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

by

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ABSTRACT

Fundamental time period of structure is the most censorious parameter for seismic design of structure. Fundamental period of building depends upon geometry of building, mechanical properties of construction materials and other various factors. In this research, impact of infill wall panel stiffness on the fundamental time period of regular reinforced concrete frame building was investigated. A total of 180 regular building models were studied 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.

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LIST OF ABBREVIATIONS AND SYMBOLS

| Symbols | Descriptions |
|----------------------------|---|
| NBC | Nepal Building Code |
| RCC | Reinforced Cement Concrete |
| MDOF | Multi-degree of freedom |
| 3D | Three Dimensional |
| A_c | Area of shear walls in first storey |
| A_i | Effective cross-sectional area of shear wall i |
| a_w | Percentage openings within infill panels |
| A_{wi} | Effective cross-sectional area of shear walls in first storey |
| B | Number of bays |
| $C_1 - C_7$ | Coefficients |
| C_t, k_t, α, C_w, m | Coefficients |
| D | Span length of building |
| d | Lateral elastic displacement of the top level of building |
| D_e | Length of the shear wall in the first storey |
| d_i | Elastic horizontal displacement of center of mass of building |
| E, E | Modulus of elasticity of infill wall panels |
| F | Frame types |
| F_i | Lateral force acting at level i |
| H, h, h_n | Height of building |
| I | Ratio of infill walls to total panels |
| K | Stiffness of building |
| K_s | Subgrade modulus of soil |

| | |
|------------------------------------|--|
| L | Span length / Building length along considered direction |
| M | Mass of building |
| N | Number of storeys |
| P | Shear wall ratio |
| S | Ratio in % of shear walls to total floor area |
| T, T _a , T ₁ | Fundamental time period of building |
| T _L | Lower limit for fundamental period |
| T _U | Upper limit for fundamental period |
| W _i | Seismic weight at level i |
| $\alpha, \beta, \gamma, \delta$ | Regression coefficients |
| $\alpha_1, \alpha_2, \alpha_3$ | Modification coefficients |
| ω | natural frequency of building |

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CHAPTER 1: INTRODUCTION

1.1 Background

One of the most significant parameters for seismic design of structures is the fundamental period. The fundamental period depends on the distribution of stiffness and mass of building along its height. Mathematically time period is calculated as per equation 1.1.

$$T = 2\pi \sqrt{\frac{M}{K}} \quad (1.1)$$

As a result, any structure with mass and stiffness, or both, has an influence on the building's fundamental period. There are many approaches from different literature for its calculation which often contradict with one another, making their usage doubtful. The amplitude, direction, and location of dynamic forces, particularly due to earthquakes, change dramatically over time and create major inertia effects on buildings and its components. The dynamic properties of structures, which are regulated by both their mass and stiffness properties, determine how they behave when subjected to dynamic forces.

At present, mostly the fundamental period of buildings can be calculated by a modal analysis, or by a rational method known as Rayleigh's method. The fundamental period of structures is computed using empirical equations derived from regression analysis of numerical values collected from observed periods of vibrations of real buildings during past earthquake ground motions. These empirical equations are mostly a function of height and types of building and in some codal provision also gives equation based on plan length along with height and ignores the effect of several other parameters that affect the period of building. The differences in the fundamental period of structures calculated by the empirical codal equations and computational methods of analysis (i.e., Exact eigen value analysis or Rayleigh method) is due to removal of the effects of non-structural members/secondary components such as: infill walls, are not considered in the computational methods. There have been various proposed formulae for predicting the fundamental period of reinforced concrete frames that correlate parameters besides the structure's type and height.

For determining the period of vibration of a building, the most frequent and widely used codal equation is of the form as per equation 1.2 as:

$$T = C_t H^{0.75} \quad (1.2)$$

Where, C_t is a coefficient and H is the overall height of the building. The above empirical formula was initially used by ATC3-06 for moment resisting reinforced concrete building and were theoretically derived using the Rayleigh method which is the rational energy-based method for finding the natural period. While deriving this form of formula, it was assumed that the lateral loads are distributed linearly over the height of the building at the diaphragm center of mass and the distribution of stiffness with the height produces uniform story displacement under linearly distributed lateral forces. Rayleigh formula for the computation of fundamental period T_1 (second) is given by:

$$T_1 = 2\pi \sqrt{\frac{\sum_{i=1}^n (W_i * d_i^2)}{g(\sum_{i=1}^n (F_i * d_i))}} \quad (1.3)$$

Where, d_i is the elastic horizontal displacement along applied loads at diaphragm center of mass at level i , F_i is the applied horizontal load at level i , g is an acceleration due to gravity, i is level under consideration, n is the number of levels in the structure and W_i is the seismic weight at level i .

1.2 Need of study

Many codes provide the empirical equation for the fundamental time period which is depends on height of building only. But different literatures suggest that the time period depends not only upon the building height but also on others parameters of building such as: numbers of stories, numbers of bays, spacing of bays, use of infill walls, irregularity in plan, soil surface interaction and many other factors, which affect the fundamental period. As a result, it is necessary to investigate the impact of these parameters on the foundational period.

This study will cover effects of infill walls strength by varying infill wall panel thickness and modulus of elasticity which differ stiffness parameter of infill wall, which is considered the important parameters that affect the fundamental time period of the structure, along with the height and plan dimension of structure.

1.3 Objectives

The main objective of this thesis is to find out effect of infill wall stiffness on fundamental time period of regular RC frame buildings. The specific objectives can be listed as below:

- To determine impact of infill wall stiffness on the fundamental time period of building.
- To calculate the fundamental time period of building by Rayleigh method.
- To generate an analytical expression for fundamental time period of moment resisting frame building which depends on height of building (H), base dimension (D) and infill wall parameters (modulus of elasticity (E) and thickness (t)).

1.4 Scope and limitation of the research

In this research, the fundamental period of all computer models determined by Rayleigh's method is compared with code equations. Study will be carried out to investigate the effect of each parameter (height, base dimensions, modulus of elasticity of infill wall panel and thickness of wall panel) on the fundamental period of the building.

The limitations of the study are:

- Irregular plan shapes, topology, shear walls, lift core walls etc. are not considered.
- Number of bays and storey height are kept constant.
- Only linear static method is used for analysis and fundamental period is calculated using Rayleigh method.
- The foundation is assumed to be rigid foundation.
- Both external and internal wall are of same thickness with constant opening.
- Infill wall is model as single equivalent diagonal strut model and the mass of the infill walls is applied as uniformly distributed load on the beams.

1.5 Methodology

Methodology steps for achieving the above-mentioned objectives are as follow:

1. Review of different building codes and literatures.
2. Selection of different regular framed buildings for analysis.
3. 3D Modelling in finite element software (ETABS) of considered buildings.
 - Parameters taken into consideration:
 - Ht. of the building
 - Base dimension of building
 - Strength of infill wall

Modulus of elasticity (E)

Infill wall thickness (t)

(Number of bays is taken as 3 for both direction and height of building is taken as fixed 3m)
4. The fundamental period for each building is calculated using the Rayleigh method.
5. Analysis of results and interpretation
6. Based on the parameters taken into account, an approximate formulation of the fundamental time period has been developed.

1.6 Organization of chapters

This thesis work has been mainly organized in five chapters.

- **Chapter 1** Presents an introduction on fundamental time periods, Also the need of study, objective of research and methodology to be followed to fulfill research objective.
- **Chapter 2** Presents provision of different codes and literature review on fundamental time period of a structure. It covers significant research and study conducted for finding the natural period of moment resisting RC buildings.
- **Chapter 3** Outlines analysis methods for finding out the fundamental time period of a structure. The Eigen value solution and Rayleigh method of analysis are discussed.
- **Chapter 4** Described about the modeling of the structures which includes the description of building, material properties, loads considered and infill walls materials and modeling.
- **Chapter 5** Includes the main results and discussions, sample calculation of fundamental time period by Rayleigh method, comparison of fundamental time period obtained through different codal empirical formulae and proposed equations with Rayleigh method and results are shown in tabulated form.
- **Chapter 6** Summarizes the main conclusion of the research and includes some recommendations for future research.

References and Appendix listed after chapter 6

CHAPTER 2: LITERATURE REVIEW

2.1 Review of Building Design Codes for Fundamental Time Period

Most of codes of different country suggest an empirical formula mostly based on height of building for calculation of fundamental time period of building.

2.1.1 USA

In the USA, Combined committee of Structural Association of Northern California and the San Francisco Section of American Society of Civil Engineers recommend empirical formula based on height (h) and Span length (D) of the building as per equation 2.1 as:

$$T = \frac{0.05h}{D^{0.5}} \quad (2.1)$$

Also, in 1957, Structural Engineers Association of California (SEAOC) put the similar recommendations. In 1967, UBC after introduced of concept of ductile detailing of reinforced concrete moment frames and steel moment frames. Fundamental time period was calculated as per equation 2.2 and 2.3 as:

$$T = 0.10N \quad \text{for ductile moment frames} \quad (2.2)$$

$$T = \frac{0.05H}{D^{0.5}} \quad \text{for other buildings} \quad (2.3)$$

These also allowed the building period to be determined by using the Rayleigh method and for this the lateral forces may be applied in any rational manner and not necessarily those obtained from code formulas. However, the displacements must be the displacements computed for the forces used (Anderson J.C. & Naeim F., 2012).

1978 ATC 3-06 Resource Document for Model Codes

In 1978, a national group of experts in the field of earthquake engineering was convened by the Applied Technology Council (ATC) to write a resource document for model codes that would incorporate the latest thinking and research on the design of earthquake resistant structures. The main provisions of ATC 3-06 were released by the National Earthquake Hazard Reduction Program (NEHRP) as a code, The building period can be estimated using one of the following formulae:

For Moment Resisting Frames:

$$T = C_T h_n^{0.75} \quad (2.4)$$

Where, C_T is 0.035 for steel frames and 0.030 for reinforced concrete frames.

For all other buildings:

$$T = \frac{0.05h_n}{\sqrt{L}} \quad (2.5)$$

Where, L = the length of the building in the direction under consideration (Anderson J.C. & Naeim F.).

1988 UBC

This version of the UBC gives the building period may be the building period may be determined by either analysis or by using an empirical formula. The empirical formula 2.6 has the form

$$T = C_T h_n^{3/4} \quad (2.6)$$

where C_t is 0.035 for steel moment frames, 0.030 for reinforced concrete moment frames and eccentric braced frames and 0.020 for all other buildings

UBC also incorporate the Rayleigh method for fundamental period calculation. The 1997 revision to the UBC includes many of the recommendations of ATC 3-06. The basic formula for the building period in 1997 revision is similar to that of 1988 UBC. The exception is that the constraints on the use of Rayleigh's method have been relaxed. In Zone 4, the value calculated using a Rayleigh procedure cannot be more than 30 percent that given by the formula. In the other three seismic zones, it cannot be greater than 40 percent (Anderson J.C. & Naeim F.,2012).

ASCE 7 Seismic Design Criteria

According to ASCE 7 seismic design criteria approximate fundamental period shall be determined by the equation 2.

$$T_a = C_t h^x \quad (2.7)$$

Where C_t & x are determined from table 12.8-2 of ASCE 7 and h is the height in feet, from the base to the uppermost level of the structure.

Approximate Fundamental Period T_a for tabulated values of ASCE 7 are as:

- For Steel Moment-Resisting Frames
 $T_a = 0.028 h^{0.8}$ (2.8)
- For Concrete Moment-Resisting Frames

$$T_a = 0.16 h^{0.9} \quad (2.9)$$

- All Other Structural Systems

$$T_a = 0.02 h^{0.75} \quad (2.10)$$

2.1.2 EUROPE

Eurocode 8 suggest the use of expressions based on methods of structural dynamics like Rayleigh method for the determination of the fundamental period of vibration period T_1 . For buildings with heights up to 40m, the value of T_1 may be calculated approximated by the expression 2.11.

$$T_1 = C_t H^{3/4} \quad (2.11)$$

where the value of C_t is 0.085 for MRF steel frames, 0.075 for MRF concrete frames and eccentrically braced steel frames and 0.050 for all other structures. The building height H is in meter. Alternatively, for structures with concrete and masonry shear walls, the value of C_t maybe taken as per equation 2.12.

$$C_t = \frac{0.075}{\sqrt{A_c}} \quad (2.12)$$

$$\text{Where, } A_c = \Sigma [A_i (0.2 + (\frac{l_{wi}}{H})^2)] \quad (2.13)$$

where, A_c is the total area of the shear walls in the first storey of the building in square meter, A_i is the effective cross-sectional area of the shear wall i in the direction considered in the first storey of the building in square meter, H is the height and l_{wi} is the length of the shear wall i in the first storey along the direction parallel to the applied forces, in m, with the restriction that $l_{wi} = H$ should not exceed 0.9.

