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Study on Natural Frequency of Low Rise RC Frame Building

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ABSTRACT: In general, the effect of dynamic load is not considered because its consideration in analysis makes the solution more complicated and time consuming. Therefore, the majority of Civil Engineering structures are designed with the assumption that all applied loads are static. This feature of neglecting the dynamic forces may sometimes become the cause of disaster, particularly, in case of earthquake. Some recent earthquakes have shown the need of dynamic analysis. Nowadays, there is a growing interest in the process of designing Civil Engineering structures capable to withstand dynamic loads, particularly, earthquake-induced load.Simple empirical relationships are available in many design codes to relate the height of a building to its fundamental period of vibration. These relationships have been realised for force-based design and so produce conventional estimates of period such that the lateral shear force will be conservatively predicted from an acceleration spectrum. When assessment of a structure is concerned, it is the displacement demand that gives an indication of the damage that can be expected. In this paper, the fundamental periods of a low rise building is studied using empirical formulae from IS 1893(Part 1) and finite element modelling in SeismoStruct. The results are compared and the factors are discussed on which fundamental period of a structure depends.

KEYWORDS: Fundamental Period, Reinforced Concrete Buildings, Dynamic Analysis, Lumped Mass System, Eigen Value Problem

I. INTRODUCTION

Natural disasters in the recent years have shown the world, their destructive power in terms of loss of life and property. Earthquake is one such hazard, which has resulted in heavy economical losses. More than 55% land are of Indian subcontinent is vulnerable to earthquake forces. The earthquake events in recent few decades show the necessity of earthquake engineering in India. Such hazards cannot be prevented; however, one can minimize their effects by designing the structures as per seismic codes. IS 1893: 2016 is framed keeping in mind the life safety aspect and collapse prevention of the structures and to satisfy these objective it is necessary for the structures to respond toexpected earthquake ground motions.

The estimation of the fundamental period of vibration plays a vital role in earthquake design of new buildings and performance assessment of existing structures. Stiffness, mass and strength along the height of a building influence the natural period. There are many other factors, which affect this property such as section dimensions, structural regularity, building height, number of bays and storeys, shear walls and infill, load position, soil flexibility, reinforcement ratio and extent of concrete cracking. [1, 2]The difficulty in evaluating these variables is a laborious task for the estimation of the fundamental period of a building.Eigenvalue or pushover analyses are carried outwith relative ease to compute the fundamental period of RC structures. However, performing computer analysis for the estimation of period for each structure in urban area becomes inadequate. Consequently, many empirical methods are used different classes of buildings.

There are two types of load: Static and Dynamic, which acts on a structure. Static loads are constant with time whereas dynamic loads are vary with time. Dynamic analysis and study on the response of structures excitation is more time consuming and complicated as compared to static analysis. Dynamic analysis involves the equation of motion of the structure, which is required to find the modes of vibration with the corresponding natural frequencies [3]. The lateral seismic loadsdependupon the fundamental period of the structure, which are required to be determined

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theoretically or experimentally [4]. Natural frequency has a significant role in dynamic design without involving heavy dynamic testing [5]. To determine the natural frequency and modes of vibration of structure free vibration analysis is used. Modal analysis is performedto record the free vibrational response of the structure [6].

Moment resisting frame (MRF) structures are mainly used nowadays because of their high lateral stiffness and substantial resistance to earthquakes. The researchers used different types of MRF structures to find most reliable structures under seismic load. The study showed that structures reached resonance condition under short time and to avoid this problem, the fundamental Eigen frequency should be maximized in high-rise building [7]. Many researches indicate height as the main parameter to determine the fundamental period of RC moment resisting frame structures [8–11]. Butthere are a few studies on fundamental period of steel frame structures.

The rapid evolution in the field of computer scienceover the last few decades has led to the occurrence of various Finite Element softwares focusing on the numerical solution of structural problems. Some of the previous studies has made use of different computer programming and softwares such as STAAD-pro, ANSYS, SolidWorks and SAP2000 for free vibration analysis and modal analysis to determine the natural frequency of the structure [12-16]

Thisstudy is based on modal analysis of MRF structures using SeismoStruct software to study the natural frequency and free vibration analysis is investigated as per IS 1893:2016. The results are compared of both theoretical analysis and finite element analysis.

