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Influence of Infill Wall Stiffness on The Fundamental Time Period of RC Frame Buildings

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Abstract

Fundamental time period of structure is the most censorious parameter for seismic design of structure. Vibration period of building depends upon geometry of building, mechanical properties of construction materials and other various factors. In this research, effect of infill wall panel strength on the fundamental time period of regular reinforced concrete frame building was investigated. A total of 180 regular building models were analyzed by using finite element software. Infill wall panels were modelled as single equivalent diagonal strut macro-models.It was found that infill wall stiffness has considerable influence on the fundamental period of RC building and should be considered in the prediction of fundamental period. After analysis different analytical equations are given from regression analysis in which fundamental time period of building is depends on height of building, base dimension of building, modulus of elasticity of infill wall panel and thickness of infill wall panel.

Keywords

Fundamental Time Period , Regular RC Frame Building, Infill Wall, Rayleigh Method

1. Introduction

The natural vibration period of structure is simply a time taken by structure to undergo one compete cycle of oscillation, which depends on the distribution of stiffness and mass of structure along its height. MDOF system have multiple modes of vibration, each modes have an own period, the longest period among these modes is the fundamental or natural period of structure. The fundamental period of buildings can be determined by linear dynamic such as modal analysis (Eigen vector analysis), or by a Rayleigh method which is also known as energy conservation method. The building codes from different countries for seismic design of structure gives empirical equations mostly as a height and function type of building. Different literature suggest that the time period deepens not only upon the height but also on: Storey numbers, bay numbers, spacing of bays, use of infill wall and their mechanical properties, their thickness, irregularities in plan, soil surface interaction and many other factors. Therefore, it is required to analyzed the effects of these parameters on fundamental time period of building.This study will cover effects of infill wall strength by varying infill wall panel thickness (t) and coefficient of elasticity of infill wall (E). It differs stiffness parameter of infill wall, which is considered the important parameter that affect the fundamental period of the building, along with the height and base dimension of building. The main objective of this paper is to study influence of infill wall strength on fundamental period and to generate an analytical expression for fundamental period of RC frame building based on these parameters.

2. Empirical Formulae

2.1 Seismic Design Codes

Most of seismic code, empirical expression for fundamental time period is simply related to height of buildings only. Codal provision for moment resisting RC frame building for time period of different country codes were given in table 1 . Among them, most of codes, time period is expressed as $T = C_T H^{3/4}$ Here, H is the building height in meter and C_T is coefficient that depends topology of building. Above equation is initially adopted by ATC 3-06 based on the measurements of periods of building during the San Fernando Earthquake [1] . The identical expression has been given by UBC 1988, Eurocode 8, Building code of Pakistan, IS code. Value of structural topology coefficient is 0.035 for steel frame and is 0.030 for reinforced concrete frame in ATC 3-06 and UBC 1988 code. In Eurocode 8 and IS 1893-2016, C_T is 0.085 for MRF steel frame and is 0.075 for MRF concrete. Similarly in Building code of Pakistan, C_T is 0.0853 for steel MRF and 0.0731 for RCC MRF. ASCE 7, Bangladesh building code BNBC-2015 refers, T = C_T H^x. According to ASCE 7, for steel MRF structure value of C_T is 0.028 and value of x is 0.8 similarly for concrete MRF structure building topology coefficient is 0.16 and value of x is 0.9. According BNBC-2015 The value of C_T is 0.0466, 0.0724, 0.0731 and 0.0488 for concrete MRF, steel MRF, eccentrically braced frame and other systems respectively. The values of x are 0.9, 0.8, 0.75 and 0.75 for concrete MRF, steel MRF, eccentrically braced frame and other systems respectively.Japanese Building standard (BSLJ-1981), the fundamental period of building is depends on height only, here height ratio coefficient as defined in code (α) is 0 for concrete and 1 for steel structure.

Nepal National Building code NBC-105:2020[2] refers approximate fundamental period which is similar to that given by other seismic codes: k_t H^x, Where k_t is 0.075 for MRF concrete structure, 0.085 for MRF steel structure and 0.05 for all other equation. NBC uses the amplification factor of 1.25 to above calculated time period. For MRF concrete structure NZS 1:2004 gives similar empirical expression as NBC. Many codal provision also permit the use of Rayleigh method along with this empirical formula.

