Effects of Reinforced Concrete Building Characteristics on the Fundamental Natural Period Using the Rayleigh Method

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Abstract—This study focuses on the most important single and unique property controlling the seismic response of any structure, namely; the "Fundamental Natural Period" of oscillation. The effects of the main parameters influencing the fundamental period of vibration of reinforced concrete buildings such as mass and stiffness as related to other parameters including; building height, number of storeys, type of framing system, the effect of infill brick walls, type of flooring systems and the compressive strength of concrete were investigated in this study. The work is carried out using the Rayleigh method using the STAAD-Pro Software computer program. 140 building cases were investigated to determine the natural period for different types of buildings.

Linear Equations were suggested to calculate the fundamental natural period of reinforced concrete for bare frames with a solid slab or flat plate and for structures where infill masonry walls are included. The findings indicate that the fundamental natural period of the structure is linear with the height of the building and the number of storeys. The period is reduced significantly by more than 50% when infill walls were present in both solid and flat plate construction. As the mass increases, the period increases as long as the stiffness remains constant. When the mass remains constant and the stiffness is increased, the period decreases for all building heights and for all structural flooring systems considered in this study. When the cracking effects in beams and columns were considered, the structure became more flexible and the natural period increased significantly. This behavior was apparent in both flooring systems with flat plate and solid slabs. An increase in compressive strength of concrete in columns did not have any noticeable effect on the fundamental period of the buildings under consideration.

Keywords: Fundamental natural period, Natural frequency, Earthquake, Seismic performance, Structural dynamics, Reinforced concrete buildings, Rayleigh method.

I.   INTRODUCTION

The most important step in the earthquake-resistance building design is the determination of the fundamental natural period of free vibration of the structure. This property is a unique parameter related to the response characteristics of the structure to seismic loading. The reciprocal of the fundamental period is called the fundamental frequency. The shape associated with this natural frequency is the mode shape of the vibrating structure.

In order to use any building code effectively, the local building response characteristics, as well as the anticipated loads such as wind and earthquake loadings, should be established. The type of structure, its structural form, materials, and construction details play an important role in assessing its behavior under different gravity and lateral loadings. The fundamental natural period of vibration (T_n) of the building is an important parameter for the evaluation of seismic base shear [1]. It depends on basic parameters such as building height or the number of storeys.

The current study focuses on one of the basic dynamic characteristics of structures under lateral loadings. The natural period of oscillation of any system is a unique property of that system under free vibration. When a structure is subjected to an earthquake motion it vibrates at a certain frequency termed as the natural frequency of the building. The natural frequency is the number of cycles in one second of vibration. The natural period of the system is the reciprocal of its natural frequency. It is the time required for the system to complete one cycle.

The objective of this study is to investigate the effects of the main parameters influencing the fundamental natural periods of vibrations of reinforced concrete buildings such as mass and stiffness as related to other parameters including; building height, number of storeys, type of framing system, the effect of infill brick walls, type of flooring systems and the compressive strength of concrete. The work is to be carried out using the Rayleigh method of dynamic analysis using the STAAD-Pro Software computer program. The results will be compared with the corresponding values obtained from the empirical formula recommended by different international codes for seismic design and with other similar work in the literature. 140 building cases will be investigated to determine the natural period for different types of buildings with different characteristics.

II.   A BREIF LITERATURE REVIEW

Several investigations have studied the effects of building characteristics on the natural frequencies of vibration. Bhuskade et al. [1] has studied the effects of various parameters of buildings on the natural period. They concluded that the fundamental natural period of vibration of buildings is the most important parameter in the evaluation of seismic base shear and depends on basic building characteristics such as mass, stiffness, building height and number of stories. Yogalakshmi [2] investigated the effect of building height on the natural frequency of medium to high rise buildings. His findings indicate that the height of the building was a major factor that affects the time period of vibration. The story

height and bay width also play a greater part on the time period than the effect of column sizes and number of bays. According to Sudhir et al. [3], the natural period of a building can be related to the number of stories. Whereas, the number of stories increases, the natural period also increases, although the height of the building remains constant.

M.C. Griffith and Vaculik [4] carried out an experimental program on 8 full-scale unreinforced brick masonry walls and concluded that the experimental results agree with the theoretical analytical prediction for the natural periods of the buildings investigated. H. Crowley and R. Pinho [5] studied the possibility of estimating of natural period by simplified equations that estimate the period of vibration.

They presented a simple equation which relates natural period to building height for assessment of existing of R/C building. The equation in the form of T=0.055h takes the effect of infill walls on the natural period of the building. L. Chung and T. Park [6] investigated the evaluation of natural periods using several equations. They conducted that, empirical equations applied to evaluate natural periods of R/C buildings gave various results.

Thus, the seismic loads calculated based on such empirical equations may differ greatly according to the equation applied. The values calculated based on the Rayleigh-Ritz method were twice the actual measurements. In this study, the purpose is to study the effect of the important building characteristics on the natural period of R/C buildings with and without infill walls. The study will be limited by using the Rayleigh method for free vibration.

III. STATEMENT OF THE PROBLEM AND OBJECTIVES

The objective of this work is to perform a parametric study of the reinforced concrete buildings and determine the fundamental natural period of vibration under free vibration. The work will focus on finding the fundamental period for different structural characteristics of reinforced concrete structures. These include building height, stiffness and cracking effect of infill brick walls, number of storeys, and the influence of increasing the compressive strength of concrete in columns of high-rise buildings. The Rayleigh method and STAAD-pro software program of dynamic analysis will be used in this investigation. The Rayleigh method is one of the methods recommended by the ASCE 7 standard for seismic design. The results of the work will be compared with the recommendation of the empirical equations recommend by several international codes to determine the fundamental period for base shear calculations in seismic design. These codes include UBC, IBC, Eurocode8, IS1983, Japanese standard, and others.