Alternatively, the estimation of T_1 may be made by using the expression $t_1 = 2(d)^{0.5}$ where, d is the lateral elastic displacement of the top storey of the building in (m) due to the gravity loads applied in the lateral direction.

2.1.3 NEW ZEALAND

The Rayleigh method is widely recognized as a best method for predicting the fundamental period of vibration of a structure because it is based on methods of structural dynamics and Rayleigh utilizes the actual material and member properties to form a structural stiffness matrix. Nevertheless, there are also a number of empirical methods that have been suggested by NZS 1:2004 for use in determining the fundamental natural period of structures.

Empirical method (A):

$$T_1 = 1.0k_t h_n^{3/4} \quad (\text{for serviceability limit state}) \quad (2.14)$$

$$T_1 = 1.25k_t h_n^{3/4} \quad (\text{for ultimate limit state}) \quad (2.15)$$

where, h_n is the height taken in m from the base of the structure to the uppermost seismic weight.

The values of k_t are 0.075 for MRF concrete frames, 0.11 for MRF steel frames, 0.06 for eccentrically braced steel frames, and 0.05 for other frame structures respectively.

Alternatively, the value of k_t with concrete shear walls may be taken as:

Empirical method (B):

$$K_t = \frac{0.075}{\sqrt{A_c}} \quad (2.16)$$

where, A_c is the total effective area of the shear walls in the first storey in the building found similar to the Eurocode 8 as in equation (2.13).

Alternatively, the estimation of period can also be made by using the expression 2.17.

Empirical method (C)

$$T_1 = 2\sqrt{d} \quad (2.17)$$

where, d is the lateral elastic displacement of the top of the building, in m, due to the loads applied in the horizontal direction.

2.1.4 JAPAN

According to the Building Standard Law in Japan (BSLJ-1981), the fundamental natural period of the building, T , is determined by equation 2.18.

$$T = H(0.02 + 0.01\alpha) \quad (2.18)$$

where, H is the height of the building (m) and α is the ratio of the total height of steel construction to the height of the building ($\alpha = 0$ for concrete and $\alpha = 1$ for steel construction).

2.1.5 PAKISTAN

According to the building code of Pakistan, for all buildings, the value of period, T may be calculated by equation 2.19.

$$T = C_t h_n^{3/4} \quad (2.19)$$

The value of C_t is taken as 0.0853 for steel MRF, 0.0731 for RCC MRF and eccentrically braced frames and 0.0488 for all other buildings.

$$K_t = \frac{0.073}{\sqrt{A_c}} \quad (2.20)$$

For structure with concrete or masonry shear wall. A_c determine as per equation 2.21.

$$A_c = \sum [A_e (0.2 + (\frac{D_e}{h_n})^2)] \quad (2.21)$$

where, D_e is the length of the shear wall in the first storey in the direction parallel to the applied forces and h_n is the height.

2.1.6 BANGLADESH

According to BNBC-2015, Rayleigh or modal eigenvalue analysis method can be used for determination of the period of the building in the direction under consideration. And this period should not exceed the approximate fundamental period (2.22) by more than 40 percent.

$$T = C_t h_n^m \quad (2.22)$$

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 value of m is 0.9, 0.8, 0.75 and 0.75 for concrete MRF, steel MRF, eccentrically braced frame and other systems respectively.

According to BNBC code, for masonry or concrete shear wall structures, the approximate fundamental period may be determined as per equation 2.23.

$$T = \frac{0.0062 h_n}{\sqrt{C_w}} \quad (2.23)$$

Where, C_w is calculated as per equation 2.24.

$$C_w = \frac{100}{AB} \sum_{i=1}^x \left(\frac{h_n}{h_i} \right)^2 \frac{A_i}{[1 + 0.83 \left(\frac{h}{D_i} \right)^2]} \quad (2.24)$$

where, AB is the area of the base structure, x is the number of shear walls in the building effective in resisting lateral forces in the direction under consideration, A_i , h_i and D_i are web area, height and length of shear wall i .

2.1.7 INDIA

The approximate formula for fundamental translational natural period T_a of oscillation, in second, shall be estimated by the following expressions:

a) Bare MRF building (without any masonry infills):

$$T_a = 0.075h^{0.75} \text{ for (RC MRF Building)} \quad (2.25)$$

$$T_a = 0.080h^{0.75} \text{ for (RC-Steel Composite MRF building)} \quad (2.26)$$

$$T_a = 0.085h^{0.75} \text{ for (Steel MRF building)} \quad (2.27)$$

Where, h height (m) of building, this excludes the basement storey,

b) Building with RC structural walls:

$$T = \frac{0.075h^{0.75}}{\sqrt{A_w}} > \frac{0.09h}{\sqrt{d}} \quad (2.28)$$

where, A_w is total effective area of walls in the first storey of the building given by

$$A_w = \sum_{i=1}^{N_w} [A_{wi} \{0.2 + (\frac{L_{wi}}{h})\}^2] \quad (2.29)$$

where, A_{wi} is the effective cross-sectional area of wall in the first storey in m^2 , N_w is the number of walls in the considered direction of earthquake shaking and h is the height of the building.

c) For all other buildings:

$$T = \frac{0.09h}{\sqrt{d}} \quad (2.30)$$

2.1.8 NEPAL

NBC-105:2020

The fundamental translation period shall be determined using following methods:

2.1.8.1 Rayleigh Method

The fundamental translation period in the direction under consideration, T_1 , shall be calculated as per equation 2.31.

$$T_1 = 2\pi \sqrt{\frac{\sum_{i=1}^n (W_i * d_i^2)}{g(\sum_{i=1}^n (F_i * d_i))}} \quad (2.31)$$

Where, d_i is the elastic horizontal displacement of center of mass at level i , (ignoring the effects of torsion), F_i is the lateral force acting at level i , g is an acceleration due to

gravity, i is the level under consideration, n is the number of levels in the structure and W_i is the seismic weight at level i .

2.1.8.2 Empirical Equations

The approximate fundamental period of vibration, T_1 , in seconds is determined from empirical equation 2.32.

$$T = K_t H^{3/4} \quad (2.32)$$

Where K_t

= 0.075 for Moment resisting concrete frame

= 0.085 for Moment resisting structural steel frame

= 0.075 for Eccentrically braced structural steel frame

= 0.05 for all other structural systems

Where, H is the height of the building from foundation or from top of rigid basement

The approximate fundamental time period calculated using empirical equation (2.32) shall be increased by a factor 1.25.

For determining design action lesser value of two from section 2.31 and 2.32 shall be adopted.

According to NBC for determining seismic weight at each level, W_i , shall be taken as the sum of the dead loads and the factored seismic live load between the mid- heights of adjacent stories.

Seismic load factors (λ) for live load categories as follows:

Storage = 0.6

For other purpose = 0.30

Roof = Nil

From above mentioned empirical formula from different building codes, plot of time period vs building height is plotted and compared as shown in figure (2.1). From graph fundamental time period of reinforced concrete frame building calculated from empirical formula of NBC105:2020 and NZS 1:2004(ULS) gives more values than other codes and ASCE-7 gives least values of fundamental time period than others.

Fundamental time period calculated from IS code, Bangladesh code and Pakistan codes are almost similar values.

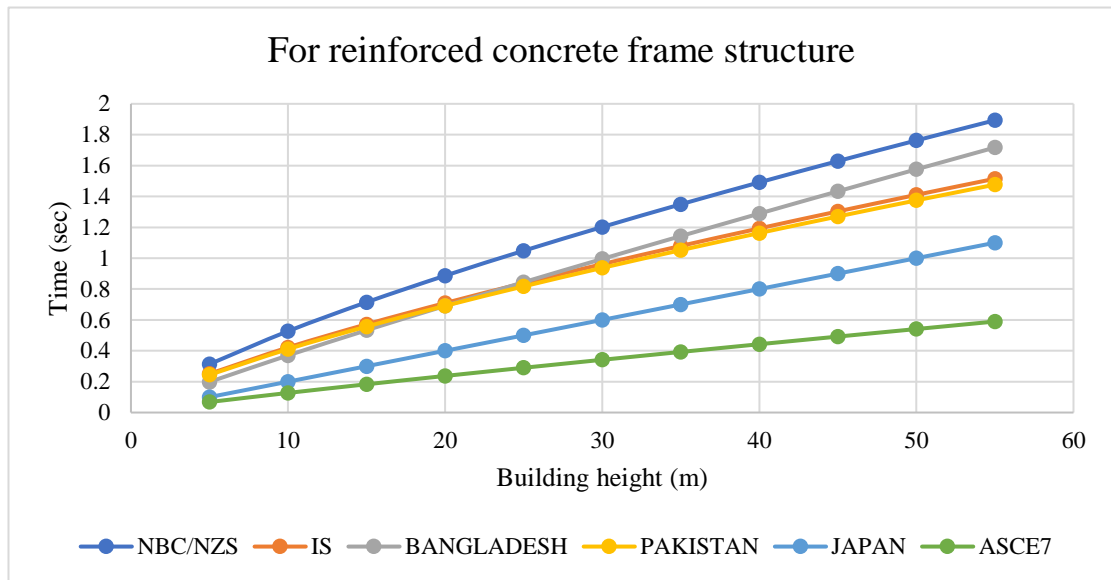


Figure 2.1 Comparison of empirical equation for fundamental time period of reinforced concrete frame structure from different building codes.

2.2 Review of Research Conducted for Fundamental Time Period

Mehmet Metin Kose (2008) studied the effects of building height, number of bays, ratio of area of shear walls to area of floor, ratio of infilled panels to total number of panels and type of frame on the period of RC buildings. In his investigation, 189 building models with selected parameters were developed and examined in 3D using the finite element method in his research. He observed that RC frames with infill walls had a 5 percent to 10% shorter period than RC frames without infill walls, regardless of whether or not they had shear walls. The existence of shear walls on a building also contributed in a 6 percent to 10% reduction in the fundamental period compared models with and without infill walls. Furthermore, fundamental periods calculated through iterative modal analysis were compared to current code predictions, which are based on data taken during earthquakes on real sample buildings. He also determines that, depending on the model parameters, the current codal equations under-predict the basic periods of the buildings by 2% to 47%. Also proposed empirical equation, which was a function of the considered parameters (height, number of bays, frame types, percentage shear wall, area ratio of infill walls), Based on the results of this research, multiple linear regression analysis was used to forecast the fundamental period of buildings as per 2.33.

$$T = 0.0935 + 0.0301H + 0.0156B + 0.0039F - 0.1656S - 0.0232I \quad (2.33)$$

Where, H is the building's height in meters, B is the number of bays, and F is the frame types (value of F as: 1 for frames with infills, 2 for frames with an open first floor, and 3 for frames without infills), S is the ratio in % of shear walls to total floor area and I is the area ratio of infill walls to total panels.

From his analysis, the fundamental period of buildings is not too sensitive to the number of bays and frame type, so he modified formula as per equation 2.34.

$$T = 0.1367 + 0.0301H - 0.1663S - 0.0305I \quad (2.34)$$

G. Asteris et al. (2015, 2016) presented a study on the fundamental period of infilled reinforced concrete RC structures by examined the factors that affect the fundamental period of RC structure such as: storey number of buildings, number of spans, length of span, soft storey, soil surface interaction, strength of infill and opening percentage. They conduct effect of number of spans on time period by varying number of spans for 8 and 14-storey building and concluded that fundamental time period of building is not influenced by the number of spans. By changing the span length, the impact of span

length on the fundamental time period of 8 and 14-story buildings are examined. As the span length increases, the time period of the building increases too. They also conducted influence of infill masonry panel stiffness on the fundamental period of building by varying masonry panel stiffness. It can be seen that the period is very sensitive to the stiffness of the infill wall. The infill wall works as a diagonal brace, controlling lateral deflection. So, if infill wall panel added to the structure, then the lateral stiffness and fundamental period of building also decreases. Also effect of span length on fundamental period of structure is similar as the infill wall stiffness increases. And decreases of fundamental period by considering infill wall thickness is similar for all height of building. Again, when infill opening percentages are between 75 and 80 percent of total infill area, the fundamental period increases linearly, but when opening percentages are larger than 80 percent, there is no influence on the fundamental period of the building. This is because when the opening percentage exceeds 80%, the infill effect on mass and stiffness of the building is minimal. Furthermore, the fundamental period is determined by the quality of the soft-storey throughout the building height. When the soft storey is at the top level which is closer to the fully infilled frame, the period value is lower. When the soft storey of a building is on the lower floor but not on the first floor, the fundamental time period seems to have a higher value. And soft storey effect on fundamental time period is less for lesser values of stiffness of wall.

A similar team investigated the parameters in determining the fundamental period of RC frame buildings and estimated fundamental period values, which were compared to those obtained from the seismic code and equations suggested by other researchers. It was found that the number of storeys, length of span (L), the stiffness of the infill wall panels (E_t), percentage of openings within infill panels (a_w), the location of soft storeys and soil type were important factors that influenced the fundamental period of RC building.