2.2 Equations Proposed by Various Researchers

For approximate calculation of fundamental time period of masonry RC infilled frame building, various empirical formulae has been given by many researchers by considering various parameters to achieve better reliability. Memet Metin Kose [3] considering height of building (H), bay numbers (B), ratio of shear wall area to floor area (S), ratio of infilled panels to total number of panels (I) and types of frames (F) in his study and proposed an empirical equation for determining fundamental time period of buildings, based on obtained results of linear regression analysis as:

$$T = 0.0935 + 0.0301H + 0.0156B + 0.0039F – 0.1656S – 0.0232I \quad (1)$$

Table 1: Empirical Time Period for MRF Building of different seismic codes

Country	Codal provision	Time Period (T)	Time period depends on
USA	Structural Association of Northen California/ UBC	$T = \frac{0.05h}{D_{0.5}}$	Height and base dimension
USA	ATC3-06/ UBC-1988	$T = C_T H^{3/4}$	Height
USA	ASCE 7	$T = C_t h^x$	Height
Europe	Eurocode 8	$T = C_T H^{3/4}$	Height
New Zealand	NZS 1:2004	$T_1 = 1.0k_1 h_n^{3/4}$	Height
Japan	BSLJ	$T = H(.02 + .01\alpha)$	Height
Pakistan	Pakistan Seismic Code-2007	$T = C_T H^{3/4}$	Height
Bangladesh	BNBC-2015	$T = C_t h^m$	Height
India	IS 1983	$T = \frac{0.09}{\sqrt{d}}$	Height
Nepal	NBC - 105	$T = K_t H^{3/4}$	Height

Complex equation for fundamental time period has been given by G. Asteris et. Al.[1] considering various parameters as: storey number, span length(L) of building, stiffness of infill panels (E_t), opening percentage in infill (a_w), the location of soft storeys and soil types. They performed regression analysis and proposed following equation:

$$\begin{aligned} T = (&0.55407 + 0.5679\sqrt{H} - 0.00048L \\ &- 0.00027a_w - 0.00425E_t + 0.00202\sqrt{HL} \\ &+ 0.00016\sqrt{Ha_w} - 0.00032HE_t \\ &+ 0.00013La_w - 0.00017LE_t + 0.00010a_wE_t)^5 \end{aligned} \quad (2)$$

Yildirim and A. Kocak [4] on their experimental study proposed the expression which represent the correlation between the ratio of infill wall (A_k) and fundamental period of vibration of bare frame (T_c) with infilled frame (T_d)

$$\Delta T(\%) = 69.1A_k^{1.08} \quad (3)$$

$$T_d = T_c(1 - \frac{\Delta T}{100}) \quad (4)$$

Similarly,a height dependent expression to calculate the fundamental period of RC moment-resisting frames constructed in turkey was derived by Kocak [5] as follows:

$$T = 0.026H^{0.9} \tag{5}$$

Amanat and Hoque [6] studied the effect of infill wall and concluded that periods obtained through eigenvalue analysis are closed to those determined from the codal formulas. An equation was proposed in the form:

$$T = \alpha_1\alpha_2\alpha_3C_tH^{3/4} \tag{6}$$

Where,α_1,α_2 and α_3 are the modification coefficients accounting for infill wall span length , number of spans and amount of infills respectively and = 0.073 for RC building. A total of 126 models of frame buildings were modeled, analyzed and designed using Finite Element software SAP2000 by J. C. Rimal [7] and suggested:

$$T = 0.030H^{0.80}D^{0.766}B^{-0.784} \tag{7}$$

Fundamental time periods were evaluated experimentally in case of 31 RC Frame buildings in Kathmandu valley by Shrestha and Karanjit [8] and proposed:

$$T = 0.093\frac{H}{\sqrt{D}} \tag{8}$$

$$T = 0.05H^{0.75} \tag{9}$$

Andre Furtado et. Al. [9] concluded that wall infill played chief role in the seismic performance of the building and highlighted the necessary to consider these parameters for the design of new structures or the structural safety evaluation of old structure.

Goel and Chopra (1997) [10] evaluated the formulas specified in the current US codes and developed enhanced empirical relationships to predict the fundamental n period of reinforced concrete and steel moment- resisting frame (MRF) buildings as:

$$T_L = 0.016H^{0.9} \tag{10}$$

$$T_U = 0.023H^{0.9} \tag{11}$$

Where, H is in feet $T_L$and T_U are the lower and upper limit of fundamental period respectively .