IV. THE FUNDAMENTAL NATURAL PERIOD

Every building has a number of natural frequencies at which it has minimum resistance to vibration induced by external forces such as wind or earthquake. The mode of vibration with the smallest natural frequency (and largest natural period) is called the fundamental mode. The associated period is called the fundamental Natural Period and the corresponding frequency is called the Fundamental Natural

Frequency. Regular buildings held at their base have three fundamental transitional natural periods in the X, Y and Z directions.

Natural frequencies and mode shapes are functions of the structural properties and boundary conditions. If the structural properties change, the natural frequencies change, but the mode shapes may not necessarily change [7].
Dynamic systems can be characterized in terms of one or more natural frequencies. The natural frequency is the frequency at which the system would like to vibrate if it were given an initial disturbance and allowed to vibrate freely. There are many methods to evaluate the natural frequencies; the Newton's law of motion, Rayleigh method, energy methods and Lagrange equations. The ASCE-7 permits the use of properly substantial analysis (e.g. Rayleigh method or dynamic modal analysis) to determine the fundamental period provided that the value of the period determined using these methods, T rational may not exceed the value of Ta recommended by the ASCE-7 code. Thus, T rational $\leq C_u T_a$. Rayleigh's method directly yields the natural frequency. Rayleigh's method, however, requires an assumed displacement function. This method reduces the dynamic system to a single degree of freedom. For a multi-degree of freedom system, the Rayleigh method can be expressed in the following form:

$$\omega_n^2 = \frac{[X]^T [K][X]}{[X]^T [M][X]}$$

$$T_n = \frac{2\pi}{\omega_n}$$

Where:

ω_n = Fundamental angular natural frequency (radians/s).

[K] = Stiffness matrix.

[M] = Mass matrix.

[X] = Assumed mode shape (deflected shape).

$[X]^T$ = Assumed mode shape (deflected shape) transposes

T_n = Fundamental natural transitional period.

V. PARAMETRIC STUDY OF DIFFERENT R/C BUILDING DETAILS

In this study, over 140 building cases were considered, with a various number of floors and specifications that influence the mass and stiffness of the structures.

A. *Details of buildings considered for the effects of building heights on the natural fundamental period.*

It makes sense to study the behavior of changing the structure height, as increasing the building height would increase its mass, therefore the natural period. Table I shows the building details while Fig. 1 and Fig. 2 show the elevations and plans of the studied structures.

- All beams are (250*400).
- All slab thicknesses = 200mm.
- f_c'= 30 MPa, f_y = 420 MPa.
- Infill walls for all cases = 250mm.
- Live load= 3KN/m^2.
- Bay length in X-direction plan is 5m (center to center). (7bays) = 35m.
- Bay length in Z-direction plan is 5m (center to center). (5bays) = 25m.

TABLE I. EFFECT OF HEIGHT CASE SPECIFICATIONS

No. of storeys	Building height (m)	Column size (mm)	Slab thickness (mm)	R/C frame	R/C frame + infill	R/C flat plate	R/C flat plate +infill
				Bld.#	Bld.#	Bld.#	Bld.#
2	6	500*500	200	A-2	B-2	C-2	D-2
5	15	500*500	200	A-5	B-5	C-5	D-5
10	30	500*500	200	A-10	B-10	C-10	D-10
15	45	500*500	200	A-15	B-15	C-15	D-15
20	60	500*500	200	A-20	B-20	C-20	D-20
25	75	500*500	200	A-25	B-25	C-25	D-25

10	30	600*600	200	E-10	F-10	G-10	H-10
15	45	700*700	200	E-15	F-15	G-15	H-15
20	60	800*800	200	E-20	F-20	G-20	H-20
25	75	900*900	200	E-25	F-25	G-25	H-25
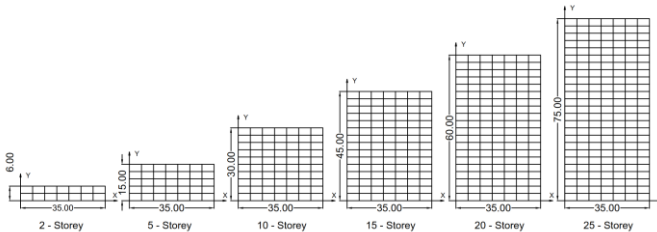
Fig. 1. Reinforced concrete buildings elevations for the effect of height case.

Fig. 2. Reinforced concrete building floor plans for the effect of height case.

Fig. 3. Reinforced concrete buildings elevations for the effect of stiffness case.
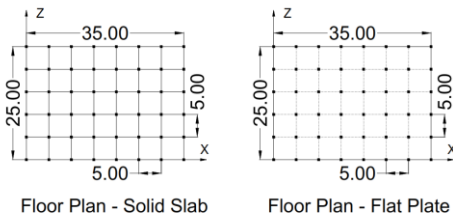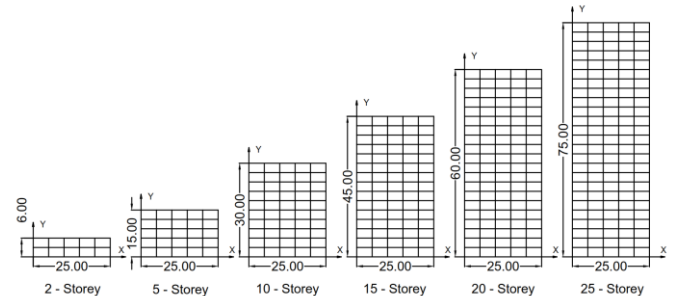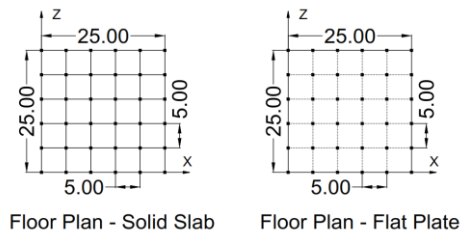

Fig. 4. Reinforced concrete building floor plans Floor plans for effect of stiffness.