They also performed a regression analysis and proposed a new empirical equation which give better predictive results compared with available equations in the literature. The equation proposed is as per equation 2.35.

$$T = (0.55407 + 0.5679\sqrt{H} - 0.00048L - 0.00027a_w - 0.00425E_t + 0.00202\sqrt{HL} + 0.00016\sqrt{Ha_w} - 0.00032HE_t + 0.00013La_w - 0.00017LE_t + 0.00010a_w E_t)^5 \quad (2.35)$$

Yildirim & A. Kocak (2009) in their paper, the effect of infill wall ratio on the period of reinforced concrete framed buildings was investigated. The effect of the infill wall on structure response and performance is investigated using reinforced concrete framed buildings with varying storey heights and infill wall ratios. In the x and y axes, analyses were undertaken for four and five distinct infill wall layouts. According to their studies, the fundamental time for a wall with infill is 10 to 50 percent shorter than for a bare frame. The period changes from (14-30) percent for structures of low and medium heights with an infill wall ratio of 0.20-0.40. They develop an equation (2.36) which reflects the relationship between the infill wall ratio and the fundamental period of vibration based on analysis of their experiments.

$$\Delta T(\%) = 69.1A_k^{1.08} \quad (2.36)$$

$$T_d = T_c \left(1 - \frac{\Delta T}{100}\right) \quad (2.37)$$

Where, ΔT is ratio of the decrease in the period of infill walls according to the period without infill walls (%), A_k is the ratio of infill wall area to (structural element area (column area) + infill wall area), T_d is the period of the building with infill walls and T_c is the period of the building with bare frames.

A Kocak et al. (2013) in their research, effect of infill walls to stiffness of RCC framed and load bearing structure are studied considering wall opening too. Infill wall was modeled by equivalent strut model suggested by FEMA-274 and FEMA-306. Six different types of opening scenarios fully closed, small window, small windows at middle, large and small window, door, and for these different coefficients of modulus of elasticity (β) are calculated for equivalent pin jointed diagonal models. Six distinct combinations of outside and interior infill walls are investigated. From their analysis they conclude that due to infill wall consideration in model's stiffness of building is increased and their affect remarkably seen in fundamental time period of buildings. Between bare frame and fully infilled frame, time period values reduce by about 70%, and between infilled frame with window-door openings building and fully infilled framed building, time period values decrease by around 15%.

Similar studies were conducted by Kocak (2008). Using experimental and analytical methods, they evaluated the fundamental vibration period of a 12-story RC structure in Turkey at various phases of construction. For a fully elastic state, the following building

height-dependent relationship (equation 2.38) was established to estimate the fundamental period of vibration of Turkish RC moment-resisting frames.

$$T = 0.026H^{0.90} \quad (2.38)$$

Five buildings were studied experimentally using the proposed equation, and it was observed that the fundamental periods of these buildings were in good agreement with those estimated using the proposed equation.

Amanat and Hoque (2006) used 3D FE modeling and modal eigen value analysis to investigate the fundamental periods of vibration of a set of standard RC framed buildings, taking into account the effect of infill walls. The period projected by the codal empirical formula is much longer than the period obtained by analysis when the models do not incorporate infill, justifying the establishment of an upper limit on the period by code. When the influence of infill was included in the models, the eigenvalue analysis periods were found to be near to those predicted by the code formulae. It was also observed that changing the amount of infills resulted in some change in the determined period. An equation 2.39 was proposed of the form:

$$T = \alpha_1 \alpha_2 \alpha_3 C_t H^{3/4} \quad (2.39)$$

Where, α_1 , α_2 and α_3 are coefficients accounting for span length of infill, number of spans, and amount of infills respectively and $C_t = 0.073$ for RC building.

They conclude that for each 1 m change in span from the reference value of 6m there is change in period by about 8%. The period is about 1.25 times the codal standard for 20% infill, and around 0.88 times the period estimated by the Bangladesh code for 80% infill.

Ibrahim Oz et al. (2020) looked at 40 existing buildings in Turkey and created nonlinear models that took into account fixed-base and stiff, moderate, and soft soil conditions. Buildings constructed before and after the Turkish Earthquake Code of 1998 were divided into two categories: old and new buildings. The substructure approach was utilized to reflect different soil conditions categorized according to shear wave velocities, and nonlinear time history analysis was employed to determine inelastic deformation demands. Twenty real acceleration data from significant earthquakes were used. Their findings reveal that soil-structure interaction, particularly in soft soil

conditions, has a considerable impact on the seismic response of low-rise buildings that are stiffer and stronger.

Jagadish C. Rimal (2019) investigated the fundamental time period of Moment resisting RC Frame buildings with height less than 40m. A total of 126 models of frame buildings were modeled, analyzed and designed using Finite Element software SAP2000 after which the fundamental time period was obtained for each. the fundamental period, such as height of building (H), bays number (B), length or base dimensions (D), and floors number was investigated, and an approximate formulation of time period was established using regression analysis. He suggested equation 2.40.

$$T = 0.030H^{0.82} D^{0.766} B^{-0.784} \quad (2.40)$$

Where, H represents the height in meters, D represents the base dimension in meters, and B represents the number of bays.

The time period was determined using the Rayleigh approach. He also contends, like others, that for constant bay length, the number of bays has no major effect on the fundamental period.

Mahesh R. Bhatt (2019) studied the influence of irregularities in stiffness and mass on the fundamental period of RC framed buildings including infills. They investigate 60 building models with a regular distribution of mass and stiffness in elevation and design them using a static model according to IS 1983:2002. Regular, irregular, and bare framed structures are examined based on the fundamental periods of the 6th, 9th, and 12th floors. The results reveal that infill has a large impact in fundamental times, and that the position and amount of irregularity have a major effect in fundamental periods. The time duration of irregular buildings was observed to be longer than that of regular buildings and shorter than that of bare frame buildings. Additionally, there is a positive correlation between the elevation of mass irregularity and the fundamental time period, as well as a negative correlation between the elevation of stiffness irregularity and the fundamental period. When mass irregularity was in the bottom half of the building and stiffness irregularity was in the top portion of the building, there was no notable impact in the fundamental period.

Goel and Chopra (1997) evaluated the formulas specified in the current US codes and established enhanced empirical equations to evaluate the fundamental vibration period of RC and steel moment- resisting frame (MRF) structures based on available data for

vibration period of 27 RC buildings and 42 steel buildings gained from vibrations observed during eight California earthquakes happening between 1971 and 1994. Based on the regression analysis of measured data for fundamental period of 27 RC MRF buildings, the equations are as 2.41 and 2.42.

$$T_L = 0.016H^{0.90} \quad (2.41)$$

$$\text{And, } T_U = 0.023H^{0.90} \quad (2.42)$$

were proposed for RC MRF buildings, where T_L and T_U represent the lower limit of fundamental period and upper limit for fundamental period. They came to the conclusion that the period from rational analysis should not be greater than 1.4 times the value of recommended equations. Because the analysis was based on data from California buildings, it was suggested that the established equations be applied with caution to buildings in other parts of the world.

Ramila Shrestha and Sudip Karanjit (2017) in this research, the fundamental period of the 31 RC infill structures in Kathmandu valley was determined using ambient vibrations collected at every building. The use of geophones was used to measure the ambient vibrations of buildings in Kathmandu. Fundamental time periods were measured empirically and estimated using several codal formulas. A single variable regression analysis was performed, and the relationship between time and building height was determined. In this study, the codal time period was shown to be longer than the experimental time period. The relationship between time period, height, and horizontal dimension was also established using multivariable regression analysis. The impact of the base dimension of the building on the fundamental time period is quite little, according to the multivariable regression formulation. The fundamental period of time of RC structures in our usual approach can be better associated by height only relation ($T = 0.05 H^{0.75}$) than height and base-dimension relation ($T = 0.093 \frac{H}{\sqrt{D}}$) presented by code. In the majority of situations, the fundamental time period derived from the codal formula for RC building with infill and from experimental results was found to be close.

André Furtado et al. (2019), the impact of infill masonry walls on the seismic performance of a 15-story high-rise structure in Kathmandu, Nepal, during the Gorkha Earthquake in 2015 was investigated. Ambient vibration studies were conducted to determine the building's vibration modes and natural frequencies. The masonry infill

walls were found to play a major role in the structure's seismic performance, underscoring the need of considering these aspects during the design of new buildings or the building structural assessment of existing buildings.

Gorge D. Hatzigeorgiou and Gorge Kanapitas (2013) In their work, they offer an empirical method for predicting the fundamental time period of RC buildings based on vibration analysis of 20 different buildings in Greece. Finite element models were used to consider and evaluate the soil surface interaction and the existence of exterior and internal infill walls, which were previously overlooked in analyses. Model eigen value analysis was used to determine the fundamental period of the buildings under consideration. They presented an empirical equation for the fundamental period T based on their examination of the following parameters: influence of soil surface contact, infill wall panels, concrete shear walls, and building span length., proposed empirical equation 2.43 for the fundamental period is as:

$$T = \frac{H^{C_1} L^{C_2} (C_3 + C_4 W)}{[1 - \exp(-C_5 K_S^{C_6})] \sqrt{(1 + C_7 \rho)}} \quad (2.43)$$

Where, K_S is the subgrade modulus of soil, ρ is the shear wall ratio, $C_1 - C_7$ are coefficients, H and L are building height and length along considered direction.

P.M. Pradhan et al. (2012) studied the fundamental period of vibration of building with, without and partially infilled frames. They found that vibration period of structure is reduced by (2.22-3.08) times for aspect ratio (height to span ratio) between 0.6:1 to 1.5:1. For partially infilled frame height up to 40% stiffness increment is insignificant but when infill wall height is greater than 40%, the bare frame becomes stiffer and thus more decrease in period.

P.K. Aninthaneni and R.J. Dhakal (2016) provided a more reliable equation for determining the basic time period of a regular structure. In their research method adopted for analysis is MacLeod's method by predicting roof deflection of building. They also considered Eigen value and Rayleigh method of calculation of fundamental period for the validation of their proposed equation. Equation 2.44 proposed is as:

$$T = 0.17 \varphi_3 \sqrt{\frac{W_s h^2 n_s (1 + \lambda)}{(n_b + 1) E_c I_c}} \quad (2.44)$$

Where, n_b is the number of bays, E_c and I_c are the modulus of elasticity of concrete and effective moment of inertia of column respectively.

2.3 Review of Research Conducted for Diagonal Equivalent Methods of Masonry Infill Panel

FEMA 356 Explained information of infill frame for determination of strength and stiffness of infill panel wall from mechanical properties of materials used in construction. Elastic stiffness by considering crack section on infill wall panel can be expressed with diagonal equivalent strut of width (a), which has similar thickness and elastic modulus with the masonry wall panel.

$$a = 0.175 (\lambda_1 h_{col})^{-0.4} r_{inf} \quad (2.43)$$

where:

$$\lambda_1 = \left[\frac{E_m t_{inf} \sin 2\theta}{4 E_c I_c h_{inf}} \right]^{1/4} \quad (2.44)$$

h_{col} = Height of column between beams

h_{inf} = Infill wall panel height

E_c = Expected modulus of elasticity of infill materials

I_c = Moment of inertial of column

r_{inf} = Infill panel diagonal length

t_{inf} = Infill panel thickness and equivalent diagonal strut

θ = Angle whose tangent is the infill height to length aspect ratio, radians

λ_1 = Coefficient (equation 2.44)

Malcolm Homes (1961) gives the equivalent width (equation 2.45) of strut which is one third of the diagonal length of infill wall panel.

$$W = 1/3 d_{inf} \quad (2.45)$$

Where, W is width of equivalent strut and d_{inf} is the diagonal length of infill wall panels.

B. Stafford Smith and C. Carter (1969) to compute the lateral stiffness of composite frames, an equation based on the behavior of multi-story infilled framed buildings was proposed, as well as a design method based on the equivalent strut concept. They conclude that the stiffness and strength of infilled frames are determined by the relative

stiffness of the frame and the infill. Based on their study, the following elements determine the effective width of an infill:

1. The column's relative rigidity and the infill
2. Infill attributes such as length and height
3. The infill materials' stress-strain relationship
4. The magnitude of the infill's diagonal load

From their research:

$$W = 0.58 \left(\frac{1}{H}\right)^{-0.445} (\lambda_1 H_{inf})^{0.335} d_{inf} \left(\frac{1}{H}\right)^{0.064} \quad (\text{Amalia and D. Iranata, 2017}) \quad (2.46)$$

$$\lambda_1 = \left[\frac{E_I t_{inf} \sin 2\theta}{4 E_{col} I_{col} H_{inf}} \right]^{0.25} \quad (2.47)$$

In which E_I , t_{inf} and H_{inf} are young's modulus of elasticity, thickness of infill and height respectively. E_{col} and I_{col} are the young's modulus of elasticity and second moment of area of the column, and θ is the slope of the infill diagonal to the horizontal.