2.3 Research related for Diagonal Equivalent methods of masonry infill panel

FEMA 356[11] explains the determination of strength and stiffness of infill wall from mechanical properties of materials used in construction. Elastic stiffness by considering crack section on infill wall panel can be expressed by equivalent diagonal strut having width, a, which has similar thickness and elastic modulus with the masonry wall panel.

$$a = 0.175(\lambda_1 h_{col})^{-0.4} r_{inf} \tag{12}$$

$$\lambda 1 = [\frac{E_m t_{inf} sin2\theta}{4E_cI_ch_{inf}}]^{1/4} \tag{13}$$

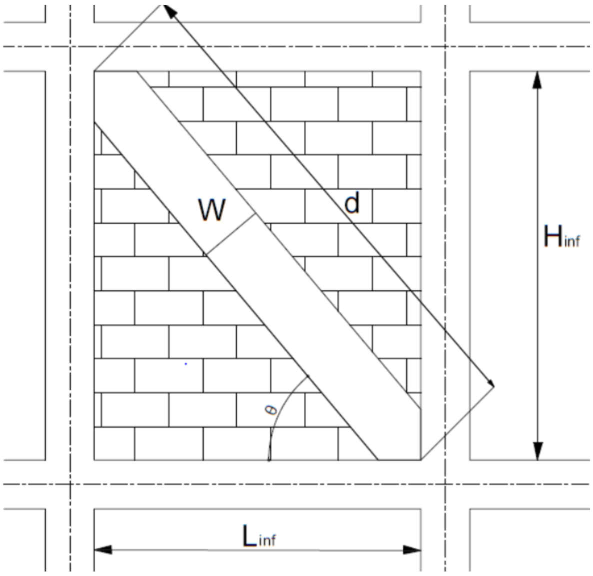


Figure 1: Typical representation of Single Strut Model

where,λ_1 is coefficient, h_{col} is the height of column between beams, h_{inf} is the height of infill wall panel, E_c is an elasticity modulus of infill materials, I_c is the moment of inertial of column, r_{inf} is the diagonal length of infill wall panel, t_{inf} is th thickness of infill wall panel and equivalent strut, θ is an angle whose tangent is the infill height to length aspect ratio. Al-Chaar suggest an equivalent masonry strut is connected to the building frame member as pin connection. He gave reduction factor for opening (r_f) of infilled wall as:

$$R_f = 0.6[\frac{A_0}{A_p}]^2 - 1.6[\frac{A_0}{A_p}] + 1 \tag{14}$$

Where, A_0 and A_p are area of full infill panel and area of opening in infill. Paulay and M. Priestley expressed an analytical expression based on a beam on elastic foundation analogy modified by experimental results which shows the effective width W of the diagonal strut depends on the relative stiffness of frame and infill wall panels, having diagonal length of infill wall (d_m). Potentially High value of width of strut is given by them as:

$$W = 0.25 d_m \tag{15}$$

According to IS 1893-2016 [12], URM infill walls be modeled as equivalent diagonal struts. Diagonal struts shall be considered as pin jointed to RC frames and width Wds of diagonal strut can be calculated as below. IS code doesn't consider effect of infill wall.

$$W_{ds} = 0.175 \alpha_h^{-0.4} L_{ds} \tag{16}$$

$$\alpha_h = h[\frac{E_m t sin 2\theta}{4 E_f I_c h}]^{1/4} \tag{17}$$

where,λ_h is coefficient, h is the height of column between beams, E_m is an elasticity modulus of infill materials,E_f is an elasticity modulus of RC frame members, I_c is the moment of inertial of column, L_{df} is the diagonal length of infill wall panel, t is th thickness of infill wall panel , θ is an angle made by diagonal strut with the horizontal.

A.R. Amalia and D. Iranata [13]performed comparative study on diagonal equivalent methods of masonry infill panel of various different fourteen methods. From their study width calculated from Al-Chaar method have widest among all and FEMA equation gives the narrowest value of width which also consider crack effective stiffness of infilled wall panel. Thus, most flexible width is given by FEMA and for this research infill wall is modeled as per equation given in FEMA.