B. Details of buildings considered for the effects of building stiffness and cracking on the natural fundamental period.

In this study, the beam elements moment of inertia (Ig) was modified to be 0.35 Ig for beams and 0.70 Ig for columns. Table II shows the specifications of the structure, Fig. 3 and Fig. 4 show the elevations and plans of cases.

- All beams are (350*400).
- All slab thicknesses = 200mm.
- f_c'= 30 MPa, f_y = 420 MPa.
- Infill walls for all = 250mm.
- Live load= 3KN/m^2.
- Bay length in both X-direction and Z-direction plan is 5m (center to center). (5bays) = 25m.

C. Details of buildings considered for the effects of building mass on the natural fundamental period.

Seismic mass plays a very important role in providing stability of structures. Table III and Table IV show the specifications of the structure for (Case A) and (Case B) while Fig. 5 and Fig. 6 show the elevations and plans of the studied structures.

- All beams are (350*400).
- f_c'= 30 MPa, f_y = 420 MPa.
- Infill walls for all cases = 250mm.
- Live load= 3KN/m^2.
- Bay length in both X-direction and Z-direction plan is 5m (center to center). (7bays) = 35m.

TABLE II. EFFECT OF STIFFNESS CASE SPECIFICATIONS

No. of storeys	Building height (m)	Column size (mm)	Slab thickness (mm)	Uncracked		Cracked (0.35 Ig beams 0.7 Ig columns)	
				R/C frame	R/C frame +infill	R/C frame	R/C frame +infill
				Bld.#	Bld.#	Bld.#	Bld.#
2	6	400*400	200	E-2	F-2	G-2	H-2
5	15	500*500	200	E-5	F-5	G-5	H-5

TABLE III. EFFECT OF MASS (CASE A) SPECIFICATIONS

No. of storeys	Building height (m)	Column size (mm)	Slab thickness (mm)	R/C frame	R/C frame + infill	R/C frame	R/C frame + infill
				Bld.#	Bld.#	Bld.#	Bld.#
2	6	400*400	200	I-2	J-2	K-2	L-2
5	15	500*500	200	I-5	J-5	K-5	L-5
10	30	600*600	200	I-10	J-10	K-10	L-10
15	45	700*700	200	I-15	J-15	K-15	L-15
20	60	800*800	200	I-20	J-20	K-20	L-20
25	75	900*900	200	I-25	J-25	K-25	L-25

TABLE IV.   EFFECT OF MASS (CASE B) SPECIFICATIONS

No. of storeys	Building height (m)	Column size (mm)	Slab thickness (mm)	R/C frame	R/C frame + infill	R/C frame	R/C frame + infill
				Bld.#	Bld.#	Bld.#	Bld.#
2	6	400*400	300	M-2	N-2	O-2	P-2
5	15	500*500	300	M-5	N-5	O-5	P-5
10	30	600*600	300	M-10	N-10	O-10	P-10
15	45	700*700	300	M-15	N-15	O-15	P-15
20	60	800*800	300	M-20	N-20	O-20	P-20
25	75	900*900	300	M-25	N-25	O-25	P-25

TABLE V.   EFFECT OF NUMBER OF STOREYS CASE SPECIFICATIONS

No. of storeys	Building height (m)	Story height (m)	Slab thickness (mm)	R/C frame	R/C frame + infill
				Bld.#	Bld.#
24	120	5	120	Q-24	R-24
27	120	4.44	120	Q-27	R-27
30	120	4	120	Q-30	R-30
34	120	3.53	120	Q-34	R-34
40	120	3	120	Q-40	R-40

Fig. 7.   Reinforced concrete building elevations of different number of storeys.
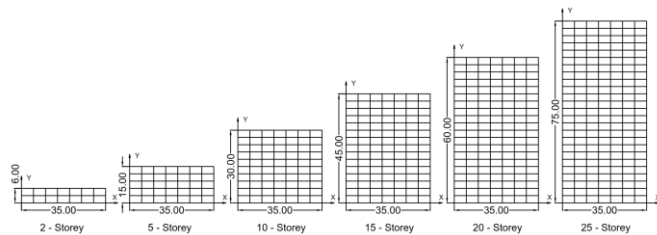
Fig. 5.   Reinforced concrete building elevations of different heights and mass.
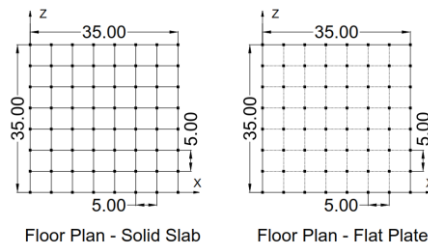
Fig. 6.   Reinforced concrete building floor plans of different heights and mass.

