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Simplified Equation for Estimating the Period of Vibration of Buildings with Moment-resisting Frame and Shear Walls

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Abstract

The aim of the present investigation has led to a simplified period–height equation for use in the seismic assessment of RC buildings, taking due accounts of the presence of moment-resisting and shear walls. The period of vibration which has been derived herein represents the period of first mode of vibration. The study includes the seismic response of regular and irregular buildings and soil flexibility using the Winkler's soil model. The parameters considered for the given study are three different types of soil (i.e, soft, medium and hard), for high seismic zone and building irregularities like plan irregularity, vertical irregularities such as, Mass irregularity, Non parallel, offset irregularity, re-entrant corners irregularity and stiffness irregularity, as per IS:1893-2002 for 10, 15, 20 storey buildings. Various analytical models for the parametric study are modeled using Etabs.V.9.2 software. Various parametric studies have carried out to estimate the fundamental time period of the structure with moment-resisting frame and shear walls.

Index Terms—*Moment-resisting frame , Time period, shear walls, Irregularity in buildings, Nonlinear regression.*

INTRODUCTION

The determination of the natural period of vibration of a reinforced concrete structure is an essential procedure in earthquake design and assessment. An improved understanding of the global demands on a structure under a given seismic input can be obtained from this single characteristic. This property is dependent on the mass, strength and stiffness of the structure and is thus affected by many factors such as structural regularity, number of storeys and bays, section dimensions, infill panel properties, axial load level, reinforcement ratio and extent of concrete cracking. Cracking of RC members is a phenomenon often ignored in period calculation however it generally occurs under gravity loading and after moderate seismic action. The stiffness of RC members significantly decreases after cracking and so this stiffness reduction should be adequately modeled in analysis to determine an expected period of vibration.

Simple empirical relationships are available in many design codes to relate the height of a building to its fundamental period of vibration. However these relationships have been realized for force based design and so produce conservative estimate of period such that the base shear force will be conservatively predicted. For the seismic design of a reinforced concrete (RC) frame, the period of vibration will not be known *a* priori and thus simplified equations are employed in the seismic design codes to relate the fundamental period to the height of the frame. These equations have traditionally been obtained by regression analysis on the periods of vibration measured during earthquakes.

IRREGULAR BUILDINGS

The buildings can be broadly categorized as regular and irregular buildings. An irregular building can be defined as a building that lacks symmetry and has discontinuity in geometry, mass or load resisting elements. The structural irregularities can be broadly categorized as horizontal and vertical irregularity.

The horizontal irregularity refers to asymmetrical plan shapes such as (L,T,U,F) or discontinuities in horizontal resisting elements such as cutouts, large openings, re-entrant corners and other abrupt changes resulting in effects like torsion, diaphragm deformation and stress concentration.

MOMENT-RESISTING FRAME WITH SHEAR WALL

Moment frames consist of beams and columns in which bending of these members provides the resistance to lateral forces. In building frame system the members columns and beams and joints of frame are resisting the earthquake forces, primarily by flexture. Shear walls must provide the necessary lateral strength to resist horizontal earthquake forces. When shear walls are strong enough, they will transfer these horizontal forces to the next element in the load path below them.

Soil–Structure Interaction

The response of a structure during an earthquake depends on the characteristics of the ground motion, the surrounding soil, and the structure itself. For structures founded on rock or very stiff soils, the foundation motion is essentially that which would exist in the soil at the level of the foundation in the absence of the structure and any excavation; this motion is denoted the **free-field ground motion.**

Equivalent Lateral Force Method

The total design lateral force or design base shear along any principal direction is given in terms of design horizontal seismic coefficient and seismic weight of the structure. Design horizontal seismic coefficient depends on the zone factor of the site, importance of the structure, response reduction factor of the lateral load resisting elements and the fundamental period of the structure. The procedure generally used for the equivalent static analysis is explained below:

(i) Determination of fundamental natural period (Ta) of the buildings

$T_a=0.075h^{0.75}$ Moment resisting RC frame building without brick infill wall

$T_a=0.085h^{0.75}$ Moment resisting steel frame building without brick infill walls

$T_a=0.09h/\sqrt{d}$ All other buildings including moment resisting RC frame building with brick infill walls.

