Assessment of Fundamental Natural Period of RCC Buildings

Ajaya R Prabhu, Premanand Shenoy, Katta Venkataramana

Abstract— **Earthquake Resistant Design (ERD) of structures is considered as an important aspect in the field of structural engineering. This generally begins with determination of the Fundamental Natural Period (FNP) of the building, which is essential to calculate the Design Base shear and Lateral forces. Most of the seismic codes specify empirical formulae to estimate the FNP of buildings, which can be used for both low and medium rise buildings. This research work is an attempt of comparing approximate FNP recommended by the IS 1893-2002 (Indian primary seismic code) with the FNPs obtained by the Eigen value analysis of Buildings modeled as MDOF systems. Numerical studies are carried out for RC moment resisting frames (without infill walls) for various functional uses like residential, commercial and FNPs of all these cases are compared with code recommended values (CRVs). In addition to this, effects of Mass and Stiffness variations on the Fundamental mode of the structure and effect of Grade of the concrete on the FNP is studied.**

Index Terms— **Fundamental Natural Period (FNP), Mass Ratio, Stiffness Ratio, Code Recommended value (CRV).**

I. INTRODUCTION

Earthquake Resistant Design (ERD) of structures has gained much importance these days with the devastating experiences human race has witnessed. With the advent of research in the dynamic behavior of structures, structural engineers have been able to reduce the ill effects of earthquakes, especially in saving human life and property. While no structure can be entirely immune to damage from earthquakes, the goal of earthquake-resistant construction is to make structures that behave better during seismic activity than their conventional counterparts. Even though it was neglected or avoided in the last century, its importance has been realized in present days. Determination of the FNP of a reinforced concrete structure is an essential procedure in the assessment of design base shear required for ERD. Though FNP primarily depends on mass, stiffness, total height and strength of the structure, it is influenced by many factors like structure regularity, number of stories and bays, infill panel properties, section dimensions, axial load level, reinforcement ratio and extent of concrete cracking (Hadzima-Nyarko et al., [1]). The fundamental 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 storeys. The empirical formula suggested by Goel and Chopra [2] adopted in most of the seismic design codes, does not incorporate the effect of parameters such as the plan area, functional use and symmetry of the buildings (Cinitha. A. et al. [3]). The Indian seismic Code IS 1893-2002 (part1) [4], has recommended an empirical relation for determination of FNP of the RCC structure given by,

$$T = 0.075 \times h^{0.75} \qquad \text{(Eq. 1)}$$

Where, T = FNP of the building in seconds
h = Height of the building in meters

This formula is based only on the height (h) of the structure and does not take other factors into consideration. In this research, FNPs of RC moment resisting frames has been determined by carrying out numerical studies, based on the functional use of the buildings and compared with the CRVs. Residential, Commercial and Commercial cum Residential buildings are considered in the research and each case is compared with the CRVs for various Heights. After this the effect of mass and stiffness variations on fundamental mode of vibration of the building is studied. Percentage of fundamental mode participation for various mass ratios between the floors, for constant stiffness is initially carried out and the same is done with the stiffness by keeping the mass constant. Finally a brief analysis is done to understand the nature of variation of FNP of the structure considering different Grades of concrete across the stories.

II. MODELING &METHODOLOGY

A Modeling

Buildings are modeled as Moment resisting frames assuming rigid connection between beams and columns and beams with infinite rigidity. All the mass is assumed to be concentrated at the floors levels (Lumped Mass), i.e., concentrated mass has only one degree of freedom (translation) in the direction of horizontal accelerations. Centre to Centre dimensions are adopted in calculation of lumped mass of the elements and columns are considered as massless units with adequate stiffness. Thus a MDOF mass- spring system is modeled. Also Damping in the system has been neglected. Modeling of the structure is indicated in the Fig.1.

Ajaya R Prabhu, Post-Graduation Student , Department of Civil Engineering, National Institute of Technology, Karnataka, Surathkal, India. Tel : +91 8746825756

Premanand Shenoy, Research Scholar , Department of Civil Engineering, National Institute of Technology Karnataka, Surathkal ,India. Tel : +91 9845083343

Katta Venkataramana, Professor , Department of Civil Engineering, National Institute of Technology, Karnataka, Surathkal India. Tel : +91 9448475875