II. SEISMIC ANALYSIS AS PER INDIAN CODE

IS 1893(Part 1): 2016 [17] provides the guidelines and provisions for earthquake resistant design. It adopts equivalent static method, response spectrum method and time history method for analysis of structures. When ground shakes, a building vibrates and natural period of time is required for free vibration of the building structure. Generally, the first mode of free vibration is critical because of high resonance risk, whereas the other modes of vibration could be critical for high-rise structure, which are assumed less critical than the natural period for low-rise building [16]. Earthquake forces deflect a structure into number of shapes, known as the natural mode shapes, which depends upon the degree-of-freedom of the system. For structural idealisation we convert an infinite degree-of-freedom to finite degree of freedom system lumped mass model by assuming the mass of the building lumped at each floor level (called node); with one degree of freedom in the directionof lateral displacement at each storey.The empirical formulas developed to estimate the fundamental period of oscillation (T_a)are given in Equations 1, 2 and 3.The fundamental period is a parameter for estimating the base shear for a structure, thus it should be sound accurate in order to prevent unsafe design.

For RC frame building without infills,

$$Ta = 0.075\ h^{0.75}\ \text{sec} \quad (1)$$

For steel frame building without infills,

$$Ta = 0.080\ h^{0.75}\ \text{sec} \quad (2)$$

For all other buildings with infills

$$Ta = \frac{0.09h}{\sqrt{d}}\text{sec} \quad (3)$$

Where

h = height (in metre) of building excluding basement storey, when walls are connected with ground floor deck but including basement storeys when they are not so connected.

The fundamental period depends upon stiffness and mass of the structure, which are not included in the above equations. So the code specifies the use of dynamic analysis which requires other periods and shapes of natural modes. In this procedure, mass matrix and stiffness matrix are calculated for equivalent model and using these stiffness and mass matrices, a generalized eigenvalueproblem is formed to compute natural frequencies and thecorresponding mode shapes.

III. CODE BASED SEISMIC ANALYSIS

The fundamental period of low-rise RC frame structure is examined in this study. Building frame is regular in plan and consists of beams and columns.The building is symmetric along X and Y-axes having plan dimensions 50m X 8m and floors having same height of 3.1m. The Building parameters are listed in the table 1 and the elevation, lumpedmass model and plan of the building are shown in figure 1,2 and 3.

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Table 1: Building Parameters

Type of structure	Multi-storey Moment resisting frame
Number of stories	Three , (G+2)
Floor height	3.1 m
Materials	Concrete (M 25) and Reinforcement (Fe415)
Live load	3kN/m^3
Size of columns	500mm X 500 mm
Size of beams	400mm X 500 mm
Specific weight of RCC	25 kN/m^3