Where,

h -is the height of building in m

d - is the base dimension of building at plinth level in m, along the considered direction of lateral force.

(ii) Determination of base shear (V_B)n of the building

$V_B = A_h \times W$ Where,

$Ah = \frac{Z}{2}\frac{I}{R}\frac{Sa}{g}$ is the design horizontal seismic coefficient, which depends on the seismic zone factor (Z), importance factor (I), response reduction factor (R) and the average response acceleration coefficients (Sa/g). Sa/g in turn depends on the nature of foundation soil (rock, medium or soft soil sites), natural period and the damping of the structure.

(iii) Distribution of design base shear

The design base shear V_B thus obtained shall be distributed along the height of the building as per the following expression: $Q_i = V_B \frac{W_i h_i^2}{\sum_{i=1}^{n} W_i h_i^2}$

Where, Q_i is the design Where, Q_i is the design lateral force, W_i is the seismic weight, h_i is the height of the 1th floor measured from base and n is the number of stories in the building.

Present Analysis

The study includes the seismic response of regular and irregular buildings and soil flexibility using the Winkler's soil model. The parameters considered for the present study are three different types of soil (soft, medium and hard), for high seismic zone and building irregularities like plan irregularity, vertical irregularities such as , mass irregularity, Non parallel, offset irregularity, re-entrant corners irregularity offset irregularity, and stiffness irregularity, as per IS:1893-2002 for 10, 15, 20 storey buildings.

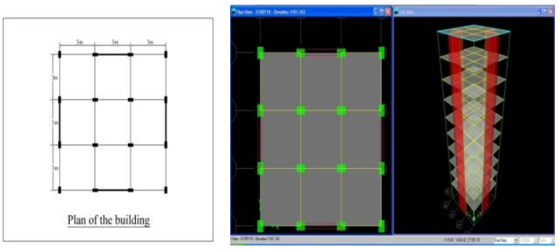


Fig 1.1 showing plan for regular building **ETABS** model screen shot of a regular 10 storied building

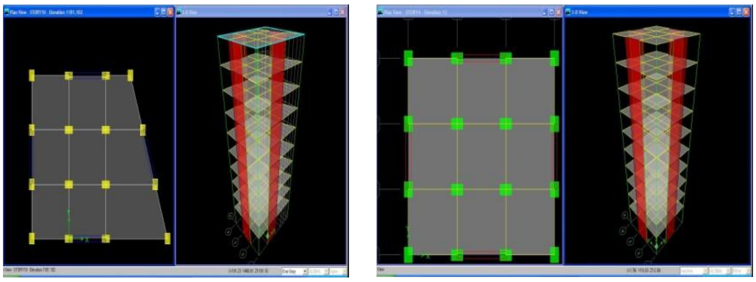


Fig 1.2 showing **ETABS** model screen shot of a Mass irregularity and Non-parallel irregularity of a 10 storied building.

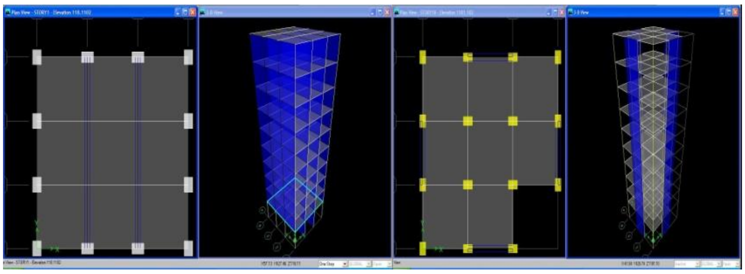


Fig 1.3 showing **ETABS** model screen shot of a offset irregularity and re-entrant irregularity of a 10 storied building.