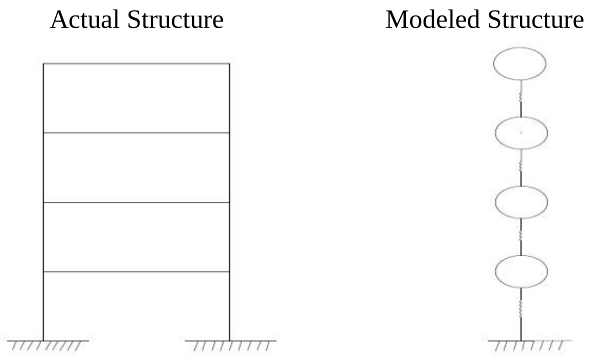

Fig.1. Modeling of the frame

B. Methodology

Eigenvalue approach is adopted to solve the natural frequencies (or Natural periods) of the modeled MDOF system. In order to solve the Eigen value problem, a program is developed in VB6 compiler. This program is fed with the lumped mass and stiffness of all storeys essentially provided natural frequencies (Eigen values) and mode shapes (Eigen vectors) of all the vibration modes. Eigen vectors are also normalized in the program to get clear idea about nature of vibration modes. Gross Moment of inertia of columns have been considered in calculation of stiffness of columns and combined stiffness of particular storey is achieved by adding stiffness of all the columns present in the storey, assuming them as parallel springs.

Table 1 Highlights of differences in Building types

	Residential	Commercial
Imposed load (kN/m^2)	2.0	4.0
% of Impose Load taken	25	50
Added Imposed Load (kN/m^2)	0.5	2
Wall Load (kN/m^2)	7.4	6.3

These differences have been taken into consideration while seismic weights are calculated at different levels.

III. NUMERICAL STUDIES

A. Comparing FNPs of Residential, Commercial, and Commercial cum Residential Buildings with the Code Recommended Values at various Heights: The studies are done by considering two bays of six mts each in x direction and four bays of three mts each in y direction. Columns with dimensions 0.45×0.45 mts, beams with dimensions 0.23×0.6 mts and walls with thickness of 0.23mts is considered in all the cases. The detail of heights of storeys considered in three cases is given in the table 2.

Table 2 Detail of Cases

Type	Height of Each story (mts)	Number of Stories
Residential (R)	3	15
Commercial (C)	4.5	10
Commercial cum Residential (C&R)	4.5*2+3*12	14

The results obtained are shown in the fig.2

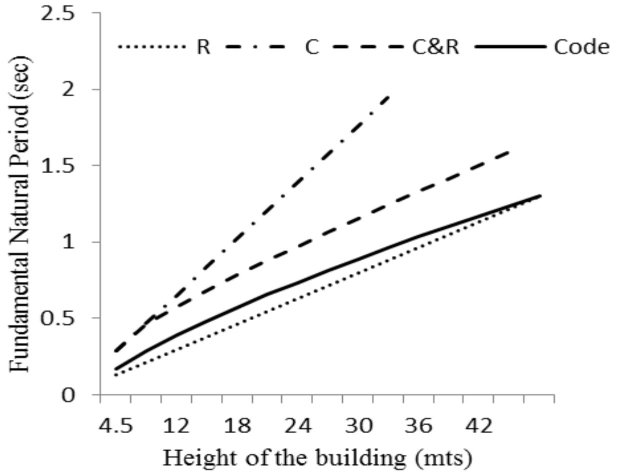

Fig.2. Comparison of FNPs with the CRVs for various functional uses

B. Finding % of 1st Mode Participation for Various Mass and Stiffness ratios

This study is done by considering mass and stiffness ratios in two different cases.

Mass Ratio is defined as the Ratio of lumped mass of any floor to the lumped mass of floor immediately below it, for the same stiffness at all storeys. Similarly Stiffness Ratio is the Ratio of combined stiffness of any storey to the combined stiffness of storey immediately below it for the same lumped mass at all the floor levels. Here, Mass ratio and stiffness ratio are the terms defined by the authors for their convenience and also for the purpose of better understanding of the readers and their scope is restricted to this paper only. The concept of Modal mass has been considered in determining the % of 1^{st} mode participation in the total vibration.

Modal mass of any mode is defined as,

$$M_k = \frac{\left[\sum_{i=1}^{n} W_i \times \Phi_{ik}\right]^2}{g \times \sum_{i=1}^{n} W_i \times (\Phi_{ik})^2} \quad \text{(Eq. 2)}$$

Where,,

g= acceleration due to gravity

W_i= Seismic weight of floor i

Φ_{ik}= Mode shape coefficient at floor i in mode k

Case 1

In this case stiffness of all the floors is kept same and lumped mass is reduced at some constant ratios from bottom to top stories (Mass ratio). Each time % of Modal mass of the first mode with respect to total modal mass is calculated. Accuracy of results are obtained up to first 5 modes.

First Mode Participation for various Mass ratios is as shown in the fig. 3.

