A Study of Fundamental Time Period of Regular Framed Structure Towards Flat Ground

Suvendu Kar[1]*, Sumit Kumar Banerjee[2], Saptadipa Bhattacharyya[3], Himanish De[4], Soumyendu Bhattacharjee[5]

[1]Assistant Professor, Department of Civil Engineering, ABACUS Institute and Engineering & Management (Affiliated under MAKAUT).
[2]Assistant Professor, Department of Civil Engineering, ABACUS Institute and Engineering & Management (Affiliated under MAKAUT).
[3]Assistant Professor, Department of Civil Engineering, ABACUS Institute and Engineering & Management (Affiliated under MAKAUT).
[4]Assistant Professor, Department of Civil Engineering, ABACUS Institute and Engineering & Management (Affiliated under MAKAUT).
[5]Assistant Professor, Department of Electronics and Communication Engineering, ABACUS Institute and Engineering & Management.

Abstract

Determining the natural time period is very crucial for seismic analysis of a structure under typical loading condition. To determine a reinforced cement concrete structure (RCC), natural time period provides a standard empirical formula which has often been used by the researchers in this domain. After performing the modal analysis of several framed structures (with different stories in STAAD. Pro v8i 556), It has been noted that there exists a discrepancy in the natural frequency output as determined by modal analysis in STAAD. Not only that, manual calculation using Code based provisions must not be sufficient to come into a conclusion. But it can be concluded that the empirical formula used to determine the structure's natural time period must consider a number of other variables in addition to the structure's total height. In this research work, using our proposed modal, we observed that the variety rises over time as the number of stories grows. Additionally, it has also been seen that the time period grows noticeably as the stored number increases.

Key Words: *Time Period, Natural Frequency, Regular Frame, RCC, Model Analysis.*

Introduction

An examination of a structure's resistance to several forces, including wind and earthquakes, is necessary to ascertain its stability. When an earthquake occurs, the lateral oscillation of the structure due to ground motion induces deformations in that direction, which may lead to the structure collapsing. Finding the structure's Natural Time Period is a prerequisite to analysing its stability during an earthquake. According to IS 1893 (PART I) 2002, the natural time duration depends on the structure's height and base dimension. However, following extensive investigation and analysis, we have concluded that a wide range of factors can influence a structure's natural time period, in addition to base dimension and total height. When designing Reinforced Concrete (RC) framed structures in the northeast, earthquake loads must be taken into consideration. A natural time span is crucial for this study. Thus, in earthquake design, determining the natural time period is crucial. It is rather simple to construct the structure further under certain seismic inputs based on natural time periods. The duration of time is contingent upon factors such as the mass, stiffness, and structural integrity of the object. Furthermore, these variables interact with the natural time period is also influenced by a number of other variables, including ground slopes, beam column dimensions, storey height, number of bays, loading patterns, structural irregularities, and reinforcing. The formula for calculating the natural time period on an RC frame structure without infill is provided in IS 1893(PART I) 2002. This formula only takes the building's overall height into account when using the seismic coefficient method to evaluate and design base shear and lateral forces caused by the building's seismic effect. However, these empirical calculations fail to consider the impact of several factors when determining the duration. Numerous studies are currently underway to ascertain the Fundamental Time Period (FTP) for framed RC structures due to the absence of suitable correlations. In this case, a brief investigation of the time period fluctuation with storey height change is conducted utilising STAAD and modal analysis in accordance with IS 1893(PART I) 2002.Pro V8i SS6.Different story buildings are subjected to typical load combinations based on IS 456. Modal analysis is conducted within the STAAD software, and the natural time period is subsequently computed using the program. Subsequently, it is calculated manually following the guidelines outlined in IS 1893 (Part I) 2002, and any discrepancies in the outcomes are observed.