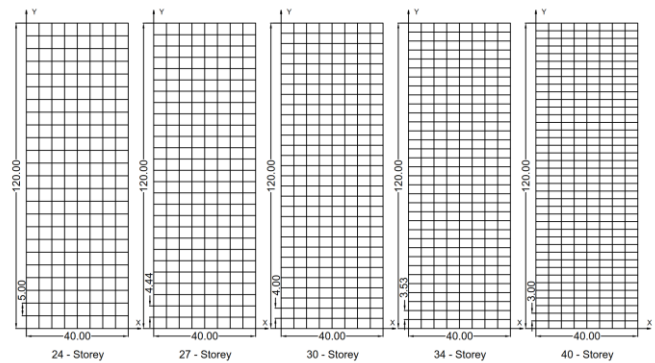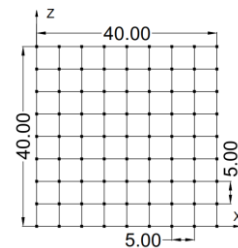
Fig. 8.   Reinforced concrete building floor plan for different number of storeys.

E. Details of buildings considered for the effect of compressive strength at the natural fundamental period

Table VI shows the specifications of the structure while Fig. 9 and Fig. 10 shows the elevation and plan of the studied structures with the following parameters:

- All beams are (300*600).
- All slab thickness =120mm.
- f_c' = varies, f_y = 420 MPa.
- Infill walls for all cases = 250mm.
- Live load= 3KN/m².
- Bay length in both X-direction and Z-direction plan is 5m (center to center). (8bays) = 40m.

D. Details of buildings considered for the effects of number of storeys on the natural fundamental period.

Table V shows the specifications of the structure. Fig. 7 and Fig. 8 show the elevations and plan of the studied structures figures with the following parameters:

- All beams are (300*600).
- All slab thickness = 200mm.
- f_c' = 30 MPa, f_y = 420 MPa.
- Infill walls for all cases = 250mm.
- Live load= 3KN/ m².
- Bay length in both X-direction and Z-direction plan is 5m (center to center). (8bays) = 40m.

TABLE VI.   EFFECT OF COMPRESSIVE STRENGTH CASE SPECIFICATIONS

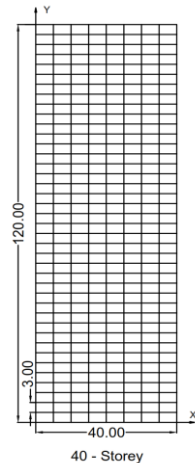| No. of storeys	Height (m)	Column size (mm)	fc' (MPa)	R/C frame	R/C frame + infill
				Bld.#	Bld.#
40	120	500*500	35	Q-35	R-35
40	120	500*500	56	Q-56	R-56
40	120	500*500	70	Q-70	R-70
40	120	500*500	84	Q-84	R-84
40	120	500*500	98	Q-98	R-98

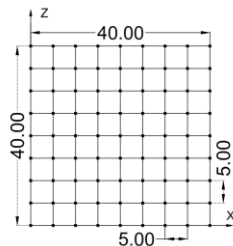Fig. 9.   Reinforced concrete building elevation with varying compressive strength.

Fig. 10. Reinforced concrete building floor plan with varying compressive strength.

VI.   PARAMETRIC STUDY OF DIFFERENT R/C BUILDING RESULTS

A. Results of the effects of building heights on the natural fundamental period.

Table VII and Table VIII show software analysis results in both directions, while Fig. 11 and Fig. 12 shows the relation between natural period and the number of storeys in different cases in X-direction and Z-direction. The results show that taller reinforced concrete buildings have larger fundamental translational natural periods than short or intermediate buildings in both solid and flat plate construction as increasing the height means increasing the mass and therefore increasing the natural period.

TABLE VII.   EFFECT OF BUILDING HEIGHT RESULTS Tx-DIRECTION

R/C frame		R/C frame + infill		R/C flat plate		R/C flat plate + infill	
Bld.#	Tn (s)	Bld.#	Tn (s)	Bld.#	Tn (s)	Bld.#	Tn (s)
A-2	0.267	B-2	0.232	C-2	0.272	D-2	0.233
A-5	0.662	B-5	0.427	C-5	0.687	D-5	0.425
A-10	1.335	B-10	0.697	C-10	1.394	D-10	0.693
A-15	2.028	B-15	0.987	C-15	2.118	D-15	0.979
A-20	2.739	B-20	1.335	C-20	2.857	D-20	1.322
A-25	3.472	B-25	1.763	C-25	3.623	D-25	1.742

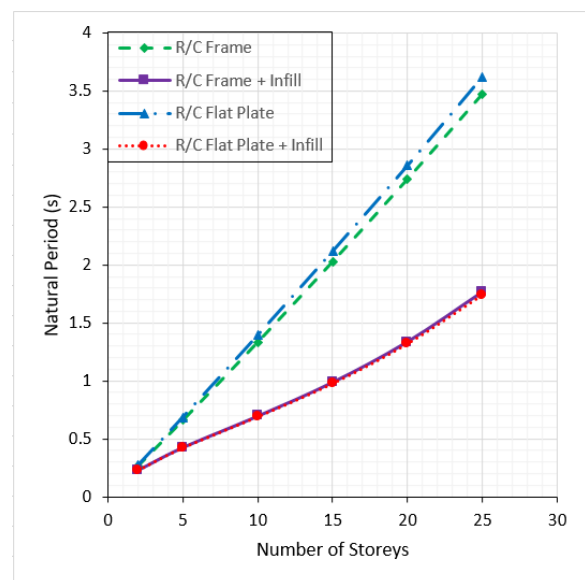

Fig. 11. Effect of building height on Tn in Tx-direction.