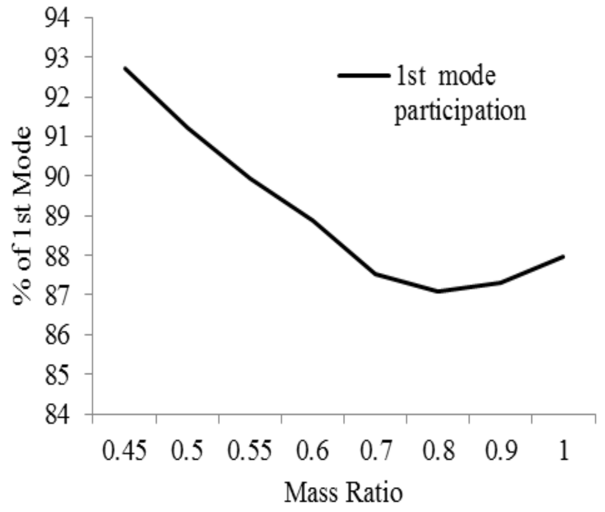

Fig. 3. Effect of Mass Ratio on the First mode Participation

Case2

In this case Lumped Mass of all the floors is kept same and Stiffness is changed at some constant ratios from bottom to top stories (Stiffness ratio). Each time % of Modal mass of the first mode with respect to total modal mass is calculated. Accuracy of results are obtained up to first 8 modes.

First Mode Participation for various Stiffness ratios is as shown in the fig. 4.

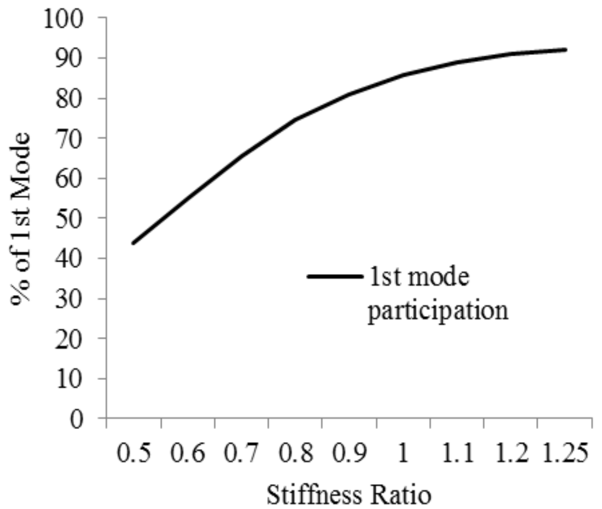

Fig. 4. Effect of Stiffness Ratio on the First mode Participation

C. Effects of Variations in Grade of Concrete on Fundamental Natural Period (FNP): In this study, a 7 storey moment resisting frame is considered with lumped mass of equal magnitude at all the floor levels and different grades of concrete across various storeys. Modulus of elasticity of concrete is calculated using the formula

$$E=5000\times\sqrt{fck} \quad \text{(Eq. 3)}$$

Where, fck is compressive strength of the concrete and E is required to calculate the stiffness of the column. The details of various cases considered in this study are given in the table 2.

Table 3 Details of Study

Grade of the concrete (Mpa)				
	Type 1	Type 2	Type 3	Type 4
1^{st} story	35	30	25	35
2nd story	35	30	25	30
3rd story	35	30	25	25
4th story	35	30	25	25
5th story	35	30	25	20
6th story	35	30	25	20
7^{th} story	35	30	25	20

FNPs are obtained for all the types and plotted along with CRVs.