3. Methodology

In this study, different 180 RC framed buildings were taken for the analysis and their modelling was performed using ETABS V19. The beams, columns of the building elements are modeled using frame elements. The slab of the building is modeled as thin shell area element and auto-meshing of the slab was performed by the software. Foundation is assumed to be rigidly fixed at ground level. For the modeling of infill masonry walls macro modeling approach is adopted where single strut model (Equivalent diagonal strut model) is used to replicate the infill frame interaction. For masonry only stiffness properties are given in material definition without density and weight of masonry is applied to beam by manual calculation considering constant infill wall opening of 30%. The considered buildings are regular in shape having equal three number of bays in both horizontal directions. Fundamental period of building is determined through Rayleigh method and effect of different considered parameters on fundamental period is analyzed and based on regression analysis, an analytical expression based on these considered parameters for calculation of fundamental time period is proposed.

3.1 Building parameters and material properties

The size of the columns and beam are shown in Table 2. Beam and column sizes are taken by considering least percentage of reinforcement bar.

Table 2: Column and Beam sizes for different storey

No. of storey	Column size	Beam size
3	350mm X 350mm	300mm X 250mm
6	500mm X 500mm	300mm X 250mm
9	600mm X 600mm	550mm X 400mm

Table 3: Column and Beam sizes for different storey

Compressive strength of concrete	25 MPa
Modulus of elasticity of concrete	2500 MPa
Poisson's ratio of concrete	0.2
Unit Weight of concrete	25 kN/m^3
Tensile yield strength of rebar	500 MPa
Modulus of elasticity of reinforcement bar	200000 MPa
Poisson's ratio of rebar	0.3
Number of storeys	3, 6, and 9
Storey Height	3m (Fixed)
Number of bays/spans	3numbers (Fixed)
Span/bays length	3m,3.5m and 4m
Slab thickness	150mm
Unit weight of brick masonry	17.3 kN/m3

The building parameters and materials properties considered for analysis are listed in Table 3. Also, the design of RC frames was based on NBC 105:2020 considering the flexural and shear stiffness of cracked concrete section in the analysis, which is as shown in table 4.

Table 4: Effective stiffness of structual components

Components	Flexural stiffness	Shear stiffness
Beam	$0.35E_cI_g$	$0.40E_cA_w$
Column	$0.70E_cI_g$	$0.40E_cA_w$

3.2 Properties of infill wall

Mechanical properties of masonry and wall panel was taken from previous experimental study .In the present study, thickness of wall is taken constant for both external walls and internal walls with constant 30% opening. The unit weight of brick masonry is taken as 17.3 kN/m3. Poisson ratio of wall panel is 0.32 [14]. The modulus of elasticity of infill wall panel and thickness is varied as per Table 5. This range of modulus of elasticity and thickness of wall panel will cover almost all types of masonry wall constructed on Kathmandu valley.

Table 5: The considered Modulus of Elasticity and Thickness of Infill Wall Panel

E (MPa): 2000, 3500, 4300, 5200, 6000
t(mm): 100, 150, 200, 250

3.3 Modeling and structural design of building

Initially frame buildings were designed and passed according to linear static method taking in reference the design building code NBC: 105-2020. All the building elements were checked and verified to ensure that all the members could resist the loads applied on them. For designing purpose, initially, code-based fundamental time period was taken. Live load intensity of 3 kN/m2 is applied for typical floor levels and nil for top floor. Similarly, floor finish of 1 kN/m2 is applied for all the floor levels.

In this study the infill wall is modeled as macro modeling as single equivalent strut . Infill wall panel is represented by a diagonal compression strut of thickness equal to that of infill and width calculated from equation 12 . Load of infill walls is applied as uniformly distributed frame load on beams and only stiffness properties of walls are given in strut modeling. Strut elements were connected to frame joints with pin connection i.e. moment release connection so that strut member only take compression forces and the tensile strength of the strut are neglected.

For design of building models load combination are taken as for limit state method for parallel systems of NBC. In this research, for seismic weight calculation,live load is taken as 30% of live load along with dead load as per code . Importance factor was taken 1.25, seismic zone factor of 0.35 and site soil condition was taken to represent the very soft soils of Kathmandu valley in the design process. The 3D model of sample building with diagonal strut is shown in figure 2.

3.4 Rayleigh method

For linear elastic analysis, Rayleigh method is based on energy conservation concept , where period is calculated by equating kinematic energy and potential energy .Rayleigh method is mostly accepted method of finding the fundamental time period of structure and is prescribed by most of codes and used by many researches and gives satisfactory approximation of fundamental period of building.