Fundamental Time Period of Regular Framed Structure: A Literature Review

Over the course of several years, the fundamental examination of FTP has been the subject of extensive investigation, which is crucial for understanding seismic activity in structures. The basic time period of the structure can be established using the empirical formula outlined in IS 1893 (Part I) 2002. This expression suggests that the FTP is exclusively determined by the base size and overall building height. However, a number of studies have shown that in addition to those two elements, there are additional variables that also significantly affect how natural time periods are calculated and analysed. Basement stories where the walls are attached to the building columns are excluded. It does, however, offer basement levels without these connections. Clause 7.6.2 further elucidates that the practical depiction is applicable for approximating the Ta (FTP) of various structures, encompassing those featuring moment-resisting frames coupled with brick infill panels. Researchers undertook an extensive regression analysis to propose a modification to the code-based empirical formula for calculating FTP periods. This modification was based on the examination of approximately 417 frames, each characterized by varying slopes, numbers of stories, and spans. The study's findings helped identify the FTP for RC frames situated on sloped surfaces. The influence of ground slope has been considered in the suggested formula, and an analogous height parameter has also been added to affect stiffness and mass irregularity. Based on nonlinear pushover (NSP) analysis and incremental dynamic analysis (IDA) methods, Kar et al. (2018) investigate the nonlinear seismic behaviour of RC buildings on hill slopes. They found that buildings on slopes have lower ductility reduction factors and total response reduction factors than buildings on flat terrain. In a parametric analysis on a structure's time period, Cutinha et al. (2018) found that the number of storeys, beam, column, and bay dimensions, in addition to the structure's height and base dimension, all influence the structure's time period. To establish the inherent dynamic characteristics of the system, including its natural frequencies, damping coefficients, and modal patterns, for constructing a mathematical representation elucidating its dynamic response. The method in question is frequently called "Modal Analysis". The representation in mathematics that results from using this data to reflect these features is titled the modal model of the system, and the data itself is referred to as the modal data. The following empirical formulas are applicable for predicting the theoretical FTP (Ta) in seconds for moment-resisting frames lacking brick infill panels, as per IS 1893(PART I)2002:

$\boldsymbol{T_a = 0.075h^{0.75}}$ for RC frame building

$\boldsymbol{T_a = 0.085h^{0.75}}$ for steel frame building

Where 'h' represents the building height in meters. For all other buildings, as well as those with moment-resisting frame structures and brick infill panels, the empirical formula for determining the estimated FTP (Ta) is as follows:

$T_a = \frac{\boldsymbol{0.09h}}{\boldsymbol{\sqrt{d}}}$, Where

In this case, 'h' indicates the building's vertical measurement, while 'd', contemplating the lateral force's direction, is the dimensions of base framework of the building, measured precisely at the plinth in meters. In their study, De et al. (2018) examined FTP of RC frames positioned on sloping terrain. Their analysis involved an extensive regression study of free vibration conducted on around 417 frames with varying slopes, numbers of stories, and spans. Subsequently, they proposed a modification to the existing code-compliant empirical expression used for calculating FTPs. Notably, their modified formula acknowledges the consequence of ground slope and introduces an additional parameter, referred to as the equivalent height, to address variations in stiffness and mass distribution. Kar et al. (2018) investigates Nonlinear seismic behavior of RC buildings on hill slopes based on nonlinear pushover (NSP) analysis and incremental dynamic analysis (IDA) methods and found out that the ductility reduction factor and the overall response reduction factor obtained for buildings on slope are less as compared to buildings on flat ground. Cutinha et al. (2018) done a Parametric study on time period of a structure and observed that not only height and base dimension of structure is involved in time period determination but also number of storeys, beam dimension, column dimension, number of bays affects the time period. Singh et al. (2011)

analyzed Seismic Behavior of buildings located on slopes and observed that in hilly areas buildings have to be configured differently due to scarcity of flat ground A system's inherent dynamic characteristics, such as its natural frequencies, damping factors, and mode shapes, are all identified through the process of modal analysis. A mathematical abstraction that depicts the system's responsive behavior is created using these properties. The data that describes these properties is called modal data, and its mathematical representation is frequently referred to as the system's modal model. In modal analysis, we address the following:

$[K]\{x_i\} = \lambda_i[M]\{x_i\}$ where i=1, 2, ……. n
$\lambda = \omega^2$ and $\{x_i\}$ =mode shape vector

In employing the Eigenvalue method, researchers typically define the command for modal calculation within the specified load case, ensuring that the load data for the mass matrix are explicitly provided.

