comparison of Time Period with stiffness variation (Base case col size 1.00 × 1.00 m)

Plan	Base Dimension	T for Column Size				Percentage variation with col size 1.00 × 1.00		
	L × B m	1.00 × 1.00 sec	0.75 × 0.75 sec	0.60 × 0.60 sec	0.50 × 0.50 sec	0.75 × 0.75	0.60 × 0.60	0.50 × 0.50
B1	24 × 24	3.73	3.84	4.17	4.72	2.89	11.85	26.47
B2	30 × 30	4.56	4.71	5.0791	5.68	3.21	11.28	24.51
B3	36 × 36	5.50	5.69	6.10	6.76	3.60	11.02	23.03
B4	42 × 42	6.52	6.78	7.23	7.94	3.97	10.89	21.88
B5	48 × 48	7.62	7.94	8.44	9.21	4.31	10.84	20.97
B6	54 × 54	8.78	9.19	9.73	10.56	4.60	10.82	20.24
B7	60 × 60	10.01	10.50	11.10	11.98	4.87	10.84	19.64
B8	66 × 66	11.30	11.88	12.53	13.47	5.11	10.88	19.16
B9	72 × 72	12.64	13.32	14.03	15.02	5.33	10.94	18.78

5. CONCLUSION

Results of the analysis are depicted in Tables 2 to 6, in which values of the fundamental period of vibration derived from the analysis are tabulated along with the base dimensions. Separate tabulations are made for column dimensions 1.00x1.00m to 0.50x0.50m. considering the base case as building with base dimension of 24m, values of the time period of different buildings are compared and percentage variations are depicted in these tables, similarly percentage variation of base dimensions are also tabulated.

From the Table 2, it can be observed that the value of T i.e. fundamental natural period of vibration corresponding to first mode of vibration varies from 3.738 sec to 12.6483 sec for a building with base width of 24 m and 72 m respectively having column size as 1.0 mx1.0 m, similarly from the Table 5, it can be observed that the value of T i.e. fundamental period of vibration varies from 4.723 sec to 15.023 sec for a building with base width of 24 m and 72 m respectively having column size as 0.50 m x 0.50 m, against the time period of 2.1915 sec derived on the basis of formula prescribed in the Indian seismic code. It is observed that the time period comes out of dynamic analysis is higher than that derived from code base formula and also one important conclusion can be drawn that value of period of vibration increase with increase in plan area, which ultimately reduces the base shear. Considering the base case as a building with base width of 24 m, variation in time period comes out to be 22.21% to 238.66% whereas in base dimension is observed to be 25% to 200%, hence it can be concluded that percentage variation in time period is almost identical to the percentage variation of base dimension. Similar results are tabulated in table no 3 to 5.

Table 6 depicts the changes observed in value of period of vibration by changing column dimensions from 1.0 m x 1.0 m to 0.50 m x 0.50 m. It is observed that time period increases by almost 26.47% for 24m wide building to 18.78% for 72 m wide building.

In view of the results obtained in the analysis, values of the time period of vibration so derived, differs substantially, and the difference comes out to be on higher side, which results in reduction in base shear and make the structure economical. Further conclusions can be drawn for the changes made in column dimensions i.e. reduction in column sizes increase in the value of time period. Hence period formulae mentioned in seismic codes needs to be reviewed with respect to plan area of the structure.

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