R.J. Mainstone and G.A. Weeks (1970) described the number of full-scale tests on walls built as infilling to concrete steel frames and from their experiment tests proposed an equation 2.48 for the width of an equivalent strut as:

$$W = 0.175 d_{inf} (\lambda_h H_{inf})^{-0.4} \quad (2.48)$$

Which is similar to FEMA 306 and expression for coefficient λ_h is same as given by Stafford smith.

Paulay and M. Priestley (1992) Expressed an analytical expression based on a beam on elastic foundation analogy modified by experimental data which shows the effective width w of the diagonal strut is dependent on the relative stiffness of frame and infill wall panels. Potentially High value of width (equation 2.49) of strut is given by them as

$$W = 0.25 d_m \quad (2.49)$$

Where, d_m is the diagonal length of infill wall.

Liau and Kwan (1983) studied the nonlinear behavior of infill and frame not bonded case for both experimentally and analytically and proposed an expression for width of diagonal strut as per equation 2.50.

$$W = \frac{0.95 H_{inf} \cos\theta}{\sqrt{\lambda_h H_{inf}}} \quad (2.50)$$

Ghassan Al-Chaar (2002) gives the in-plane strength of URM infills. The comparable masonry strut should be pin attached to the frame component. The strut is attached to the column by a distance L_{column} from the face of the beam and distance is calculated using:

$$L_{column} = \frac{a}{\cos\theta_{column}} \quad (2.51)$$

The equivalent masonry strut should be pin-connected to the frame members, and its equivalent breadth (a) should be as per equation 2.53.

$$\tan\theta_{column} = \frac{h - \frac{a}{\cos\theta_{column}}}{l} \quad (2.52)$$

$$\text{Width (a)} = 0.175 d_{inf} (\lambda_h H_{inf})^{-0.4} \quad (2.53)$$

In case of opening in masonry panels, the equivalent strut is acts as similar to fully infilled frame and the reduction factor is given as per equation 2.54.

$$\text{Reduction factor for opening } (R_f) = 0.6 \left[\frac{A_o}{A_p} \right]^2 - 1.6 \left[\frac{A_o}{A_p} \right] + 1 \quad (2.54)$$

Where: A_o is the area of openings and A_p is the area of infill panel. If the holes are more than or equal to 60% of the area of the infill panel, the infill impact should be ignored.

IS 1893-2016, Unreinforced masonry infill walls should be modelled as equivalent diagonal struts, as per IS regulation. Diagonal struts are assumed pin jointed to RC frames, and the width W_{ds} as per equation 2.55 of an equivalent diagonal strut is as follows. IS code doesn't consider effect of infill wall.

$$W_{ds} = 0.175 \alpha_h^{-0.4} L_{ds} \quad (2.55)$$

Where:

$$\alpha_h = h * \sqrt[4]{\frac{E_m t \sin 2\theta}{4 E_f I_c h}} \quad (2.56)$$

Where, E_m and E_f are the moduli of elasticity of the materials of infill wall and RC frame members, I_c is the moment of inertia of the adjoining column, t is the thickness of the infill wall panel and θ is the angle made by diagonal strut with the horizontal.

A.R. Amalia and D. Iranata (2017) done comparative study on diagonal equivalent methods of masonry infill panel of various different fourteen methods. Also, experimental test result is compared with diagonal strut methods. From their study Al-Chaar (2002) method have smaller value of width which was widest among all and FEMA equation gives the narrowest equivalent diagonal width. Thus, most flexible width is given by FEMA-274/306, because it has shown to be the most popular throughout time and is accepted by the most of scholars working on infilled frame analysis. Thus, in this study infilled was analyzed by using the equation given in FEMA-274/306 as diagonal strut model.

CHAPTER 3: THEORETICAL FORMULATION

3.1 Methods of Finding Time Period

3.1.1 Modal Analysis

Modal analysis can be used to understand how the structure behaves under dynamic conditions. Modal analysis involves the linear dynamic analysis of the structure under free vibration condition to determine the natural frequencies as well as vibration mode shapes at natural frequencies.

Modal analysis to find the natural period can be described by Eigenvector analysis.

Uncouple damped equation 3.1 of motion as:

$$[m]\ddot{v} + [c]\dot{v} + [k]v = \{P(t)\} \quad (3.1)$$

For a freely vibrating undamped system, by omitting the $[c]$ and $\{P(t)\}$ and the equation (3.1) becomes as:

$$[m]\ddot{v} + [k]v = 0 \quad (3.2)$$

Here, 0 is zero vector and problem for which the equilibrium condition of equation (3.2) will be satisfied by analogy with the behavior of SDOF system, it assumed that the free vibration motion is simple harmonic and may be expressed for a MDOF system as:

$$\{v(t)\} = \{\hat{v}\} \sin(\omega t + \theta) \quad (3.3)$$

Here, \hat{v} is the shape of the system and θ is phase angle and substituting the value of $\{v(t)\}$ in the equation (3.2),

$$([k] - \omega^2[m])\{\hat{v}\} = 0 \quad (3.4)$$

Equation (3.4) is one way of expressing eigenvalue or characteristic value problem.

Which is non-trivial solution if

$$|[k] - \omega^2[m]| = 0 \quad (3.5)$$

This equation 3.5 is known as frequency equation of system. the roots of which are called as Eigenvalues. The positive square roots of these Eigen values are called as natural frequencies ω of the system. The lowest value of ω is called as fundamental frequency.

For each Eigen value, the system assumes a distinct shape which is called as normal mode shape or Eigenvector. The relation between time period and frequency is given by as per equation 3.6.

$$T = \frac{2\pi}{\omega} \quad (3.6)$$

3.1.2 Rayleigh Method

For linear elastic analysis, The Rayleigh approach is based on the concept of energy conservation, which states that if no damping force exists to absorb energy, the energy in a freely vibrating system must remain constant. The Rayleigh principle can also be used to systems with discrete coordinates for displacements. It is important to express the displacement of a structure in terms of an assumed form and a generalized-coordinate amplitude in order to use this method. Let assumed free vibration displacements is expressed as per equation 3.7.

$$\{v(t)\} = \{\phi\}Z(t) = \{\phi\}Z_0(t)\sin\omega t \quad (3.7)$$

where $\{\phi\}$ is the assumed shape vector and $Z(t)$ is the generalized coordinate expressing its amplitude.

Then the maximum kinetic energy of the structure is given by as per equation 3.8.

$$\begin{aligned} T_{max} &= \frac{1}{2} \{\dot{v}\}_{max}^T [m] \{\dot{v}\}_{max} \\ &= \frac{1}{2} Z_0^2 \omega^2 \{\phi\}^T [m] \{\phi\} \end{aligned} \quad (3.8)$$

And the maximum potential energy of structure is given by as per equation 3.9.

$$\begin{aligned} V_{max} &= \frac{1}{2} \{v\}_{max}^T [K] \{v\}_{max} \\ &= \frac{1}{2} Z_0^2 \{\phi\}^T [K] \{\phi\} \end{aligned} \quad (3.9)$$

Equating equation (3.9) and (3.8) we get,

$$\omega^2 = \frac{\{\phi\}^T [K] \{\phi\}}{\{\phi\}^T [m] \{\phi\}} \quad (3.10)$$

In practical analysis, the assumed shape vector $\{\phi\}$ can be taken as the lateral displacement vector d resulting from a set of users applied lateral load pattern F to the structure, that is:

$$\{\phi\} = \{d\}, \{k\} \{d\} = \{F\} \quad (3.11)$$

From equation 3.10 and 3.11,

$$\omega^2 = \frac{\{d\}^T [F]}{\{d\}^T [m] \{d\}} = \frac{\sum_{i=1}^n (F_i * d_i)}{(\sum_{i=1}^n (w_i * d_i^2))} \quad (3.12)$$

d_i = elastic lateral displacement of center of mass at level i , F_i = lateral force applied at floor level i , g = acceleration due to gravity, i = level consideration, n = number of levels in the structure, w_i = seismic weight at considered level i . Thus, the time period is given by equation as per equation 3.13.

$$T_1 = 2\pi \sqrt{\frac{\sum_{i=1}^n (w_i * d_i^2)}{g(\sum_{i=1}^n (F_i * d_i))}} \quad (3.13)$$

This Rayleigh method is applied in this research to calculate the fundamental time period of various models.

3.2 Equivalent Static Method (ESM)

Regardless of the building characteristics, the equivalent static technique can be utilized for all serviceability limit state (SLS) computations.

When at least one of the following requirements is met, the Equivalent static Method for ultimate limit state (ULS) can be used.

- The structure's height is less than or equal to 15 meters.
- The structure's natural time period is shorter than 0.5 seconds.
- According to the NBC: 105:2020 code, the structure is not irregular and has a height of less than 40 meters.

3.3 Diagonal Equivalent Methods of Masonry Infill Panel

Equivalent diagonal strut model is important tool for analysis of infilled frames where an equivalent strut is used to represent the behavior of masonry infilled in frames. The modelling of infill by equivalent diagonal strut method is faster and economical in analysis and hence large numbers of models can be modelled in short duration. The single strut model method is easy for modelling and considered in many design codes.

Equivalent strut is connected to the two diagonal ends of infill area at frame through pin connected. Sample infill wall geometry is shown in figure (3.1).

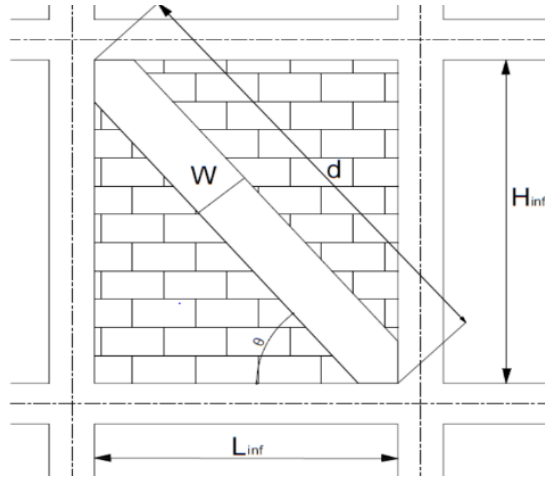


Figure 3.1 Infill wall geometry

The width of the strut is taken equal to the infill wall thickness and depth depends on mechanical parameters of infill walls. For depth calculation, various researchers and codes give different equations, which are discussed in chapter (2.4).

3.4 Regression Analysis

Regression analysis is a statistical technique for determining the relationship between a dependent and one or more independent variables. Regression analysis can be used to identify the strength of a relationship between variables and to model how they will interact in the future. Simple linear regression analysis, multiple linear regression analysis, and nonlinear regression analysis are all examples of regression analysis.

Simple linear regression analysis: This model assesses a dependent variable's basic linear relationship with an independent variable. Expression for simple linear regression analysis as per equation 3.14.

$$y = a + \beta x + e \quad (3.14)$$

where, y is the dependent variable, x is the independent variable, a is an intercept, β is the slope of equation and e is error.

Multiple linear regression analysis: This model is similar to simple linear model but having multiple independent variables. Expression of multiple regression analysis as:

$$y = a + \beta x_1 + \gamma x_2 + \delta x_3 + \lambda x_4 + e \quad (3.15)$$

where, y is the dependent variable, x_1, x_2, x_3, x_4 are the independent variables, a is an intercept, α, β, δ and λ are the slopes and e is error.

CHAPTER 4: DESCRIPTION OF MODELING

4.1 Structural Description

In this section, building geometry and considered parameters for modeling of building are described.

4.1.1 Materials Properties

A RCC framed buildings of three, six and nine storey having following material properties are used in modeling:

Concrete Properties (IS:456-2000)

Compressive strength of concrete = 25 N/mm²

Concrete's Modulus of Elasticity = 25000 N/mm²

Poisson's ratio of concrete = 0.2

Density of concrete = 25 kN/m³

Reinforcement bar Properties

Reinforcement bar yield strength= 500 N/mm²

Poisson's ratio = 0.3

Unit Weight of reinforcement bar = 7850kg/m³

4.1.2 Building Forms

The buildings taken for analysis in this study is regular RCC framed buildings having 3, 6 and 9 storeys. All considered buildings are of regular shape with 3 number of spans in both directions. Span lengths of building varied between 3.0m, 3.5m and 4.0m. All of the buildings under consideration have a story height of 3.0m. The thickness of the slab is 150mm. The size of the beam for building height 9m (3storey building) and 18m (6 storey building) is kept 250mm*300mm and for 27m height (9storey building) 400mm*550mm, while column size for 27m height building is 600mm*600mm, for 18m height building is 500mm*500mm and for 9m height building is 350mm*350mm. Beam and column sizes are taken by considering low reinforcement ratio and also follow the previous similar works of J.C. Rimal (2019). Here, frames elements are designed as per latest NBC code using finite elements software considering seismic zone factor (Z) is 0.35, soil type D (very soft soil-Kathmandu valley) with importance

factor (I) taken as 1.25. Also, the analysis shall be performed considering coefficient flexural and shear stiffness of cracked structural members (beam and column section) according to latest NBC code.