TABLE VIII.   EFFECT OF HEIGHT RESULTS Tz-DIRECTION

R/C frame		R/C frame + infill		R/C flat plate		R/C flat plate +infill	
Bld.#	Tn (s)	Bld.#	Tn (s)	Bld.#	Tn (s)	Bld.#	Tn (s)
A-2	0.268	B-2	0.233	C-2	0.273	D-2	0.231
A-5	0.666	B-5	0.431	C-5	0.689	D-5	0.428
A-10	1.349	B-10	0.719	C-10	1.402	D-10	0.714
A-15	2.057	B-15	1.005	C-15	2.136	D-15	1.048
A-20	2.801	B-20	1.453	C-20	2.906	D-20	1.524
A-25	3.584	B-25	2.061	C-25	3.717	D-25	2.032

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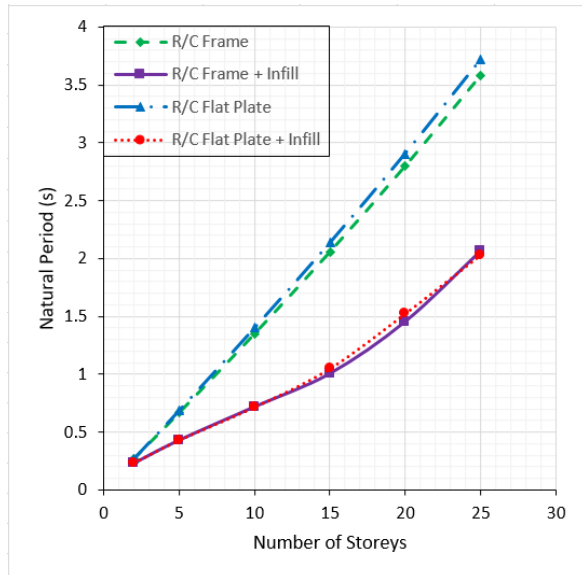**Vol. 10 Issue 11, November-2021**

Fig. 12. Effect of building height on Tn in Tz-direction.

B. Results of the effects of building stiffness and cracking on the natural fundamental period.

Table IX and Fig. 13 showing the relation between Tn and number of storeys in different cases, we can notice that the structure became more flexible and the natural period increased significantly. This behavior is apparent in both flooring systems with flat plate and solid slabs.

TABLE IX.   EFFECT OF BUILDING STIFFNESS RESULTS

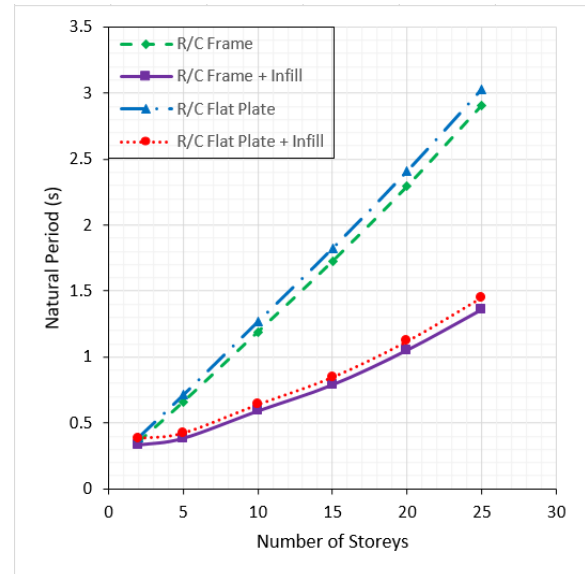| No. of storeys	Uncracked				Cracked 0.35Ig beams 0.7 Ig columns			
	R/C frame		R/C frame + infill		R/C flat plate		R/C flat plate + infill	
	Bld. #	Tn (s)	Bld. #	Tn (s)	Bld. #	Tn (s)	Bld. #	Tn (s)
2	E-2	0.354	F-2	0.333	G-2	0.393	H-2	0.384
5	E-5	0.658	F-5	0.384	G-5	0.715	H-5	0.425
10	E-10	1.189	F-10	0.590	G-10	1.270	H-10	0.640
15	E-15	1.724	F-15	0.788	G-15	1.824	H-15	0.847
20	E-20	2.293	F-20	1.050	G-20	2.409	H-20	1.120
25	E-25	2.907	F-25	1.357	G-25	3.030	H-25	1.451

Fig. 13. Effect of building stiffness and cracking on the natural fundamental period.

C. Results of the effects of building mass on the natural fundamental period.

Table X and Table XI shows software analysis results while Fig. 14 and Fig. 15 show the relation between Tn and number of storeys in different cases. As the building increased in height, slab thickness and the columns, it caused the mass to increase and therefore the natural period to increase, as long as the stiffness remains constant.

TABLE X.   EFFECT OF BUILDING MASS ON Tn (CASE A) RESULTS

R/C frame		R/C frame + infill		R/C flat plate		R/C flat plate + infill	
Bld.#	Tn (s)	Bld.#	Tn (s)	Bld.#	Tn (s)	Bld.#	Tn (s)
I-2	0.363	J-2	0.388	K-2	0.362	L-2	0.388
I-5	0.654	J-5	0.757	K-5	0.692	L-5	0.821
I-10	1.193	J-10	1.422	K-10	1.270	L-10	1.536
I-15	1.718	J-15	2.057	K-15	1.855	L-15	2.252
I-20	2.183	J-20	2.717	K-20	2.475	L-20	2.994
I-25	2.865	J-25	3.401	K-25	3.134	L-25	3.770