From Rayleigh method fundamental time period is calculated as:

$$T_1 = 2\pi\sqrt{\frac{\sum_{i=1}^{n} w_i d_i^2}{g\sum_{i=1}^{n} F_i d_i}} \tag{18}$$

Where,

(F_i) , (d_i) and (w_i) are the lateral force, horizontal displacement due to applied lateral force and seismic weight at foor i respectively.

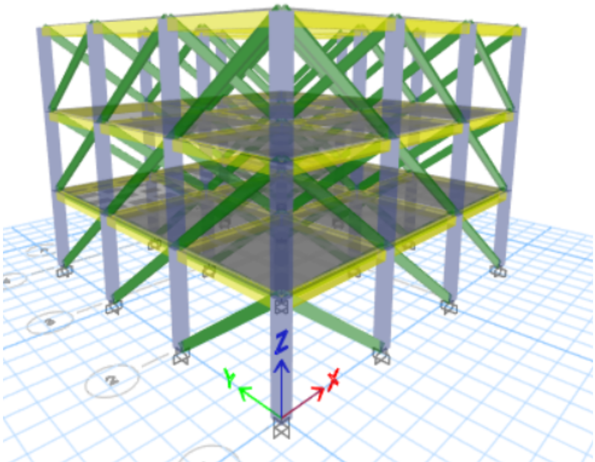


Figure 2: 3D model of sample building with diagonal strut

4. Results and Discussion

4.1 Effect of variation of infill wall strength on the fundamental time period of building

4.1.1 Effect of modulus of elasticity(E) of infill wall panel

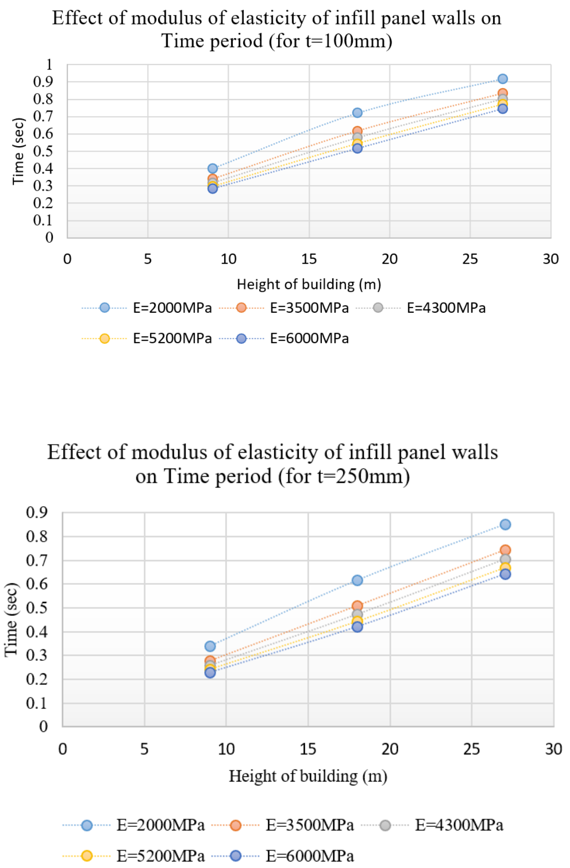


Figure 3: Effect of modulus of elasticity of infill wall panel on fundamental time period (for span length 4m)

Elasticity modulus of infill wall was varied between 2000-6000MPa (2000,3500,4300,5200 and 6000). Results upon analysis show that, for constant wall thickness, time period decreases when modulus of elasticity of infill wall panel increases. This variation can be observed in figure 3 . For eg: For a height of 9m, and thickness of infill 100mm, T=0.402sec for E = 2000MPa and T=0.284sec for E= 6000Mpa. Similarly for other considered thickness of walls, same kind of significant variation was found in time period for varying modulus of elasticity. The variation of time period was found more in 9m building than for 27m building. Thus, for low rise buildings the modulus of elasticity of infill wall has significant effect in time period than that for the high-rise buildings.