Table 4. 1 Beam and column sizes for different storey

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

Table 4. 2 Effective stiffness of structural components (NBC:105-2020)

| Components | Flexural stiffness | Shear stiffness |
|------------|--------------------|-----------------|
| Beam | $0.35 E_c I_g$ | $0.40 E_c A_w$ |
| Columns | $0.70 E_c I_g$ | $0.70 E_c A_w$ |

4.2 Loads and Seismic Weight

4.2.1 Load on Building

The models are given a dead load, a live load, and an earthquake load. In addition to the members' own weight, each floor slab has a 1kN/m^2 Floor Finish applied to it. For all typical floors, live loads are assumed to be 3kN/m^2 , with a nail for the top floor. The load due to brick infill walls is found out by considering the specific weight of brick masonry as 17.3kN/m^3 (Phaiju S. & Pradhan P., 2018). All the beams (are equally loaded with considered thick walls with 30% opening (for wall walls in a building).

Table 4. 3 Load on building

| Description | Load |
|---------------------|---|
| Concrete | 25kN/m^3 |
| Masonry Brick Panel | 17.3kN/m^3 |
| Floor Finish | 1.0kN/m^2 |
| Live load | 3.0kN/m^2 [For Typical Floors] |
| Live load | Nil (Roof) |

4.2.2 Load Combination

For design of building models load combination are taken as for limit state method for parallel systems of NBC:105-2020. The following load combination has been used when the seismic load impact is paired with other load effects.

$$1.2DL + 1.5 LL$$

$$DL + \lambda LL \mp E \tag{4.1}$$

Where, $\lambda = 0.6$ for storage facility and 0.3 for other uses

4.2.3 Seismic Weight

The seismic weight at each level, W_i shall be taken as the sum of the dead loads and the factored seismic live load between the mid-heights of adjacent stories. Along with the dead load, 30 percent of live load is included in the seismic weight in this research (NBC:105-2020).

4.2.4 Description of Infill Wall Parameters

Density of masonry panel = 17.3 KN/m³

Modulus of elasticity of brick panel [E_m] = 1085* f_m = [2000-6000] N/mm²

(For 1:4 Mortar Ratio, strength=3.8 N/mm²)

Compressive strength of individual bricks (f_m) = [5-23] N/mm² (Bricks used in Kathmandu valley) (Phaiju S. & Pradhan P., 2018)

Thickness of wall variation = [100-250]mm

Poisson ratio of brick panel = 0.32

4.2.5 Infill Wall Modeling

Various literature suggests various methods for modeling infilled walls as an equivalent strut frame. Among all, equation suggested in FEMA guidelines gives the narrowest equivalent diagonal width. So, most flexible width is given by FEMA-274/306, because it has shown to be the most popular throughout time and is accepted by the bulk of scholars working on infilled frame analysis. Thus, for this study unreinforced masonry walls are modelled was analyzed by using the equation given in FEMA as diagonal strut model. In modeling process only stiffness property of strut is given and wall load is applied as uniformly distributed wall loads. Equivalent diagonal compression strut

of width (a) and coefficient, λ_1 recommended by FEMA 356. Here sample figure of infill wall and representative equivalent single strut model is shown in figure (4.1).

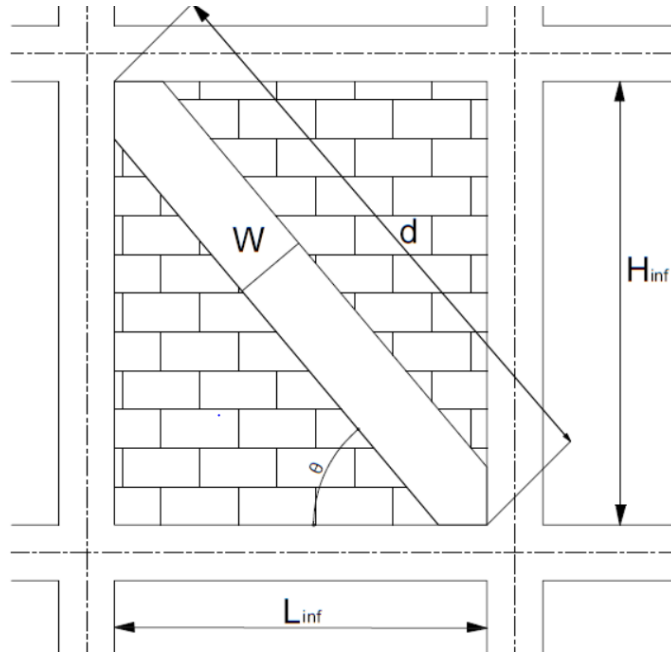


Figure 4. 1 Equivalent single strut

$$\text{Width of diagonal compression strut (w)} = 0.175 r_{inf} (\lambda_1 h_{col})^{-0.4} \quad (4.2)$$

$$\text{Coefficient } (\lambda_1) = \left[\frac{E_m t_{inf} \sin 2\theta}{4 E_c I_c h_{inf}} \right]^{1/4} \quad (4.3)$$

Where, h_{inf} is the height of infill panel, I_c is the adjacent column's moment of inertia, t_{inf} is the infill wall's thickness, θ is the angle formed by the diagonal strut and the horizontal, E_m is the elasticity modulus of the infill panel (N/mm^2) and r_{inf} is the infill's diagonal length.

$$\text{Reduction factor proposed by Al-Chaar } (R_f) = 0.6 \left[\frac{A_o}{A_p} \right]^2 - 1.6 \left[\frac{A_o}{A_p} \right] + 1 \quad (4.4)$$

Where, A_o = Area of the opening

A_p = Area of the infill panel

R_f = In plane reduction factor for the infill opening

Here, five different values for the modulus of elasticity of infill wall panels are varied from 2000 MPa, 3500MPa, 4300MPa, 5200MPa and 6000MPa and thickness of infill wall is varied from 100mm,150mm,200mm,250mm considering constant 30% opening

for both external and internal walls. In this way stiffness properties of infill wall are varied and their effect on fundamental time period is examined.

4.3 Software Modeling

In this study considered frame buildings were initially designed and approved using linear static approach as per the building design code NBC:105-2020. Software used for modeling is ETABS v19. Beams and columns are treated as frame elements with frame sections that have unique concrete and rebar material qualities. For masonry, only stiffness properties are given in material definition and weight of masonry is applied to beam by manual calculation considering constant opening of 30%. The foundation level was assumed to be fixed. Slabs with a depth of 150mm were modeled as shell elements with rigid diaphragms in each story level, and slab meshing was done by software. Material properties are explained in clause (4.1.1). Three different building height is considered ranging 9,18 and 27 meter with fixed storey height 3m and 3 different span lengths 3,3.5 and 4 m is taken with regular building having constant three numbers of spans in both directions. For each building height fixed beam and column size are taken considering lower percentage of rebar and size are explained in table (4.1). Load application in building is explained in table (4.3) and load combination are explained in clause (4.2.2).

Here, elasticity modulus of infill walls was assumed based on equation given by experimental study of Prachanda man Pradhan. The considered elasticity moduli and thickness of infill walls are given in table (4.4).

Table 4. 4 The considered building height, base dimension, Elasticity modulus and thickness of infill wall.

| | |
|---------|----------------------------------|
| E (MPa) | 2000 – 3500 – 4300 – 5200 – 6000 |
| t (mm) | 100 – 150 – 200 – 250 |
| H (m) | 9.0 – 18.0 – 27.0 |
| D (m) | 3.0 – 3.5 – 4.0 |

The infill is modeled as macro modeling with an equivalent single strut as per FEMA 356 in this research. A single equivalent diagonal compression strut of thickness identical to the infill panel, width computed from equation (4.2) and diagonal length between two compression corners is used to substitute the infill panel.

In this way with 3 different building heights (9m,18m and 27m), three different base dimensions (3m, 3.5m and 4m), 5 different elasticity modulus of infill walls and 4 different infill wall thickness, Total 180 different buildings were modelled and fundamental time period of the building were determined by Rayleigh method. Here sample plan of building are shown in figure 4.2 and sample of 3D model of building with single strut and sample elevation with single strut model are shown in figure 4.3.