Novelty of the work:

When evaluating the seismic resilience of frames made of reinforced concrete, the FTP is crucial in order to determine the duration, or more accurately, the natural duration, IS 1893(PART I) 2002 offers an empirical calculation that takes into account the building's overall height as well as its base measurement. However, in our modal analysis using STAAD.Pro V8i SS6, we have observed that the time period calculated by the software tends to be slightly higher compared to the results obtained from the IS code-based formula. By running the modal analysis in almost 5 different RC framed Structure with same number of bays but different storey number we observe the variation is in every RC frame. Code based provisions are not sufficient for determination of FTP of frame structurers.

Basic Theory of Time Period and Frequency:

All objects tend to vibrate in application to various forces. The oscillatory movement of a structure, characterized by its back-and-forth motion from its resting position, defines oscillation. The duration required to complete a single oscillation is known as the oscillation's time period. The frequency of oscillation is recognised as the number of oscillations for every unit of time in seismic analysis, determining the time period of a framework is of utmost importance. For RC structures, the time period (Tn) is intricately linked to both mass and stiffness, and it is defined as follows:

$$T_n = 2\pi\sqrt{\frac{m}{k}} \quad \text{(sec)}$$

Where,

T_n denotes the time period, with m representing mass and k representing stiffness. The frequency (f) is characterised as the reciprocal of the time period: $f = \frac{1}{T_n}$ measured in Hertz (Hz). Global seismic building standards often provide simple empirical calculations based on the frame's tallness and foundation breadth to estimate the FTP (T) for building frames. For moment-resisting frames with brick infill panels, the observation-based formula below is functional to derive an approximate FTP (Ta), in seconds:

$Ta = 0.075h^{0.75}$ for RC-framed building
$Ta = 0.085h^{0.75}$ for steel frame building

Here, h stands for the vertical stature of the building, specified in meters. When the basement walls are attached to the building columns, the basement storey is not included in this measurement. On the other hand, when they are not as connected, it includes the basement floor. This implies that the empirical expression can be used to predict the value of Ta, in seconds, for all other buildings, including moment-resisting frame buildings with brick infill panels:

$$T_a = \frac{\mathbf{0.09}\boldsymbol{h}}{\sqrt{\boldsymbol{d}}}$$

A mode shape represents the deformation that a structure exhibits when vibrating at its natural frequency. A mathematical abstraction of a system's dynamic behavior is created through the process of modal analysis, which identifies a system's intrinsic oscillatory attributes such as eigenfrequencies, damping factors, and eigenmodes. The data that describes the properties of this mathematical model is called modal data, and the model itself is identified by the modal model of the system. We deal with modal analysis.

Our Proposed Model and Description of Structure:

2,3,4 and 5 storey buildings with 4 number of bays in all direction is first designed manually and then it is modeled in STAAD.Pro considering the designed dimensions, specific loadings. Then modal analysis is requested and from that natural frequency mass participation in each no of modes and frequency is obtained. A manual calculation is also done using the specific empirical formula provided in section 7.6 of IS 1893(PART I) 2002.

Building Specification

Table 1: Building Specification

No of Storey	G+1, G+2, G+3, G+4
Bay Number (X Direction)	4
Bay Number (Y Direction)	4
Spacing of Each Bay	3m
General Beam Dimension	300mm×400mm
General Column Dimension	350mm×350mm
General Slab Thickness	100mm
General Storey Height	3.2m
Garde of Concrete	M25
Grade of Steel	Fe415

Loading Details

- Weight if water proofing treatment on roof=4.0kN/m^2
- Weight of floor finish=0.25×1.0×1.0×20=0.5kN/m^2
- Live load on floors=4.0kN/m^2
- Live load roof (considering accessible) =1.5kN/m^2
- Load on account of accidental accumulation of rainwater=3.0kN/m^2
- Weight of wall (peripheral enclosure wall) =0.23×3.2×20=14.72kN/m
- Weight of parapet=0.115×0.3×20=0.69kN/m