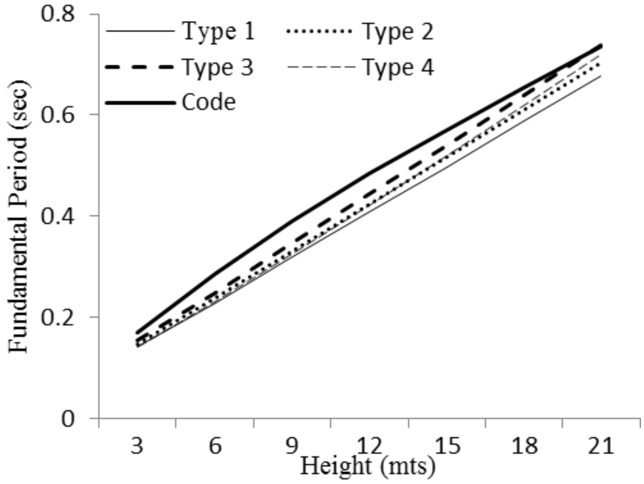

Fig. 5. Variation of FNPs with different Grades of Concrete

IV. RESULTS AND DISCUSSIONS

First study (A) shows that the Fundamental Natural Periods (FNPs) of Residential Buildings are less compared to Code Recommended Values (CRVs) but trend is in similar fashion as that of CRVs. It is found that commercial and commercial cum residential buildings shows FNPs higher than CRVs. Generally Seismic codes underestimate FNP values in order to predict higher base shears so that the design remains safe. From the research it seems that IS 1893-2002(part 1) has recommended the formula to best suit the residential buildings. In case of commercial buildings use of CRVs is fine since they are lesser than FNPs. Then Case 1 and Case2 of second study(B) respectively discusses the effects of variations in the mass and stiffness ratios on the probability of first mode participation in the total vibration of the building. It is found that decrease in the Mass Ratios and increase in the Stiffness Ratios has increased the chances of first mode participation in the total vibration. A mass ratio of about 0.5 and stiffness of about 1.2 is found to give first mode participation greater than 90%(clause 7.8.4.2 IS 1893 (Part 1) :2002). It means that design can be done considering only first mode if these criteria are achieved. Finally third study(C) shows that higher grade concretes (M35 and M30) give more deviations from the CRVs than the lower ones (M25 and M20). Also variation of grades along the stories has a tendency of shifting towards CRVs (Type 4 shown in the fig.5). So it can be inferred that instead of using only one grade of concrete throughout, we can use higher grade concretes at lower stories so that required strength can achieved and relatively lower grade at higher stories in order to achieve adequate FNP values.

V. CONCLUSIONS

The variation of FNP values in case of residential and commercial buildings has been studied by considering height of the building alone as the varying criterion. These results can be further be improved considering various other factors like different bay widths in both directions, different column sizes etc. First mode participation study has done by considering mass and stiffness factors separately, which gives an idea about how mass and stiffness contribute individually to the first mode of vibration. But both cases are very difficult to achieve in practice. Further research can be done by trying out various combinations of mass and stiffness which would achieve better first mode participation. Variation in FNPs can be further studied using different grades of concrete at heights.

REFERENCES

[1] M. Hadzima-Nyarko, D. Moric & H. Draganic, E. K. Nyarko, New Direction Based (Fundamental) Periods of RC Frames Using Genetic Algorithms,*15th World conference of earthquake engineeing*,Lisboa 2012.

[2] Goel, K. R. and Chopra, K.A., Period formulas for moment-resisting frame Buildings, *Journal of Structural Engineering*., ASCE, Vol.123, 1997, 1454-1461.

[3] Cinitha. A, Umesha. P. K, Nagesh. R. Iyer, A Rational Approach for Fundamental Period of Low and Medium Rise Steel Building, *International Journal of Modern Engineering Research (IJMER)*, Vol. 2, Issue. 5, Sep.-Oct. 2012, 3340-3346.

[4] IS 1893 (Part 1):2002, Criteria for earthquake resistant design of structures, General provisions and buildings (Fifth revision), Bureau of Indian standards, New Delhi, June 2002.

[5] IS 456:2000, Indian Standard Code for practice of plain and reinforced concrete (Fourth revision),Bureau of Indian standards, New Delhi, July 2000.

[6] M.I. Salama, Experimental estimation of time period of vibration for moment resisting frame buildings, *2nd Turkish Conference on Earthquake Engineering and Seismology* ,TDMSK -2013, September 25-27, 2013, Antakya, Hatay/Turkey.

Ajaya R Prabhu, is presently doing his Post Graduation in structural engineering at NITK Surathkal. He obtained his B.Tech Degree in Civil Engineering from AITM Bhatkal in 2014, under VTU Belgaum. He is presently doing research project in the field of earthquake engineering under the guidance of second and third author.

Premanand Shenoy obtained his B.Tech Degree in Civil Engineering from NSS College of Engineering Palakkad in 1985, University of Calicut, M.Tech Degree in Structural Engineering from NITK Surathkal in 1987 where he was a Lecturer in the Department of Civil Engineering till 1996. He is the Founder partner of Roy & Shenoy, a Structural Engineering Consultancy Firm in Mangalore. He has been involved in the design and construction of many prestigious long span and tall buildings , winning many awards. He is presently pursuing research in the field of Structural Optimization as an external registrant at NITK.

Dr. Katta Venkataramana obtained his Bachelor's Degree in Civil Engineering from University of Mysore in 1981, Master's from Kagoshima University, Japan, in 1986 and doctoral degree from Kyoto University, Japan in 1989. He was a post doctoral research fellow at University of Oxford, UK, during 1990-91. Later he worked as Assistant professor & Associate professor in Kagoshima University, Japan during 1991-2002. In September 2002, he joined NITK, Surathkal as a Professor in the Department of Civil Engineering. Presently, He is holding the additional responsibility as the Dean (Academic). His interests include Structural Dynamics, Earthquake Engineering and Offshore Structures. He is actisvely involved in collaborative research in the area of structural engineering, under the MoU signed between NITK and BARC.