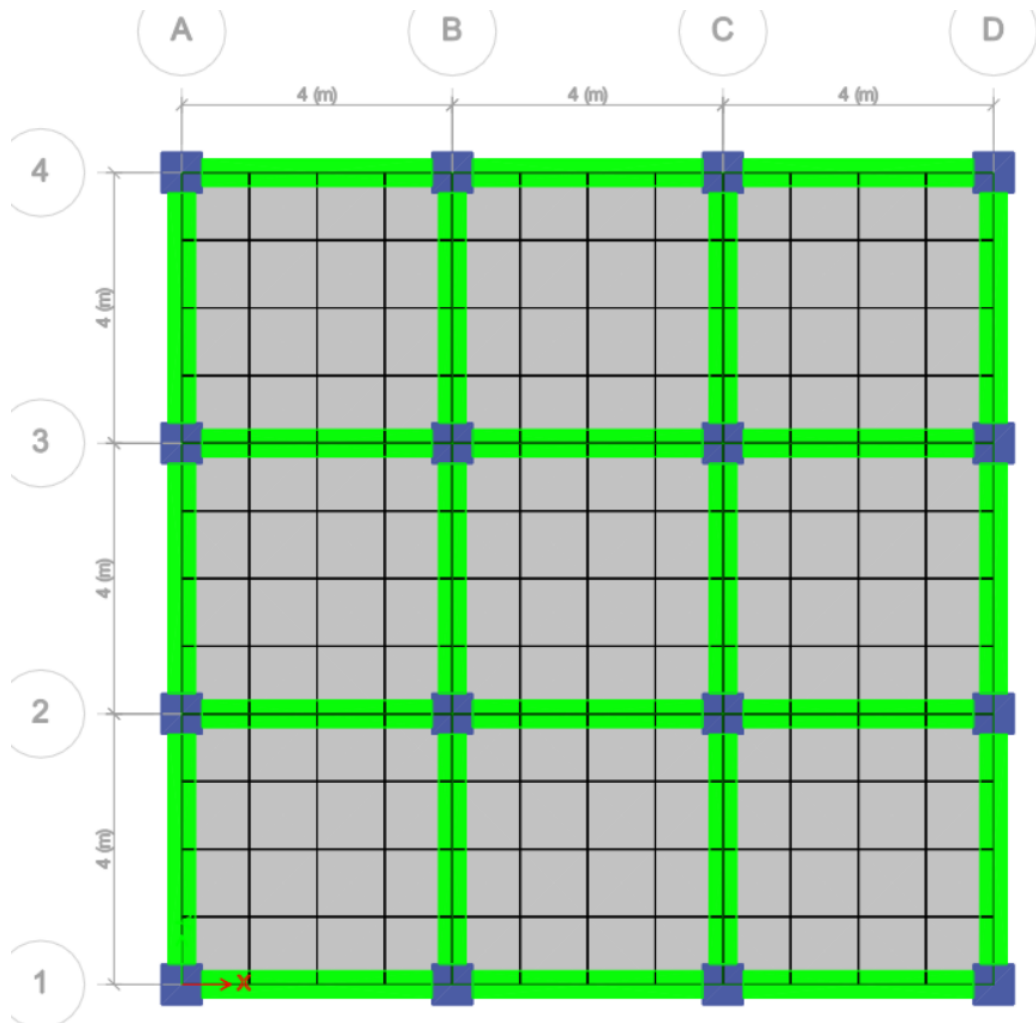


Figure 4. 2 Sample plan of building

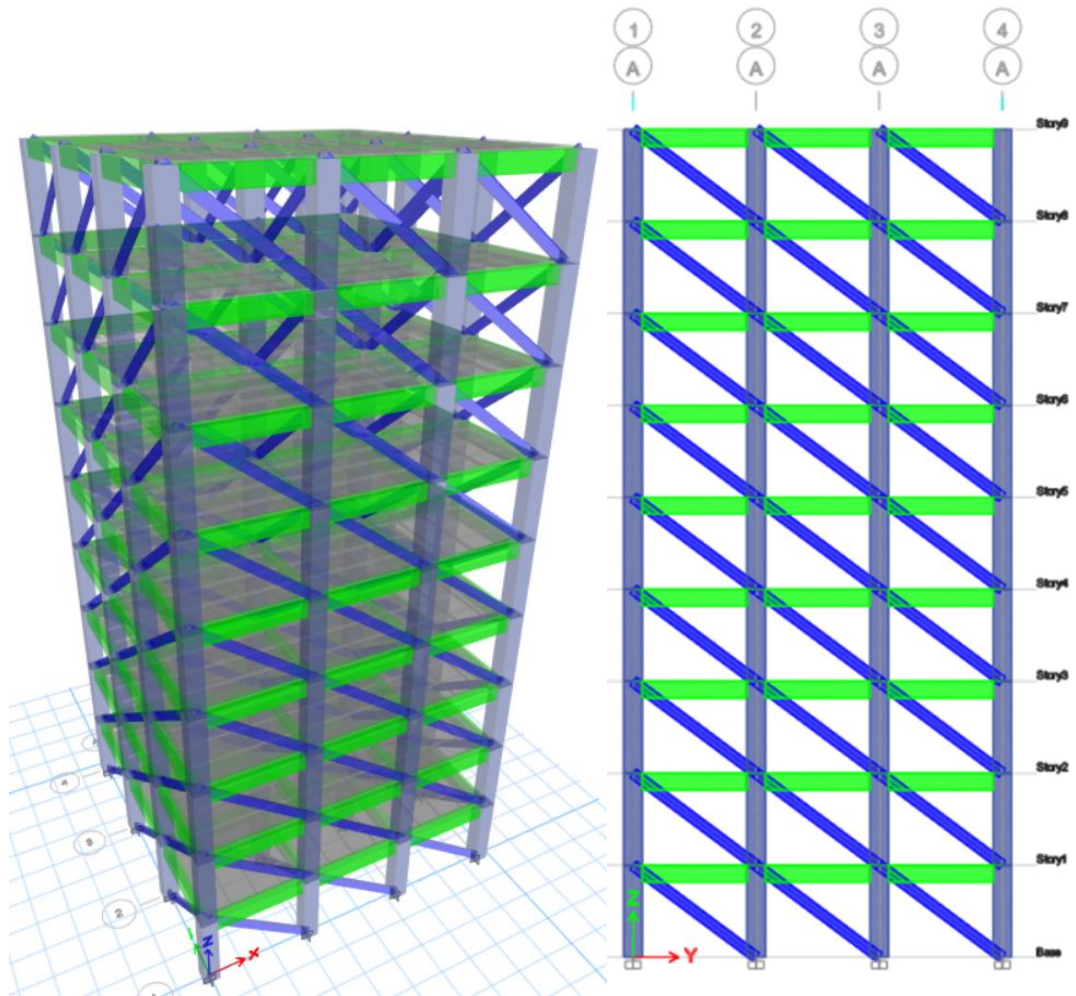


Figure 4. 3 (a) Sample 3D model of Building with single strut (b) Sample elevation of single strut model

CHAPTER 5: RESULTS AND DISCUSSION

Analysis was conducted using FEM software ETABS v19 and the time period of the building were determined using Rayleigh method. The effects of building height, building base dimension, infill wall modulus of elasticity, and wall thickness are studied.

5.1 Sample calculation

For determined the fundamental period, the building taken is 3 storey regular building having constant 3 number of bays in X and Y directions with bay length of 4m. Infill with thickness 100mm and modulus of elasticity 2000MPa. The storey height is taken as 3m, so total height of building is 9m and total base dimension is 12m. Live load of 3kN/m^2 are applied for all floor slab except top floor where live load is taken as zero and floor finish of 1kN/m^2 are applied for all floor slab. All infill wall is of same size 100mm with constant opening of 30% so all beams carry uniform load of 3.2697 kN/m . Size of beam is $250\text{mm}\times 300\text{mm}$ and size of column is $350\text{mm}\times 350\text{mm}$. Effective stiffness of cracked section of beam and column shall be taken as per Table (4.2). Slab of 150mm size is taken and model as shell element with rigid floor diaphragm in each storey. Finite element modeling of the building is done using ETABSv19. All the building elements were checked and verified to ensure that all the members could resist the loads applied on them as per load combination of equation (4.1) (NBC:105-2020). For Initial designing purpose, code-based fundamental time period was taken. The 3D model of considered sample (figure 5.1) and calculation of parameters of strut are as:

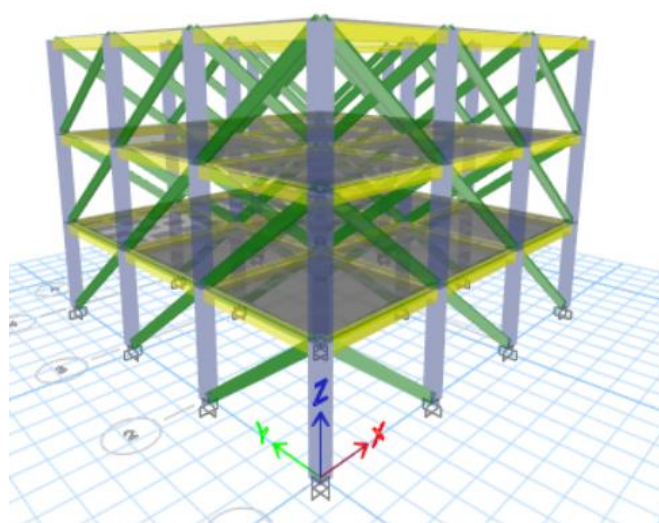


Figure 5. 1 3D model of sample building

Table 5. 1 Calculation of parameter of strut

| Parameters Data | Value | Units | Remarks |
|--|------------|-----------------|---------------|
| Characteristic Strength of Concrete (f_{ck}) | 25 | MPa | |
| Young's Modulus of Concrete (E_c) | 25000 | MPa | (IS:456,2000) |
| Young's Modulus of masonry wall (E_m) | 2000 | MPa | |
| Size of Beam (Depth X Breadth) | 300 * 250 | mm x mm | |
| Size of Column (Breadth X Width) | 350 * 350 | mm x mm | |
| Moment of inertia of Column (I_c) | 1250520833 | mm ⁴ | |
| Infill wall thickness (t_{inf}) | 100 | mm | |
| Height of the column (h_{col}) | 3000 | mm | |
| Infill wall height (h_{inf}) | 2700 | mm | |
| Length of bays | 4000 | mm | |
| Length of infill wall (L_{inf}) | 3650 | mm | FEMA-273 |
| Area of the infill (A_p) | 9855000 | mm ² | |
| Angle made by strut with horizontal (θ) | 36.49 | Degrees | |
| Diagonal Length of the Infill (r_{inf}) | 4540.099 | mm | |
| Equivalent Coefficient (λ_1) | 0.00086753 | | FEMA-273 |
| Opening reduction factor (R_f) | 0.574 | | AI-chaar,2002 |
| Equivalent width of strut (α) | 311.066 | mm | FEMA-273 |

For parameter of strut calculation:

Density of masonry panel = 17.3 kN/m³.

Poisson ratio of brick panel = 0.32.

$$\text{Coefficient } [(\lambda_1)] = \left[\frac{E_m t_{inf} \sin 2\theta}{4 E_c I_c h_{inf}} \right]^{1/4} = \left[\frac{2000 * 100 * \sin(2 * 36.49)}{4 * 25000 * 1250520833 * 2700} \right]^{1/4} = 0.00086753$$

$$\begin{aligned} \text{Width of Single equivalent diagonal compression strut (w)} &= 0.175 d_{inf} (\lambda_1 h_c)^{-0.4} \\ &= 0.175 * 4540.099 * (0.00086753 * 3000)^{-0.4} \\ &= 541.927 \text{ mm} \end{aligned}$$

$$\begin{aligned} \text{Reduction factor (} R_f \text{)} &= 0.6 \left[\frac{A_o}{A_p} \right]^2 - 1.6 \left[\frac{A_o}{A_p} \right] + 1 \\ &= 0.6 \left[\frac{0.3}{1} \right]^2 - 1.6 \left[\frac{0.3}{1} \right] + 1 \\ &= 0.574 \end{aligned}$$

Now equivalent width of strut considering opening of (30%) is 311.06mm and strut is model in ETABS as frame section through section designer having height of strut 311.06mm and width as same as wall thickness of 100mm.

According to Rayleigh method, fundamental period of building is calculated as below:

From equation (2.29)

$$T_1 = 2\pi \sqrt{\frac{\sum_{i=1}^n (w_i * d_i^2)}{g(\sum_{i=1}^n (F_i * d_i))}}$$

Table 5. 2 Calculation of fundamental time period using Rayleigh method

| <i>Here, di: horizontal displacement of center of mass at level i, Fi: lateral force acting at level i, Wi: seismic weight at level i, g: acceleration due to gravity and i: level under consideration.</i> | | | | | |
|---|---------------------|---------------------|--------------------|--|-------------------------------|
| Floor Level | W _i (kN) | F _i (kN) | d _i (m) | W _i d _i ² | F _i d _i |
| 3 | 1078.835 | 30 | 0.00093 | 0.00094 | 0.02799 |
| 2 | 1438.981 | 20 | 0.00071 | 0.00072 | 0.01412 |
| 1 | 1438.981 | 10 | 0.00034 | 0.00017 | 0.00341 |
| Sum (Σ) = | | | | 0.00182 | 0.04552 |

Here,

$$T_1 = 2\pi \sqrt{\frac{\sum_{i=1}^n (w_i * d_i^2)}{g(\sum_{i=1}^n (F_i * d_i))}} = 2\pi \sqrt{\frac{0.00182}{9.81 * 0.04552}} = 0.402 \text{ sec}$$

Thus, the value of fundamental time period as obtained by Rayleigh method is found to be 0.386 sec. Here according to NBC:105-2020 Empirical time period of 9m height building is 0.487 sec and we can conclude that empirical equation of latest NBC codes gives time period value more than that calculated from Rayleigh method for this sample building. Similarly, for considered total 180 regular building models, obtained fundamental time period is calculated using Rayleigh method are shown in Table 5.3.

Table 5. 3 Fundamental time period of considered building models using Rayleigh method

| <i>Here, H: Height of building, B: Base dimension of building, t: Infill wall thickness and E: Modulus of elasticity of infill wall panel</i> | | | | | |
|---|-------|-------|--------|---------|------------|
| S. N. | H (m) | B (m) | t (mm) | E (MPa) | Time (sec) |
| 1 | 27 | 12 | 100 | 2000 | 0.919 |
| 2 | 27 | 12 | 100 | 3500 | 0.834 |
| 3 | 27 | 12 | 100 | 4300 | 0.802 |
| 4 | 27 | 12 | 100 | 5200 | 0.771 |
| 5 | 27 | 12 | 100 | 6000 | 0.746 |
| 6 | 27 | 12 | 150 | 2000 | 0.884 |
| 7 | 27 | 12 | 150 | 3500 | 0.794 |
| 8 | 27 | 12 | 150 | 4300 | 0.758 |
| 9 | 27 | 12 | 150 | 5200 | 0.724 |
| 10 | 27 | 12 | 150 | 6000 | 0.698 |
| 11 | 27 | 12 | 200 | 2000 | 0.864 |
| 12 | 27 | 12 | 200 | 3500 | 0.765 |
| 13 | 27 | 12 | 200 | 4300 | 0.727 |
| 14 | 27 | 12 | 200 | 5200 | 0.692 |
| 15 | 27 | 12 | 200 | 6000 | 0.665 |
| 16 | 27 | 12 | 250 | 2000 | 0.851 |

Here, H: Height of building, B: Base dimension of building, t: Infill wall thickness and E: Modulus of elasticity of infill wall panel

| S. N. | H (m) | B (m) | t (mm) | E (MPa) | Time (sec) |
|-------|-------|-------|--------|---------|------------|
| 17 | 27 | 12 | 250 | 3500 | 0.746 |
| 18 | 27 | 12 | 250 | 4300 | 0.707 |
| 19 | 27 | 12 | 250 | 5200 | 0.671 |
| 20 | 27 | 12 | 250 | 6000 | 0.645 |
| 21 | 18 | 12 | 100 | 2000 | 0.722 |
| 22 | 18 | 12 | 100 | 3500 | 0.617 |
| 23 | 18 | 12 | 100 | 4300 | 0.579 |
| 24 | 18 | 12 | 100 | 5200 | 0.545 |
| 25 | 18 | 12 | 100 | 6000 | 0.517 |
| 26 | 18 | 12 | 150 | 2000 | 0.681 |
| 27 | 18 | 12 | 150 | 3500 | 0.565 |
| 28 | 18 | 12 | 150 | 4300 | 0.528 |
| 29 | 18 | 12 | 150 | 5200 | 0.495 |
| 30 | 18 | 12 | 150 | 6000 | 0.471 |
| 31 | 18 | 12 | 200 | 2000 | 0.649 |
| 32 | 18 | 12 | 200 | 3500 | 0.533 |
| 33 | 18 | 12 | 200 | 4300 | 0.497 |
| 34 | 18 | 12 | 200 | 5200 | 0.464 |
| 35 | 18 | 12 | 200 | 6000 | 0.441 |
| 36 | 18 | 12 | 250 | 2000 | 0.617 |
| 37 | 18 | 12 | 250 | 3500 | 0.511 |
| 38 | 18 | 12 | 250 | 4300 | 0.475 |
| 39 | 18 | 12 | 250 | 5200 | 0.444 |
| 40 | 18 | 12 | 250 | 6000 | 0.422 |
| 41 | 9 | 12 | 100 | 2000 | 0.402 |
| 42 | 9 | 12 | 100 | 3500 | 0.34 |
| 43 | 9 | 12 | 100 | 4300 | 0.318 |
| 44 | 9 | 12 | 100 | 5200 | 0.298 |
| 45 | 9 | 12 | 100 | 6000 | 0.284 |
| 46 | 9 | 12 | 150 | 2000 | 0.373 |
| 47 | 9 | 12 | 150 | 3500 | 0.31 |
| 48 | 9 | 12 | 150 | 4300 | 0.289 |
| 49 | 9 | 12 | 150 | 5200 | 0.27 |
| 50 | 9 | 12 | 150 | 6000 | 0.256 |
| 51 | 9 | 12 | 200 | 2000 | 0.354 |
| 52 | 9 | 12 | 200 | 3500 | 0.292 |
| 53 | 9 | 12 | 200 | 4300 | 0.271 |
| 54 | 9 | 12 | 200 | 5200 | 0.253 |
| 55 | 9 | 12 | 200 | 6000 | 0.239 |
| 56 | 9 | 12 | 250 | 2000 | 0.341 |
| 57 | 9 | 12 | 250 | 3500 | 0.279 |
| 58 | 9 | 12 | 250 | 4300 | 0.259 |
| 59 | 9 | 12 | 250 | 5200 | 0.241 |