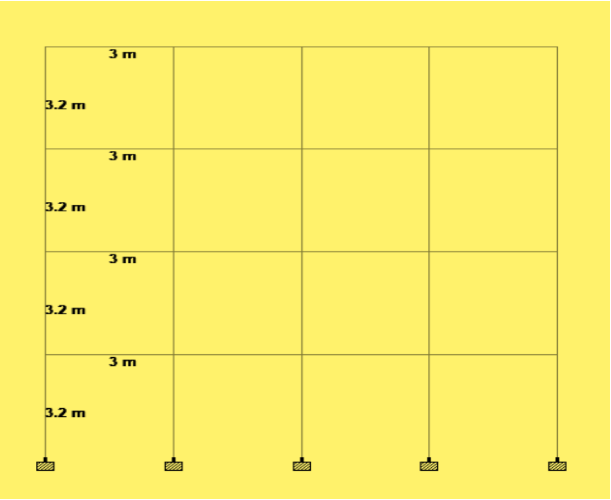

Figure I: Top View of the proposed structure

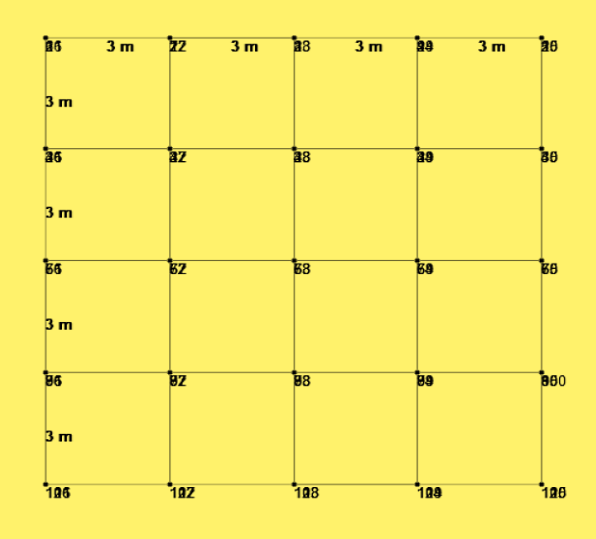

Figure II: Front View of G+3 Modeled Structure

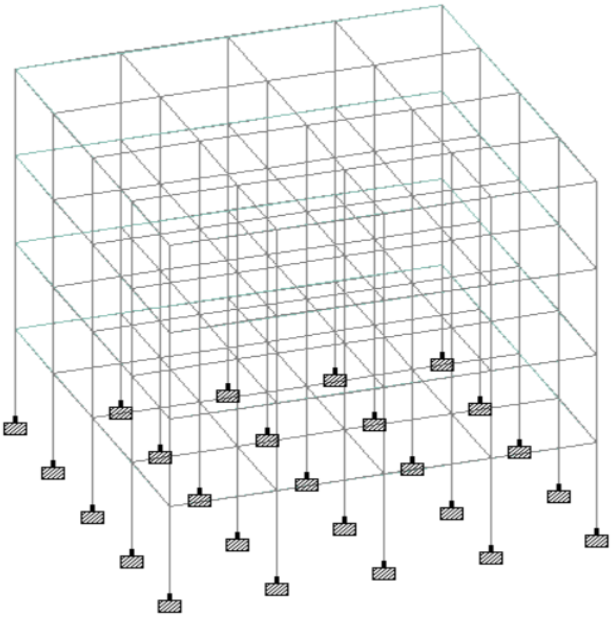

Fig III: 3D framed View of G+3 Structure

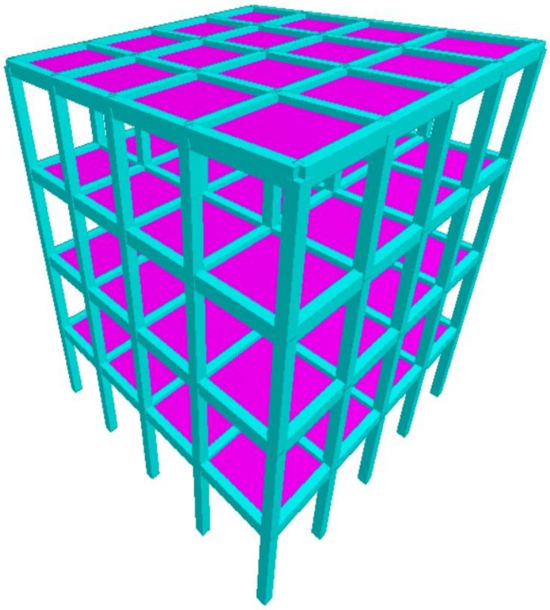

Fig IV: 3D rendered View of G+3 Structure

Observation and Results

We have modeled nearly five different multi-storied structures and observed discrepancies between the data obtained from the software after conducting modal analysis and the results of manual calculations. The investigation results are demonstrated in tabular form below;

Table 2: Comparison of FTPs Obtained using IS Code and Modal Analysis

Sl.No.	No of Storey	FTP (T, sec) - Modal Analysis	FTP (T_n, sec) - IS CODE
1	2	0.31386	0.30178
2	3	0.45473	0.40904
3	4	0.62156	0.50754
4	5	0.77945	0.60000

The FTP obtained by the IS code-based formula and through modal analysis in STAAD is compared in Table 2 for different numbers of storeys.

Subsequently, the obtained results are plotted on different graphs to observe the trend in the dissimilarity of time period with the number of storeys.

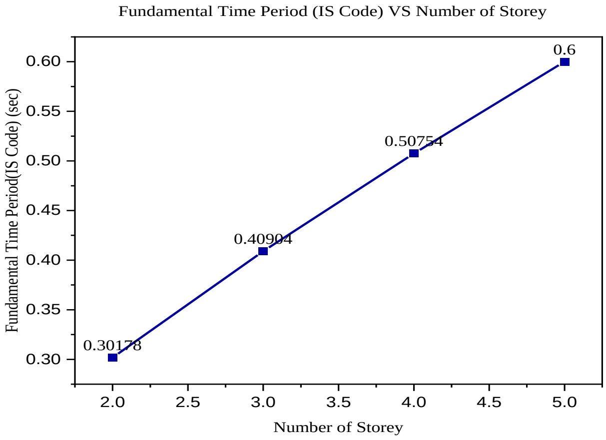