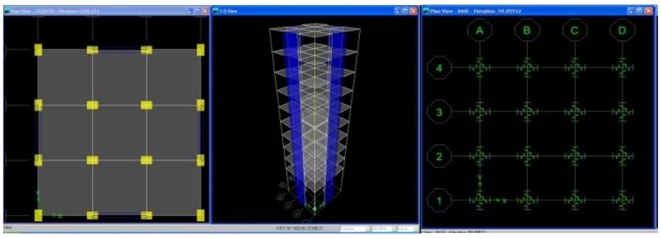


Fig 1.4 showing **ETABS** model screen shot of a Stiffness irregularity and spring constants of a 10 storied building.

Design data for all the building

Table-:1.1 Input data of all the building models

No. of storey	10, 15,20
Storey height	3.0 m
Seismic zone	V
Material Properties	
Grade of concrete	M25(SLABS), M30, M35,M40(columns)
Grade of steel	Fe 415
Density of reinforced concrete	25 kN/m^3
Member Properties	
10 Storey	
Slab	0.2m
Column	0.4mx0.6m
Shear wall	0.3 m
15 Storey	
Slab	0.2m
Column	0.4mx0.6m,.05mx0.7m
Shear wall	0.3 m
20 Storey	
Slab	0.2m
Column	0.4mx0.6m,0.5mx0.7m,0.6x0.8 m
Shear wall	0.3 m
Live Load Intensities	
Roof Floor	1.5 kN/m^2 3 kN/m^2

IS 1893 (Part 1): 2002 Equivalent Static method

Table-1.2: Input data of all the building models for equivalent static analysis.

ZONE	V
Zone factor, *Z* (Table 2)	0.36
Importance factor, *I* (Table 6	1
Response reduction factor, *R* (Table 7)	5
Damping ratio	5% (for RC framed building

RESULTS AND DISCUSSIONS

FUNDAMENTAL PERIOD OF COMBINED IRREGULARTIES FOR ALL TYPES OF SOIL

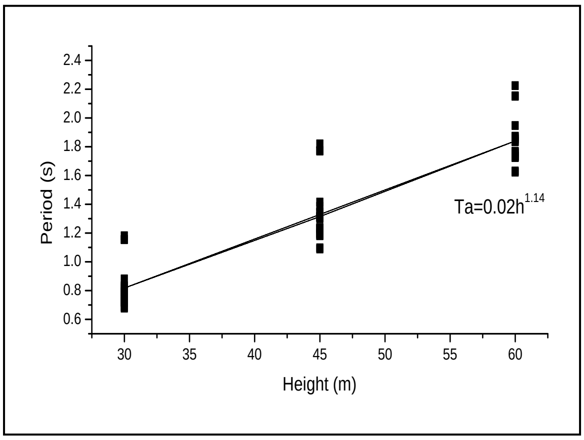
The result of, Fundamental time period are presented for different building models (10, 15 & 20 storey's) for different irregularities with spring constants and different type of soil and zone types.

Table-:1.3 Details of fundamental time period of all types of buildings and soil.

Type of Buildings	Number of Stories	Fundamental Time Periods in Seconds Soil Type		
		S1	**S2**	**S3**
Diaphragm Irregularity	**10**	0.6782	0.6847	0.7469
	15	1.0891	1.097	1.1799
	20	1.6219	1.6308	1.7359
Mass Irregularity	**10**	0.7175	0.7243	0.7867
	15	1.2295	1.2367	1.3142
	20	1.7239	1.7326	1.8345
Non Parallel Irregularity	**10**	0.7623	0.7689	0.8318
	15	1.2999	1.3069	1.3853
	20	1.7596	1.768	1.8688
Offset Irregularity	**10**	1.1536	1.1548	1.1807
	15	1.7695	1.7719	1.8195
	20	2.1495	2.1531	2.2246
Re-Entrant Irregularity	**10**	0.7239	0.7311	0.7941
	15	1.1922	1.199	1.1838
	20	1.7534	1.7653	1.8725
Stiffness Irregularity	**10**	0.817	0.8225	0.88
	15	1.3411	1.3471	1.415
	20	1.8493	1.8566	1.9464
Regular Building	**10**	0.7171	0.7238	0.7865
	15	1.2293	1.2365	1.3144
	20	1.726	1.7347	1.837