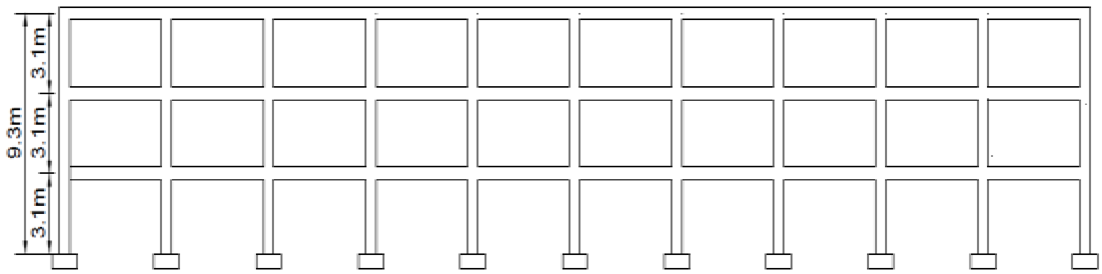

Figure 1: Elevation of the building

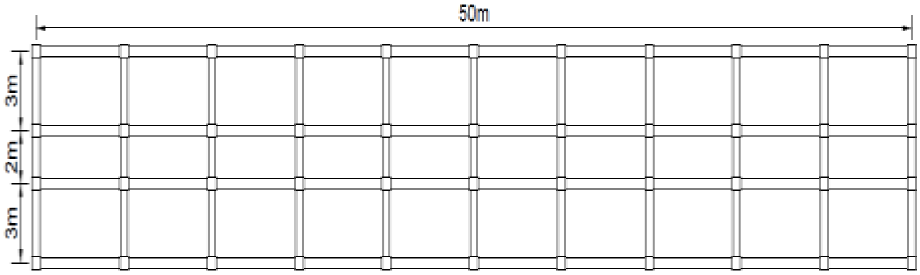

Figure 2: Plan of the building

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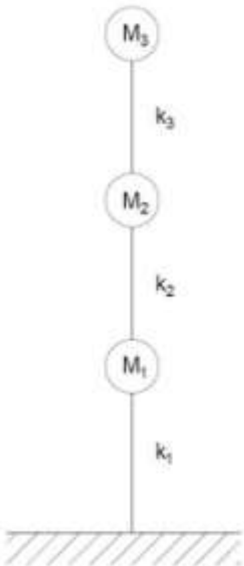

Figure 3: Lumped mass model

The mass (M) and stiffness (k) of each floor is computed and matrices are formed. These are as follows:

$$M = \begin{bmatrix} M1 & 0 & 0 \\ 0 & M2 & 0 \\ 0 & 0 & M3 \end{bmatrix} = \begin{bmatrix} 264271 & 0 & 0 \\ 0 & 264271 & 0 \\ 0 & 0 & 190.239 \end{bmatrix}$$

$$K = \begin{bmatrix} k1 + k2 & -k2 & 0 \\ -k2 & k2 + k3 & -k3 \\ 0 & -k3 & k3 \end{bmatrix} = \begin{bmatrix} 4615487900 & -2307743950 & 0 \\ -2307743950 & 461548790 & -2307743950 \\ 0 & -2307743950 & 2307743950 \end{bmatrix}$$

Solving equation (4) the natural frequency, time period and Eigen values are calculated

$$|K- \omega^2 M| = 0 \qquad (4)$$

IV. FINITE ELEMENT ANALYSIS IN SEISMOSTRUCT

The nonlinear finite element program SeismoStruct [18]has been chosen to model the frames and subsequently to do the Eigen value analysis. Building has beenidealized as three-dimensional space frame using two node frame elements. The 3D model is shown in the figure having plan dimensions 50m X 8m.

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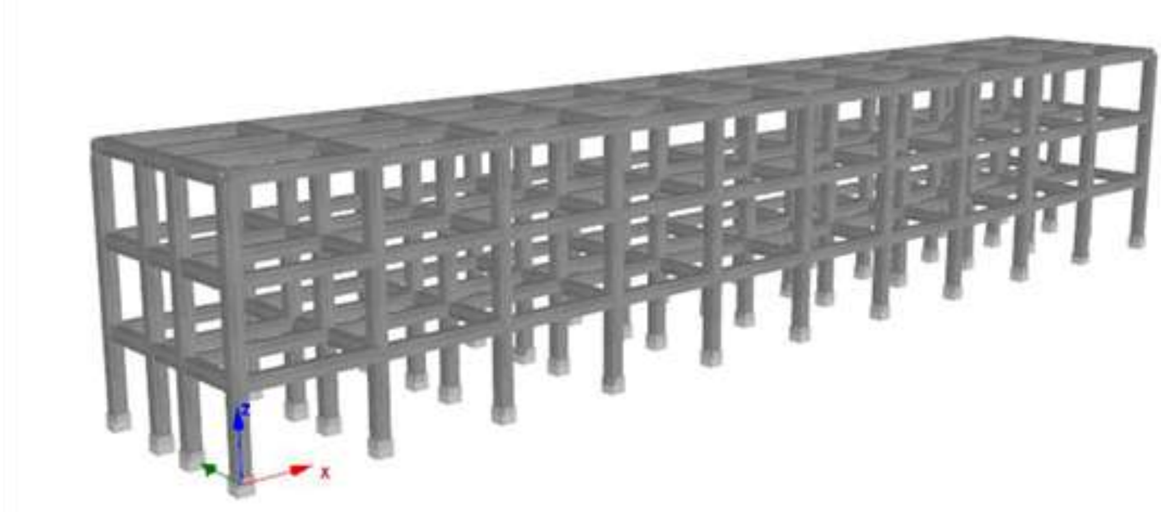

Figure 4:3D model of building in SeismoStruct

The models of Mander et al. [19]have been used for modelling the cyclic behaviour of concrete specimens, which uses a unique expression for the monotonic envelope and specific cyclic rules. The nonlinear behaviour of reinforced concrete members is highly controlled by the reinforcement. Therefore, steel models for longitudinal bars are extremely important to compute the flexural behaviour of a reinforced concrete section, and especially when it is subjected to load reversals. The Menegotto and Pinto [20] model is used for modelling the steel cyclic behaviour, where the characteristic softening of the curves in the reloading branches is automatically considered. The Menegotto and Pinto model has also been included in several studies for its simplicity and efficiency.