Here, H: Height of building, B: Base dimension of building, t: Infill wall thickness and E: Modulus of elasticity of infill wall panel

| S. N. | H (m) | B (m) | t (mm) | E (MPa) | Time (sec) |
|-------|-------|-------|--------|---------|------------|
| 60 | 9 | 12 | 250 | 6000 | 0.228 |
| 61 | 27 | 10.5 | 100 | 2000 | 0.843 |
| 62 | 27 | 10.5 | 100 | 3500 | 0.78 |
| 63 | 27 | 10.5 | 100 | 4300 | 0.754 |
| 64 | 27 | 10.5 | 100 | 5200 | 0.728 |
| 65 | 27 | 10.5 | 100 | 6000 | 0.707 |
| 66 | 27 | 10.5 | 150 | 2000 | 0.826 |
| 67 | 27 | 10.5 | 150 | 3500 | 0.75 |
| 68 | 27 | 10.5 | 150 | 4300 | 0.72 |
| 69 | 27 | 10.5 | 150 | 5200 | 0.691 |
| 70 | 27 | 10.5 | 150 | 6000 | 0.669 |
| 71 | 27 | 10.5 | 200 | 2000 | 0.814 |
| 72 | 27 | 10.5 | 200 | 3500 | 0.73 |
| 73 | 27 | 10.5 | 200 | 4300 | 0.697 |
| 74 | 27 | 10.5 | 200 | 5200 | 0.666 |
| 75 | 27 | 10.5 | 200 | 6000 | 0.643 |
| 76 | 27 | 10.5 | 250 | 2000 | 0.798 |
| 77 | 27 | 10.5 | 250 | 3500 | 0.715 |
| 78 | 27 | 10.5 | 250 | 4300 | 0.681 |
| 79 | 27 | 10.5 | 250 | 5200 | 0.649 |
| 80 | 27 | 10.5 | 250 | 6000 | 0.624 |
| 81 | 18 | 10.5 | 100 | 2000 | 0.667 |
| 82 | 18 | 10.5 | 100 | 3500 | 0.584 |
| 83 | 18 | 10.5 | 100 | 4300 | 0.55 |
| 84 | 18 | 10.5 | 100 | 5200 | 0.519 |
| 85 | 18 | 10.5 | 100 | 6000 | 0.487 |
| 86 | 18 | 10.5 | 150 | 2000 | 0.646 |
| 87 | 18 | 10.5 | 150 | 3500 | 0.54 |
| 88 | 18 | 10.5 | 150 | 4300 | 0.506 |
| 89 | 18 | 10.5 | 150 | 5200 | 0.475 |
| 90 | 18 | 10.5 | 150 | 6000 | 0.453 |
| 91 | 18 | 10.5 | 200 | 2000 | 0.619 |
| 92 | 18 | 10.5 | 200 | 3500 | 0.512 |
| 93 | 18 | 10.5 | 200 | 4300 | 0.478 |
| 94 | 18 | 10.5 | 200 | 5200 | 0.442 |
| 95 | 18 | 10.5 | 200 | 6000 | 0.427 |
| 96 | 18 | 10.5 | 250 | 2000 | 0.591 |
| 97 | 18 | 10.5 | 250 | 3500 | 0.493 |
| 98 | 18 | 10.5 | 250 | 4300 | 0.459 |
| 99 | 18 | 10.5 | 250 | 5200 | 0.43 |
| 100 | 18 | 10.5 | 250 | 6000 | 0.389 |
| 101 | 9 | 10.5 | 100 | 2000 | 0.374 |
| 102 | 9 | 10.5 | 100 | 3500 | 0.32 |

Here, H: Height of building, B: Base dimension of building, t: Infill wall thickness and E: Modulus of elasticity of infill wall panel

| S. N. | H (m) | B (m) | t (mm) | E (MPa) | Time (sec) |
|-------|-------|-------|--------|---------|------------|
| 103 | 9 | 10.5 | 100 | 4300 | 0.3 |
| 104 | 9 | 10.5 | 100 | 5200 | 0.282 |
| 105 | 9 | 10.5 | 100 | 6000 | 0.269 |
| 106 | 9 | 10.5 | 150 | 2000 | 0.351 |
| 107 | 9 | 10.5 | 150 | 3500 | 0.294 |
| 108 | 9 | 10.5 | 150 | 4300 | 0.274 |
| 109 | 9 | 10.5 | 150 | 5200 | 0.255 |
| 110 | 9 | 10.5 | 150 | 6000 | 0.242 |
| 111 | 9 | 10.5 | 200 | 2000 | 0.335 |
| 112 | 9 | 10.5 | 200 | 3500 | 0.276 |
| 113 | 9 | 10.5 | 200 | 4300 | 0.259 |
| 114 | 9 | 10.5 | 200 | 5200 | 0.242 |
| 115 | 9 | 10.5 | 200 | 6000 | 0.229 |
| 116 | 9 | 10.5 | 250 | 2000 | 0.324 |
| 117 | 9 | 10.5 | 250 | 3500 | 0.268 |
| 118 | 9 | 10.5 | 250 | 4300 | 0.248 |
| 119 | 9 | 10.5 | 250 | 5200 | 0.232 |
| 120 | 9 | 10.5 | 250 | 6000 | 0.22 |
| 121 | 27 | 9 | 100 | 2000 | 0.776 |
| 122 | 27 | 9 | 100 | 3500 | 0.728 |
| 123 | 27 | 9 | 100 | 4300 | 0.707 |
| 124 | 27 | 9 | 100 | 5200 | 0.686 |
| 125 | 27 | 9 | 100 | 6000 | 0.67 |
| 126 | 27 | 9 | 150 | 2000 | 0.768 |
| 127 | 27 | 9 | 150 | 3500 | 0.708 |
| 128 | 27 | 9 | 150 | 4300 | 0.684 |
| 129 | 27 | 9 | 150 | 5200 | 0.66 |
| 130 | 27 | 9 | 150 | 6000 | 0.641 |
| 131 | 27 | 9 | 200 | 2000 | 0.763 |
| 132 | 27 | 9 | 200 | 3500 | 0.695 |
| 133 | 27 | 9 | 200 | 4300 | 0.668 |
| 134 | 27 | 9 | 200 | 5200 | 0.642 |
| 135 | 27 | 9 | 200 | 6000 | 0.624 |
| 136 | 27 | 9 | 250 | 2000 | 0.76 |
| 137 | 27 | 9 | 250 | 3500 | 0.686 |
| 138 | 27 | 9 | 250 | 4300 | 0.657 |
| 139 | 27 | 9 | 250 | 5200 | 0.63 |
| 140 | 27 | 9 | 250 | 6000 | 0.609 |
| 141 | 18 | 9 | 100 | 2000 | 0.633 |
| 142 | 18 | 9 | 100 | 3500 | 0.554 |
| 143 | 18 | 9 | 100 | 4300 | 0.524 |
| 144 | 18 | 9 | 100 | 5200 | 0.496 |
| 145 | 18 | 9 | 100 | 6000 | 0.473 |

Here, H: Height of building, B: Base dimension of building, t: Infill wall thickness and E: Modulus of elasticity of infill wall panel

| S. N. | H (m) | B (m) | t (mm) | E (MPa) | Time (sec) |
|-------|-------|-------|--------|---------|------------|
| 146 | 18 | 9 | 150 | 2000 | 0.612 |
| 147 | 18 | 9 | 150 | 3500 | 0.517 |
| 148 | 18 | 9 | 150 | 4300 | 0.486 |
| 149 | 18 | 9 | 150 | 5200 | 0.458 |
| 150 | 18 | 9 | 150 | 6000 | 0.438 |
| 151 | 18 | 9 | 200 | 2000 | 0.592 |
| 152 | 18 | 9 | 200 | 3500 | 0.493 |
| 153 | 18 | 9 | 200 | 4300 | 0.463 |
| 154 | 18 | 9 | 200 | 5200 | 0.424 |
| 155 | 18 | 9 | 200 | 6000 | 0.415 |
| 156 | 18 | 9 | 250 | 2000 | 0.566 |
| 157 | 18 | 9 | 250 | 3500 | 0.477 |
| 158 | 18 | 9 | 250 | 4300 | 0.447 |
| 159 | 18 | 9 | 250 | 5200 | 0.42 |
| 160 | 18 | 9 | 250 | 6000 | 0.4 |
| 161 | 9 | 9 | 100 | 2000 | 0.347 |
| 162 | 9 | 9 | 100 | 3500 | 0.3 |
| 163 | 9 | 9 | 100 | 4300 | 0.282 |
| 164 | 9 | 9 | 100 | 5200 | 0.266 |
| 165 | 9 | 9 | 100 | 6000 | 0.255 |
| 166 | 9 | 9 | 150 | 2000 | 0.329 |
| 167 | 9 | 9 | 150 | 3500 | 0.279 |
| 168 | 9 | 9 | 150 | 4300 | 0.261 |
| 169 | 9 | 9 | 150 | 5200 | 0.245 |
| 170 | 9 | 9 | 150 | 6000 | 0.234 |
| 171 | 9 | 9 | 200 | 2000 | 0.317 |
| 172 | 9 | 9 | 200 | 3500 | 0.266 |
| 173 | 9 | 9 | 200 | 4300 | 0.248 |
| 174 | 9 | 9 | 200 | 5200 | 0.232 |
| 175 | 9 | 9 | 200 | 6000 | 0.221 |
| 176 | 9 | 9 | 250 | 2000 | 0.309 |
| 177 | 9 | 9 | 250 | 3500 | 0.257 |
| 178 | 9 | 9 | 250 | 4300 | 0.239 |
| 179 | 9 | 9 | 250 | 5200 | 0.224 |
| 180 | 9 | 9 | 250 | 6000 | 0.197 |

5.2 Effect of modulus of elasticity (E) of infill wall panel on fundamental time period of building

Elasticity modulus of infill wall was varying between 2000-6000MPa (2000,3500,4300,5200 and 6000). Results upon analysis shows that, for constant wall thickness, time period decreases when modulus of elasticity of infill wall panel increases.

Different figures shown below (for 4m span length) shows the effect of modulus of elasticity of infill wall panel on fundamental time period for different wall thickness (100,150,200,250 mm). This range of modulus of elasticity and thickness of wall panel will cover almost all types of masonry wall constructed on Kathmandu valley.