Note: The notations used below are as follows

S1=Hard soil
S2=medium soil
S3=Soft soil
Regular=Building with no irregularity
Diaphragm=Building with diaphragm irregularity
Mass=Building with mass irregularity
Offset=Building with offset irregularity
Non parallel=Building with non-parallel irregularity
Stiffness=Building with stiffness irregularity
Rentrant =Building with rentrant corner irregularity



Graph-1: Showing simplified equation generated using nonlinear regression analysis

The period height relationship for building with moment-resisting frame and shear wall for combined irregularities by considering all types of soil may be estimated by the analytical expression:

$T_a = 0.02h^{1.14}$………. *eqn*

T_a=Natural time period of structure in seconds
h=Height of the building in 'm'
These improved formulas for estimating the fundamental periods of Reinforced concrete buildings with moment-resisting frame and shear walls are developed using regression analysis of the generated time period data from above models.

Table-**:1.4 New Time Period formula Vs IS: 1893-2002 code formula for Time Period for different soils**

IS;1893-2002 code formula for time period	**New formula for time period from the present study**	**Type of soil**	**Story Height (m)**	**Spectral acceleration co efficient (Sa/g)**	
				From code formula	**From new formula**
$T_a=0.075h^{0.75}$	**$T_a=0.02h^{1.14}$**	Soil 1	30	1.0401	1.0353
		Soil 1	45	0.7674	0.6521
		Soil 1	60	0.6185	0.4697
		Soil 2	30	1.4146	1.4079
		Soil 2	45	1.0436	0.8868
		Soil 2	60	0.8411	0.6388
		Soil 3	30	1.737	1.7288
		Soil 3	45	1.2815	1.088
		Soil 3	60	1.0328	0.7845

CONCLUSION

- The fundamental natural period of a particular structure increases as the Stiffness of soil decreases.
- The natural period of the structure increases with the increase in number of stories.
- The fundamental time period of a structure with diaphragm irregularity decreases as compared to time period of regular building.
- The fundamental time period of a structure with mass irregularity decreases as compared to time period of regular building.
- The fundamental time period of a structure with non-parallel irregularity increases as compared to time period of regular building.
- The fundamental time period of a structure with offset irregularity increases as compared to time period of regular building.
- The fundamental time period of a structure with re-entrant corners irregularity decreases as compared to time period of regular building.
- The fundamental time period of a structure with stiffness irregularity increases as compared to time period of regular building.

The present study has led to a simplified fundamental natural time period formula for buildings with moment-resisting frame and shear walls. This can be used to perform seismic analysis (Equivalent static) in similar lines as that in IS: 1893-2002 codal provisions.
The equation formulated from the present study is:

$$\boxed{T_a=0.02h^{1.14}}$$

Where,
T_a =Natural time period of structure in 'Seconds'
& h=Height of the building in 'm'

Based on the present study, we can conclude that the new formulation for Time period calculation of buildings with moment-resisting frames and shear walls overestimates the spectral accelerations resulting in larger seismic forces when compared to the current codal provisions for OMRF & SMRF.

Scope of future work

- Study on these buildings considering 3D continuum model of soil, structure and foundation can be performed.
- Study on these buildings can be performed using Time history analysis and push over analysis.
- Study on these buildings considering the effect of openings in brick infill can be performed.

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