4.1.2 Effect of thickness of infill wall panel

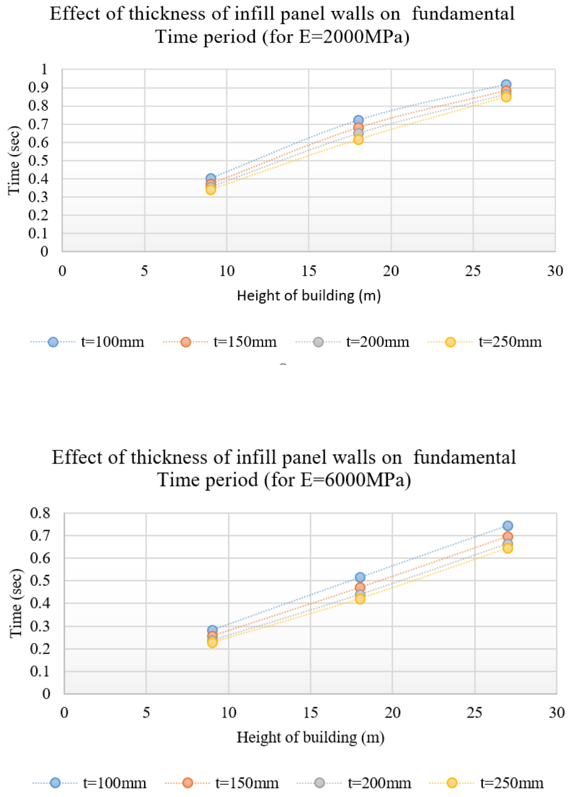


Figure 4: Effect of thickness of infill wall panel on fundamental time period (for span length 4m)

Thickness of infill wall panel was varied between 100 – 250 mm (100,150,200,250 mm) and their effect on fundamental time period for a constant modulus of elasticity were investigated. Plot of fundamental time periods versus height of building for different wall thickness are shown in figure 4. For eg: For a height of 9m, and modulus of elasticity of infills 2000MPa, T=0.402 sec for t=100mm and T=0.341sec for t =250mm. Similarly for other considered values of E, same kind of significant variation was found in time period for varying thickness of walls. It was observed that as the thickness of wall increases the fundamental time period decreases. This decreasing pattern is similar for all three different heights of building with varying thickness of wall. Result on analysis show that for greater building height fundamental time period is less affected by infill wall thickness than for lower height building. For other span lengths 3 and 3.5m pattern of variation is similar to that for 4m span.

4.2 Regression Analysis

Fundamental vibration period of considered 180 building models are determined through Rayleigh method and effect these consider parameters upon the fundamental period is analyzed. Multiple linear regression analysis was done to obtain an approximate empirical formulae. Initially, considering the fundamental period of building as the function of building height, base dimension, thickness and modulus of elasticity of wall and regression analysis is done. The proposed expression of fundamental time period is of the form:

$$T = \alpha \frac{H^{\beta} D^{\gamma}}{E^{\delta} t^{\lambda}} \tag{19}$$

Here, α, β ,γ ,δ ,λ are coefficients of regression. After analysis values of unknown regression coefficients are obtained and proposed analytical expression is as:

$$T = 0.452 \frac{H^{0.874} D^{0.333}}{E^{0.284} t^{0.164}} \tag{20}$$

Here, from analysis obtained value of R^2 is 0.993 and the standard error is 0.033. similarly for other consideration, obtained equation are as follows:

$$T = 0.987 \frac{H^{0.874}}{E^{0.284} t^{0.164}} \tag{21}$$

Here, obtained R^2 is 0.985 and the standard error as 0.051.

$$T = 0.02 H^{0.874} D^{0.333} \tag{22}$$

With R^2 as 0.9069 and standard error as 0.127.

$$T = 0.04 H^{0.874} \tag{23}$$

Having R^2 as 0.898 and standard error as 0.133. Here from different regression analysis, the value of R^2 and standard error for equation 20 is lower than other equations. Thus, the fundamental time period equation as proposed in equation 20, which is best fitted among all. Also,period and height depended relation of equation 24 have higher value of R^2 and standard error than other equation. Which shows that time period is not fully dependent on height of building but also the stiffness of infill wall plays considerable role in fundamental period of building.

4.3 Comparison between time period from Rayleigh method with proposed equation

For verification of the fundamental period using the developed analytical equations, real building having three number of storey (figure5) is chosen, having following properties: column (350mmx350mm) , beam (350mmx250mm), slab 127mm. The average wall thickness was taken as 150mm and modulus of elasticity of infill wall panel was taken as 2700MPa.Now we can estimate fundamental period of building using proposed equations and obtained time period value is compared with the fundamental period obtained from Rayleigh method and calculated as per latest building code NBC105: 2020. Table 6 shows the comparison of different proposed empirical equations for chosen real building.