Figure V : The variation of FTP (manual calculation using IS Code) with no of storeys of building

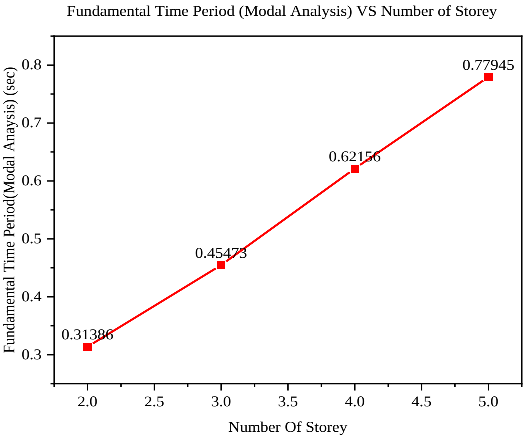

Figure VI : The variation of FTP (Modal analysis) with no of storeys of building

The FTP, determined through modal analysis and according to the IS code, has been graphed against the number of storeys in Figure VI and Figure VII, respectively. From these curves, we observe how the FTP varies with the increase in storey numbers, indicating a trend of increasing time period with height due to the increase in mass but decrease in overall stiffness. Additionally, to further analyze this variation, another graph has been plotted in Fig. 3, showing how the time period upsurges with an increment in building storeys.

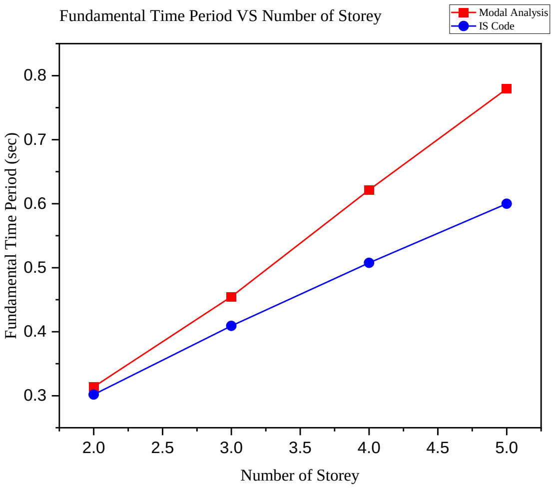

Figure VII: FTP VS Storey Number

In modal analysis, the entire mass of the structure does not participate in the first mode, but the involvement of mass gradually increases in each subsequent mode. The participation of mass in each mode in each structure is shown in Table 3. Accounted the mass participation of first 6 modes in the analysis. It concludes that the whole mass is not participated at the very first time when a ground excitation hits the structure.