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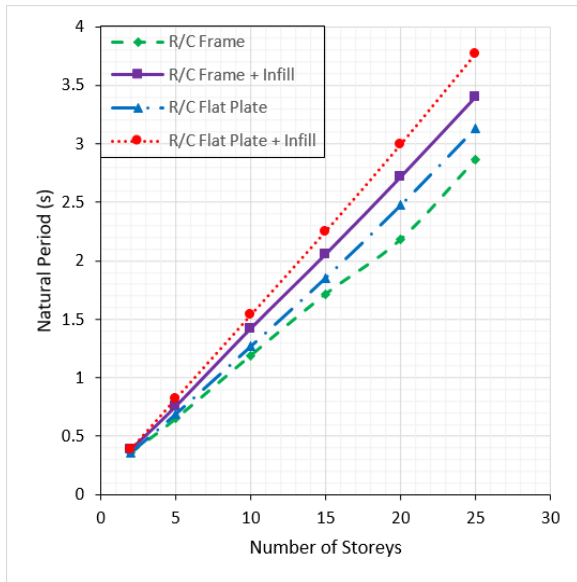**Vol. 10 Issue 11, November-2021**

Fig. 14. Effect of building mass on Tn (Case A).

TABLE XI.   EFFECT OF BUILDING MASS ON TN (CASE B) RESULTS

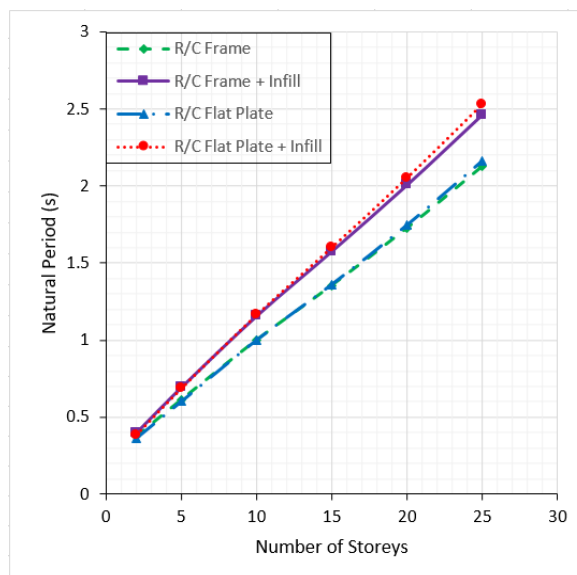| R/C frame		R/C frame + infill		R/C flat plate		R/C flat plate + infill	
Bld.#	*Tn (s)*	*Bld.#*	*Tn (s)*	*Bld.#*	*Tn (s)*	*Bld.#*	*Tn (s)*
M-2	0.377	N-2	0.400	O-2	0.363	P-2	0.386
M-5	0.615	N-5	0.695	O-5	0.602	P-5	0.688
M-10	1.002	N-10	1.158	O-10	1.000	P-10	1.165
M-15	1.356	N-15	1.577	O-15	1.360	P-15	1.602
M-20	1.727	N-20	2.008	O-20	1.745	P-20	2.053
M-25	2.127	N-25	2.463	O-25	2.160	P-25	2.530

Fig. 15. Effect of building mass on Tn (Case B).

D. Results of the effects of number of storeys on the natural fundamental period

Table XII and Fig. 19 shows results, we can notice that increasing the number of storeys in a building of the same height has made the fundamental period decreased slightly in bare buildings but in buildings with infill walls there was no effect.

TABLE XII.   EFFECT OF NUMBER OF STOREYS RESULTS

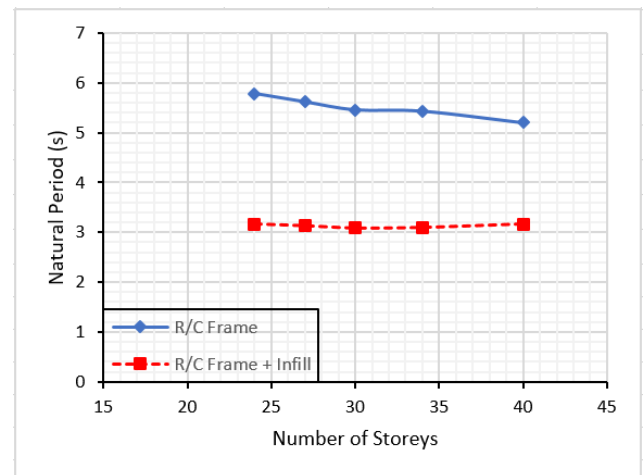| No. of Storeys	Height (m)	Colum size (mm)	R/C frame		R/C frame + infill	
			Bld.#	Tn (s)	Bld.#	Tn (s)
24	120	500*500	Q-24	5.780	R-24	3.164
27	120	500*500	Q-27	5.618	R-27	3.134
30	120	500*500	Q-30	5.461	R-30	3.095
34	120	500*500	Q-34	5.434	R-34	3.105
40	120	500*500	Q-40	5.208	R-40	3.164

Fig. 16. Effect of number of storeys on Tn.

E. Results of the effect of compressive strength on the natural fundamental period

Table XIII shows software analysis results while Fig. 17 shows the relation between Tn and compressive strength. It can be noticed that increasing the compressive strength in a building of the same height and same no. of storeys has made the fundamental period decreased slightly.