Table 2: Concrete Mander et al model parameters

Mean compressive strength (kPa)	30000.00
Mean tensile strength (kPa)	2200.00
Modulus of Elasticity (kPa)	25742960.20
Strain at peak stress	0.002
Specific weight (kN/m^3)	25.00
Confinement Factor	1.2

Table 3: Menegotto-Pinto steel model parameters

Yield strength (kPa)	415000.00
Modulus of Elasticity (kPa)	200000000
Strain Hardening Parameter	0.005
Specific weight (kN/m^3)	78.00

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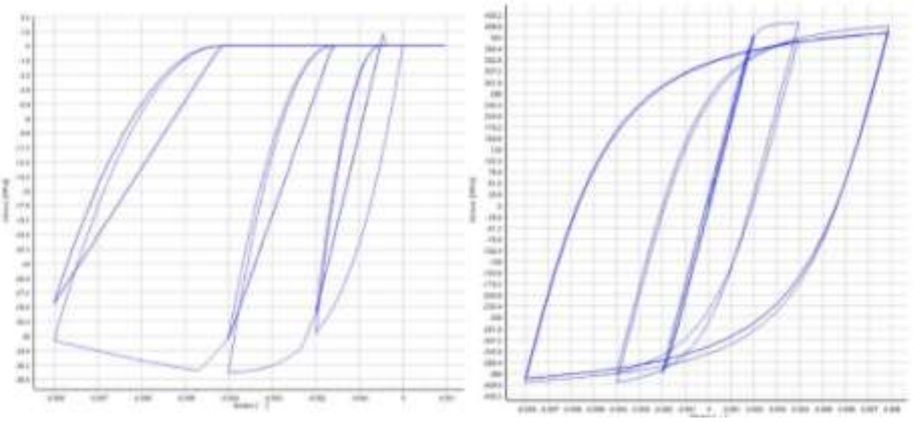

(a) (b)

Figure 5: Constitutive relationships for (a) concrete and (b) reinforcement steel.

Reinforced concrete sections are defined for column and beam sections in SAP 2000 and SeismoStruct. Column sections having cross section of 0.5m x 0.5m and beam sections having cross section of 0.4m X 0.5m are used throughout the model. The structural detailing is shown in Fig 3. The sectional stress-strain state of inelastic beam-column frame element is obtained through the interaction of the nonlinear uniaxial stress-strain response of the individual fibres into which section is subdivided. A fibre-based finite element approach is adopted to model the building with SeismoStruct. Inelastic plastic hinge force based element is used in SeismoStruct for both beam and column with an adequate discretization.