Table 3 Mass Participation in each Mode

Sl. No	No of Storey	Mode	Mass Participation
1	2	1	86.005
		1+2	86.005
		1+2+3	89.406
		1+2+3+4	97.814
		1+2+3+4+5	97.814
		1+2+3+4+5+6	97.814
2	3	1	84.974
		1+2	84.974
		1+2+3	93.473
		1+2+3+4	95.477
		1+2+3+4+5	95.477
		1+2+3+4+5+6	97.558
3	4	1	83.975
		1+2	83.975
		1+2+3	94.545
		1+2+3+4	94.545
		1+2+3+4+5	98.233
		1+2+3+4+5+6	98.333
5	5	1	82.628
		1+2	82.628
		1+2+3	93.259
		1+2+3+4	93.259
		1+2+3+4+5	97.233
		1+2+3+4+5+6	98.116

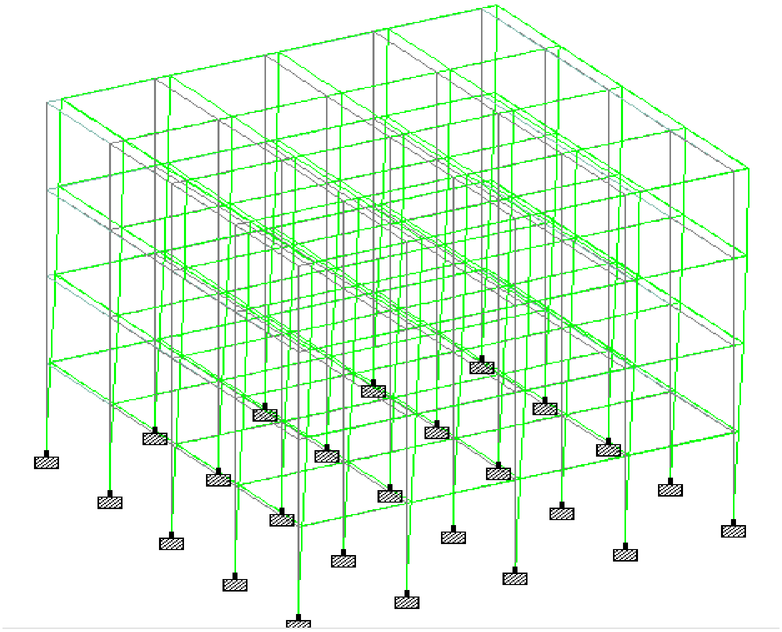

Fig VII: Deformation of the structure in Mode 1 after applying all the loads

After reviewing all the results and graphs of the examination, it becomes evident that the FTP of the structure rises with an increment in building storeys. Moreover, the variation in both FTPs increases as the number of storeys rises, attributed to the increased mass of the structure and the corresponding decrease in overall stiffness.

Conclusion

It is observed that due to increase in overall mass and decrease in overall stiffness the time period increases with increase in overall height of the structure in both the cases. The variation of those two-time period is increasing with increase in storey number. By those analyses it is clear that the Natural time period should not only be governed by overall height of structure there should be other parameters which are also responsible for affecting the FTP. Such as Ground Slopes, Structural integrity, Irregularity of structure Beam Ratio, Column Ration No of bays and may be other several factors. The graphs have been showing that the FTP is varying almost linearly with the Number of Storey in both the cases in the case of zero sloping ground but it may be not the case in the sloping ground. Mass participation is not fully accounted at the initial phase of ground excitation. As the no of mode increases mass participation will be higher. Normally, it contributes above 95% after reaching to fourth mode.

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