TABLE XIII.   EFFECT OF COMPRESSIVES STRENGTH RESULTS

No. of Storeys	Height (m)	Column size (mm)	fc' (MPa)	R/C frame		R/C frame + infill	
				Bld.#	*Tn (s)*	*Bld.#*	*Tn (s)*
40	120	500*500	35	S-35	4.807	T-35	2.915
40	120	500*500	56	S-56	4.310	T-56	2.590
40	120	500*500	70	S-70	4.098	T-70	2.450
40	120	500*500	84	S-84	3.937	T-84	2.341
40	120	500*500	98	S-90	3.802	T-90	2.309
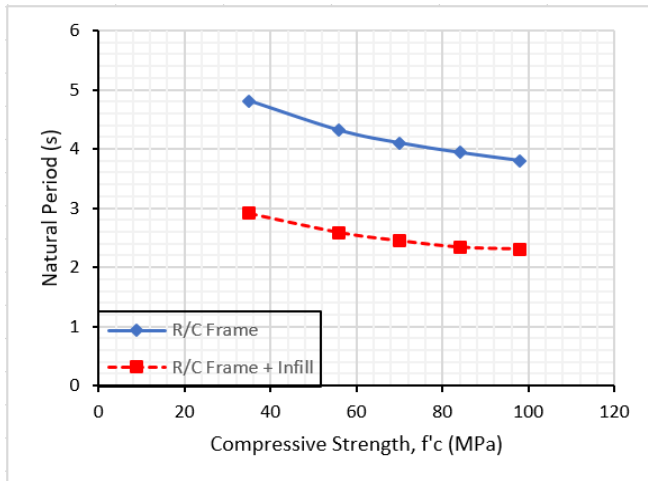
Fig. 17. Effect of compressive strength on Tn.

Fig. 18. Comparison of Ta to the current study Tn-X direction.

VII. DISCUSSION OF RESULTS

Seismic building codes generally consider the natural period as a necessary parameter to estimate the structure response coefficient. Therefore, there are empirical formulas based on general properties of the buildings the determine natural period, which could be known before a preliminary analysis, these equations can calculate the neutral period by the building characteristics such as building height H or dimensions D. The natural period formulas proposed by some of the chosen seismic codes are shown in the next Table XIV:

TABLE XIV.   Ta FORMULAS ON INTERNATIONAL CODES

Code Name	Ta formula	Parameters
UBC 1997[8]	0.073 H^0.75	H: height of the structure.
Eurocode 8 [9]	0.075 H^0.75	H: height of the structure.
ASCE 7-16[10]	T=0.1N	N: number of floors.
Japan 1981[11]	T=0.02H	H: height of the structure.
India 1984 and others (*) [12]	$T = 0.09h/\sqrt{D}$	H: height of the structure. D: dimension parallel to the applied seismic force

(*): Egypt 1988, IBC-2009, NEHRP 1994 Iran 1988, Indonesia 1983.

The results shown in the Fig. 18 and Fig. 19 below are the data obtained using the Rayleigh method to determine the fundamental natural period of different reinforced concrete buildings. It is clear from the figures relating T_n and building height that there is a strong linear relation between the two. Moreover, the effect of infill walls on the reduction of the fundamental period is appreciable. There is great scatter as to the recommended formulas from different codes and no definite conclusion can be made.

Studying the trends of the data from this investigation the general equations can be recommended (discussed in the following section) for reinforced concrete frames with solid and flat slabs and for reinforced concrete with infill walls.

The fundamental natural period of reinforced concrete bare frames & masonry infill with solid slabs and flat plates was predicted by excel as a linear equation as shown in the Fig. 20, 21, 22 and 23.
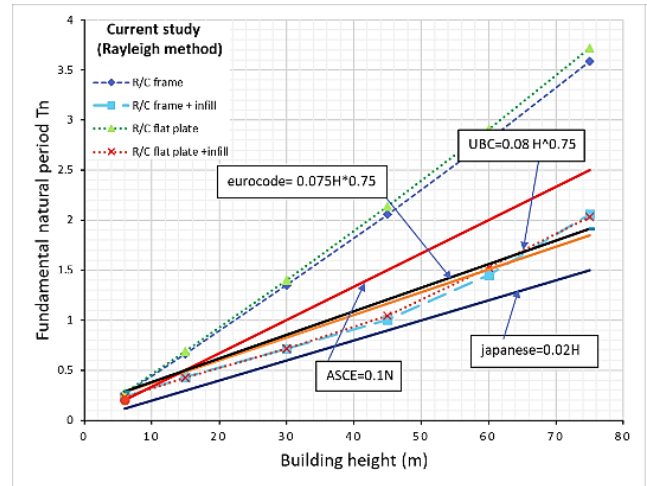

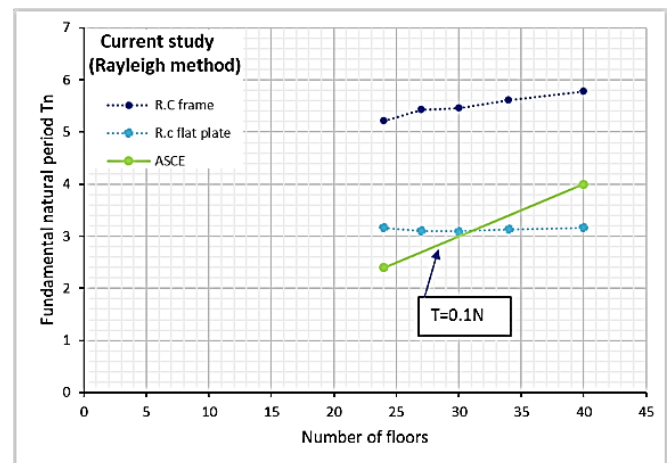
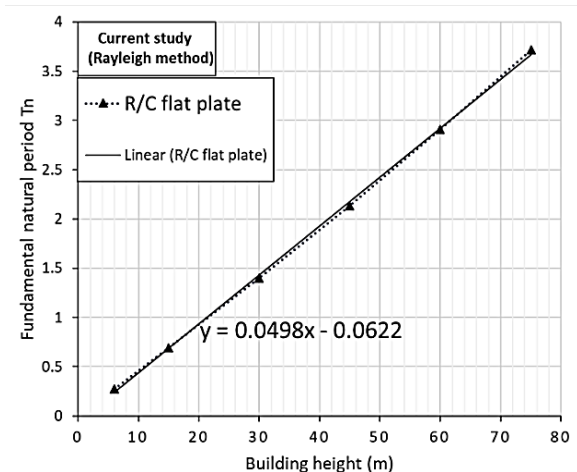Fig. 19. Comparison of empirical formulas to the current study Tn-Z direction.