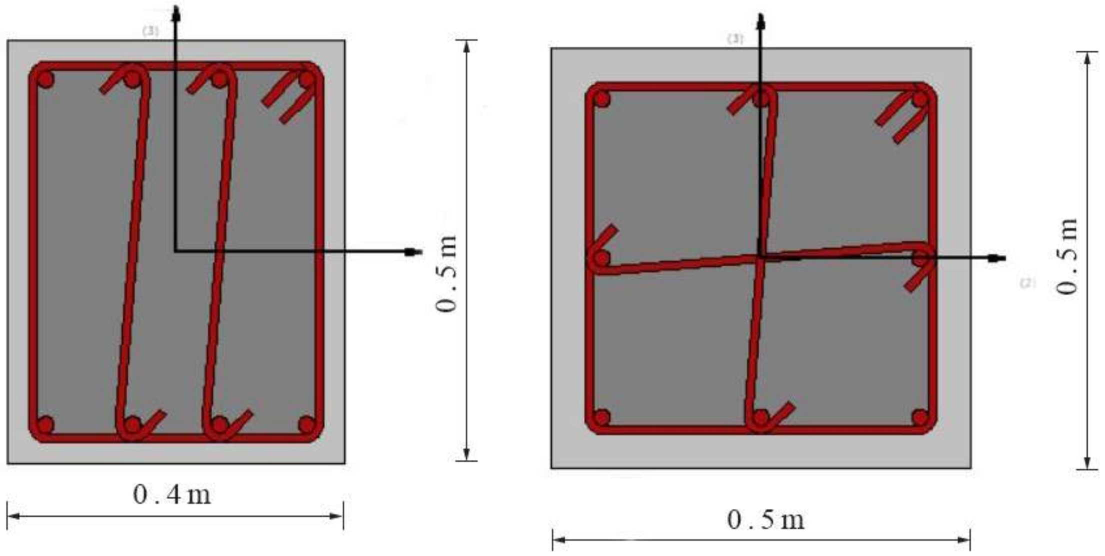

Figure 6: Beam and Column cross-sections

V. RESULTS AND DISCUSSION

The fundamental period from both the approaches are tabulated and compared. The fundamental mode for theoretical and numerical analyses are estimated to be 0.14s and 0.178s. The natural frequencies and natural periods from both methods are shown as follows:

Table4: Natural frequencies and time periods from both approaches

Modes	Theoretical Analysis		SeismoStruct Analysis	
	Natural frequency, ω(rad/sec)	Natural Time period,T (sec)	Natural frequency, ω(rad/sec)	Natural Time period,T (sec)

Mode 1	45.1	0.140	33.42	0.178
Mode 2	124. 21	0.051	35.62	0.176
Mode 3	172.24	0.036	40.50	0.155
Mode 4	-	-	51.53	0.122
Mode 5	-	-	102.77	0.0611
Mode 6	-	-	105.60	0.0595
Mode 7	-	-	108.89	0.0577
Mode 8	-	-	145.91	0.0431
Mode 9	-	-	178.44	0.0352
Mode 10	-	-	181.40	0.0346
Mode 11	-	-	294.33	0.021
Mode 12	-	-	349.62	0.018

SeismoStruct uses Jacobi algorithm with Ritz transformation, to solve the Eigen values so 12 modes are generated whereas in theoretical analysis three modes are generated as the multi- degree freedom system has been idealised into single degree of freedom system.The modal mass $M_k$are calculated as per IS 1893(Part 1): 2016 using equation

$$M_k = \frac{[\sum_{i=1}^{n} W_i\, \varphi_{ik}]2}{g[\sum_{i=1}^{n} W_i\, \varphi_{ik}]2}$$

Where
g = acceleration due to gravity
φ_{ik} = mode shape coefficient at floor i
W_i = seismic weight at floor i of the structure
N = number of floors of the structure
The fundamental frequencies and modal mass of the three modes are compared and relative percentage of error is calculated.

Table 5: Comparison ofnatural frequencies

S.N	ω(theoretical)			ω(SeismoStruct)			% of error in ω		
	ω_1	ω_2	ω_3	ω_1	ω_2	ω_3	e_1	e_2	e_3
1	45.1	124.41	172.24	33.4	102.77	178.4	35	21	4

Table 6: Comparison of modal mass

S.N	M(theoretical)			ω(SeismoStruct)			% of error in ω		
	M_1	M_2	M_3	M_1	M_2	M_3	e_1	e_2	e_3
1	91%	7.6%	2.89%	86%	10.84%	3.19%	6	29	9

VI. CONCLUSION

An investigation has been performed on the natural period of vibration of low-rise by means of codal design analysis and finite element modelling. For this, a 3-storey RC frame building has been considered. The natural periods and frequencies obtained from the eigenvalue analysis in SeismoStruct were compared against the period obtained from IS 1893: 2016.Some conclusions can be drawn from this study, which can be applied, to full-scale structures.The fundamental frequency of structure decreases with decreasing stiffness and increasing height of structures the stiffness and mass of the structure is dependent on the dimension of the column elements. Thus, any change in column dimension abruptly alters the dynamic behaviour. The results of numerical model are satisfactory with the theoretically analysed results as the relative error is in the range (1-35). Some of the reasons are material elasticity and structural rigidity with lumped massare considered in theoretical analysis while there is no idealisation in SeismoStruct. SeismoStruct provides more generalised and realistic results of fundamental period.

Nonlinear analysis such as pushover analysis and time history analysis can be performed on this building to simulate the plastic behaviour of critical sections of the structure. Many researchers and designers are adopting these methods to estimate the seismic performance of the structures.

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