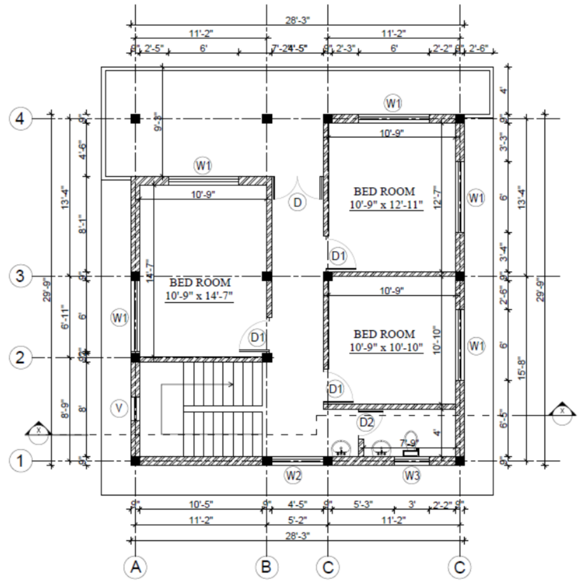
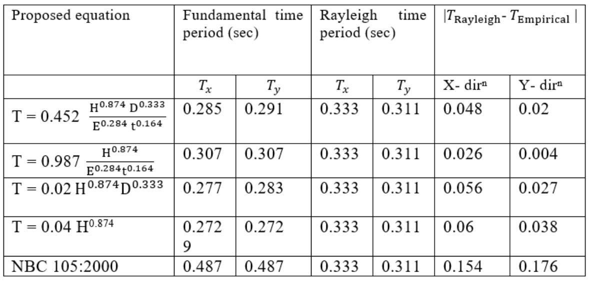


Figure 5: Plan of sample real building

Table 6: Comparison of different empirical equation for chosen real building



Proposed equation	Fundamental time period (sec)		Rayleigh time period (sec)		$\lvert T_{\text{Rayleigh}} - T_{\text{Empirical}} \rvert$	
	T_x	T_y	T_x	T_y	X- dir^n	Y- dir^n
$T = 0.452 \frac{H^{0.874} D^{0.333}}{E^{0.284} t^{0.164}}$	0.285	0.291	0.333	0.311	0.048	0.02
$T = 0.987 \frac{H^{0.874}}{E^{0.284} t^{0.164}}$	0.307	0.307	0.333	0.311	0.026	0.004
$T = 0.02 H^{0.874} D^{0.333}$	0.277	0.283	0.333	0.311	0.056	0.027
$T = 0.04 H^{0.874}$	0.272 9	0.272	0.333	0.311	0.06	0.038
NBC 105:2000	0.487	0.487	0.333	0.311	0.154	0.176

Here, comparison result shows that for real building, proposed empirical equation gives fundamental time period values very closed to fundamental period obtained through Rayleigh method. These difference in period results is closed to the similar comparison results of J.C. Rimal [7] and R. Dhakal [15] in their research works.Thus, for practical application proposed equation gives the fundamental time period close enough to the fundamental period obtained using the Rayleigh method.

5. Conclusions

After study of results obtained from 180 considered models by considering effect of infill wall stiffness along with height and base dimension of building on fundamental time period of building, the following conclusion can be drawn:

- Infill wall panel stiffness has considerable effect on fundamental time period of building. For 3 to 6 storey building, time period is decreased by around 30% by considering infill wall panel with (E = 2000MPa and t = 100mm) and decreased by around 65% for infill wall panel having (E = 6000MPa and t = 250mm) and these values for 9 storey building is around 10% and 35% respectively. Thus, for low to medium height building infill wall plays more important role on fundamental time period.
- By increasing the modulus of elasticity and thickness of wall, this increases the stiffness of a building and decrease the fundamental period of building. Decreasing pattern is almost constant with increasing rate of stiffness. As a result of this infill walls and their modulus of elasticity and thickness should be considered for determination of fundamental time period.
- Increasing the span length also increases the fundamental time period of building.
- The proposed analytical expression which includes height of building, base dimension, wall thickness and modulus of elasticity shows better results for prediction of fundamental time period of building.

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