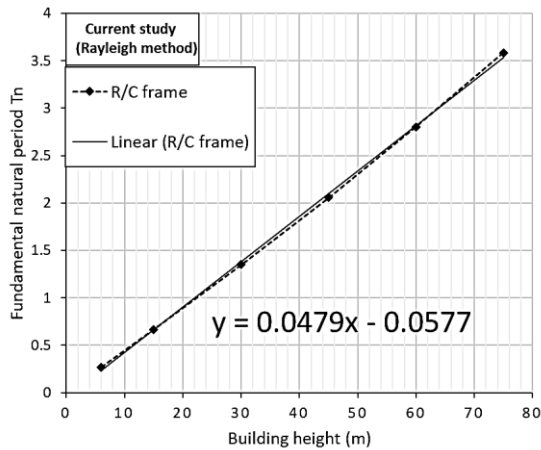Fig. 20. Excel predicted linear equation for RC flat plate with bare frames.

Fig. 21. Excel predicted linear equation for RC Frame with bare frames.

From this data the fundamental natural frequency of reinforced bare frames with solid slab or flat plate can be simplified as the following linear equation:

Tn=0.045H

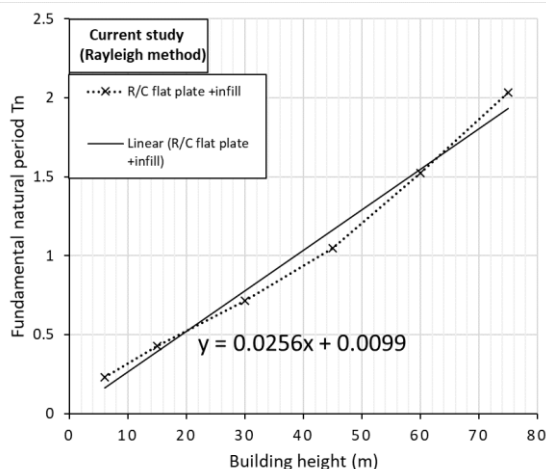where H is the total height of the building in meters.

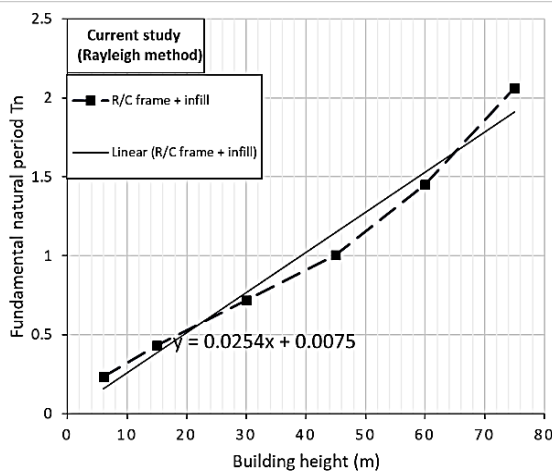Fig. 22. Excel predicted linear equation for RC Flat Plate + Infill.

Fig. 23. Excel predicted linear equation for RC Frame + Infill.

As when the infill masonry walls are included the excel predicted equation is:

Tn=0.025H

In terms of number of floors, the recommended simplified equations from the excel data take the following format:
- Reinforced concrete bare frame: **Tn=0.15N**
- Reinforced concrete frame with infill walls: **Tn=0.10N**
This last equation has been recommended by many investigators and is shown in the above graphs.

VIII.   CONCLUSIONS

In summary, some major and general trends related to fundamental natural periods of reinforced concrete buildings of regular geometries are:

1. The fundamental natural periods of reinforced concrete buildings increase with increasing of mass and decreases with increasing stiffness. However, when cracking is considered in both columns and beams, the natural periods significantly increase.

2. Increasing the number of storeys in a building of the same height, the fundamental period decreased slightly in R/C bare buildings but in buildings with infill walls there was no effect.

3. The fundamental natural periods of reinforced concrete buildings depend greatly on the unreinforced masonry infill walls.

4. The fundamental natural periods do not decrease significantly with increasing concrete compressive strength in columns.

5. Flat plate flooring systems have slightly larger natural period than buildings with solid concrete slabs in buildings with and without infill masonry walls.

6. The empirical formulae for natural period recommended by (ASCE-7-16) were in close agreement with the results obtained by the Rayleigh method in this study. Other formulas recommended by different codes were significantly different.

7. The fundamental natural period of reinforced concrete bare frames with solid slabs or flat plates can be predicted by the following linear equation: **Tn=0.045H,** where H is the total height of the building in meters. When the infill masonry walls are included, the recommended equation is **Tn=0.025H.** In terms of number of floors (N), the recommended equations take the following format for Reinforced concrete bare frames; Tn=**0.15N,** while in reinforced concrete frames with infill walls **Tn=0.10N.**

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