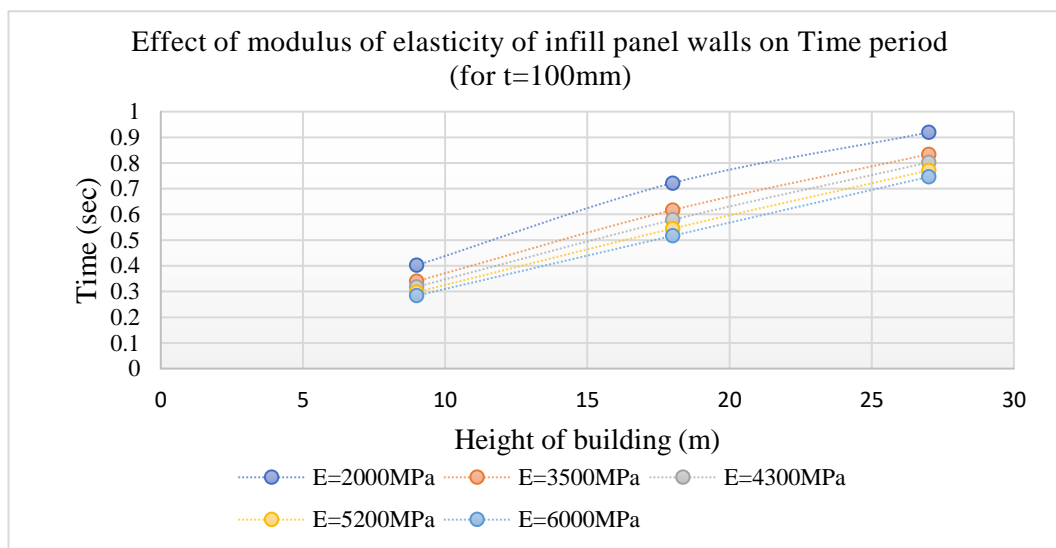


Figure 5.2 Effect of modulus of elasticity of infill wall panel (t=100mm) on fundamental time period

From above figure 5.2, it is cleared that for constant wall thickness, fundamental time period decreases when modulus of elasticity of infill wall panel is increases. For a height of 9m and thickness of infill 100mm, $T = 0.402$ sec for $E = 2000$ MPa and $T = 0.284$ sec for $E = 6000$ MPa. Here, time period is decreased by around 30% for 9m height of building. Similarly, for 18m height of building, $T = 0.722$ sec for $E = 2000$ MPa and $T = 0.517$ sec for $E = 6000$ MPa, here, period is decreased by around 29%. For 27m height of building, $T = 0.919$ sec for $E = 2000$ MPa and $T = 0.746$ sec for $E = 6000$ MPa, that is period is decreased by around 19% only. The variation of fundamental time period was found more in 9m height of building than for 27m height of building. Thus,

for low rise buildings the modulus of elasticity of infill wall has significant effect in the fundamental period than that for the high-rise buildings.

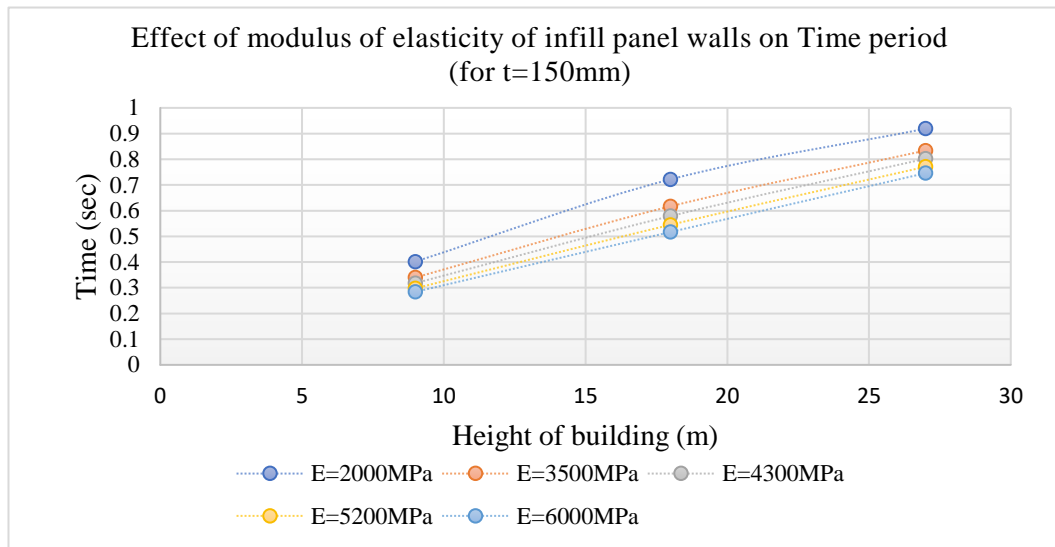


Figure 5.3 Effect of modulus of elasticity of infill wall panel (t=150mm) on fundamental time period

Similarly, for constant 150mm (figure 5.3) wall thickness, $T = 0.372\text{sec}$ for $E = 2000\text{MPa}$ and $T = 0.256\text{sec}$ for $E = 6000\text{MPa}$ and time period is decreased by around 31% for 9m height of building. Similarly, for 18m height of building, $T = 0.681\text{sec}$ for $E = 2000\text{MPa}$ and $T = 0.471\text{sec}$ for $E = 6000\text{MPa}$, here, period is decreased by around 31%. And for, 27m height of building, $T = 0.884\text{sec}$ for $E = 2000\text{MPa}$ and $T = 0.698\text{sec}$ for $E = 6000\text{MPa}$, that is period is decreased by around 21%.

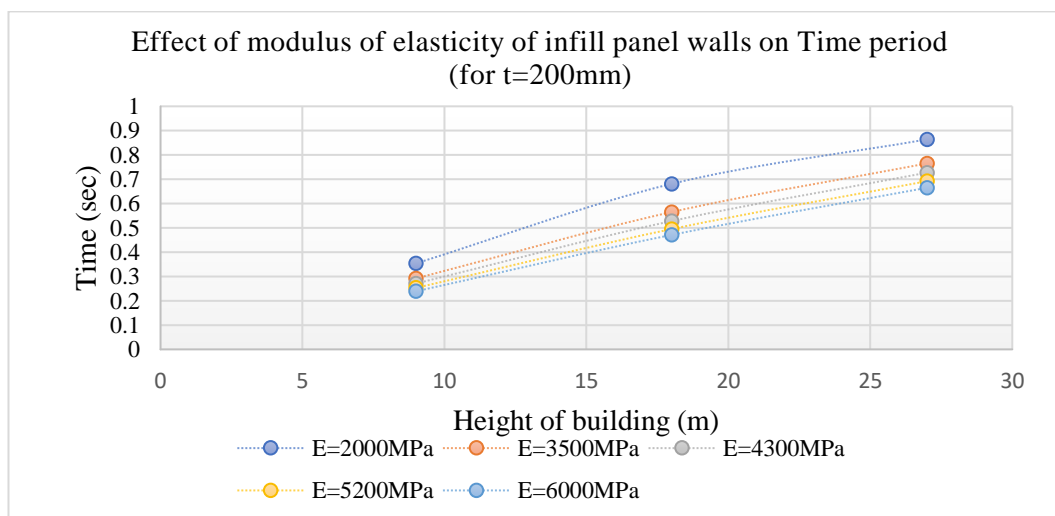


Figure 5.4 Effect of modulus of elasticity of infill wall panel (t=200mm) on fundamental time period

From figure 5.4, similarly for 200mm thick wall, time period is decreased by around 33% for 9m height of building, decreased by around 31% for 18m height of building and that for around 23% for 27m height of building.

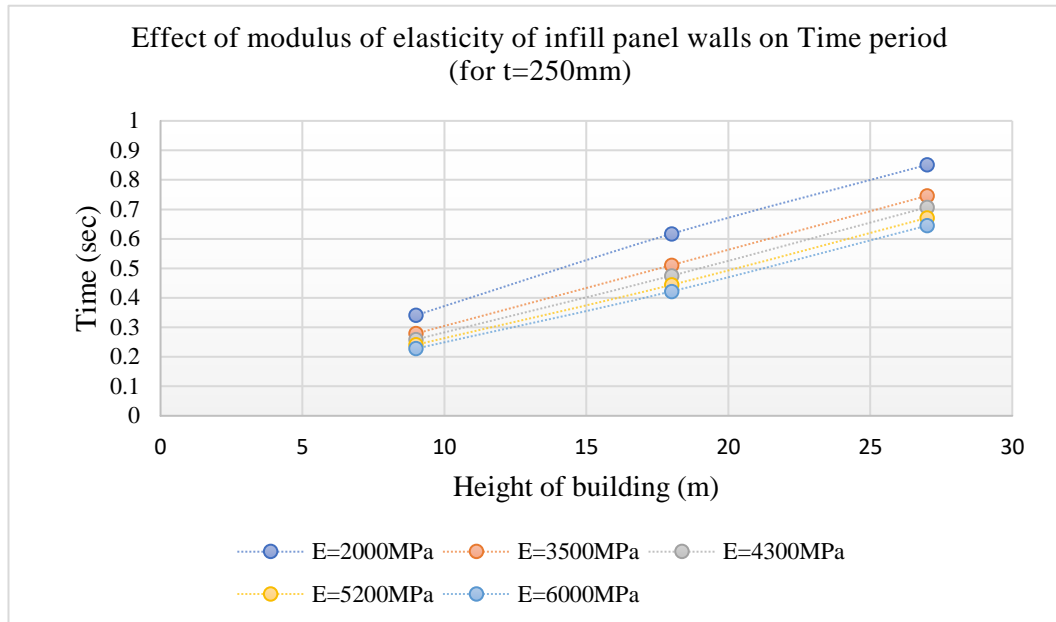


Figure 5.5 Effect of modulus of elasticity of infill wall panel (t=250mm) on fundamental time period

And for 250mm wall panel thickness (figure 5.5), $T = 0.341\text{sec}$ for $E = 2000\text{MPa}$ and $T = 0.228\text{sec}$ for $E = 6000\text{MPa}$, that is time period decreased by around 33% for 9m height of building. Similarly, for 18m height of building, $T = 0.681\text{sec}$ for $E = 2000\text{MPa}$ and $T = 0.471\text{sec}$ for $E = 6000\text{MPa}$, here, period is decreased by around 32%. And for, 27m height of building, $T = 0.884\text{sec}$ for $E = 2000\text{MPa}$ and $T = 0.698\text{sec}$ for $E = 6000\text{MPa}$, that is period is decreased by around 24%.

For other different bay length, the effect of modulus of elasticity of infill wall panel on the fundamental time period are similar pattern and which are presented in APPENDIX A and APPENDIX B.

5.3 Effect of thickness of infill wall panel on fundamental time period of building

Thickness of infill wall panel was varying between 100mm-250mm (100, 150, 200 and 250 mm) and their effect on fundamental time period for constant modulus of elasticity were investigated. This range of variation of infill wall thickness will cover almost all types of infill walls used in buildings. Here opening consideration in building is taken as fixed value of 30% and all infill walls (outer and inner walls) are of same size for each building. Plot of fundamental time periods versus height of building (for 4m span length) for different wall thickness were presented below:

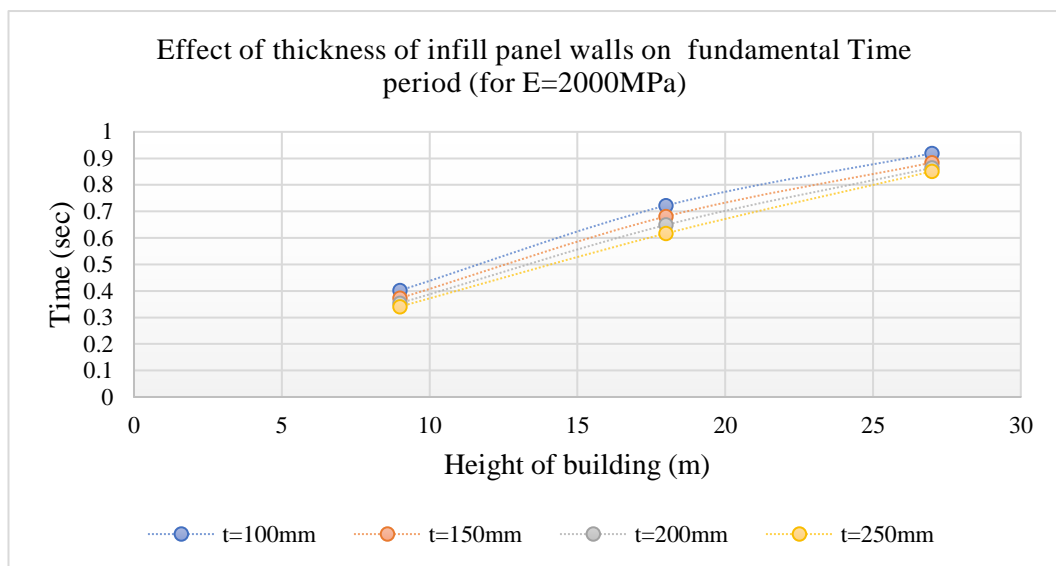


Figure 5.6 Effect of thickness of infill panel walls on fundamental time period (for E=2000MPa)

From figure 5.6, for height of 9m, and constant modulus of elasticity of infills 2000MPa, $T = 0.402$ sec for $t=100$ mm and $T = 0.341$ sec for $t=250$ mm, that is period is decreased by around 16%. Similarly, for 18m height of building, $T = 0.722$ sec for $t=100$ mm and $T = 0.617$ sec for $t=250$ mm, where period decreased by 15%. And for 27m height of building, $T = 0.919$ sec for $t= 100$ mm and $T = 0.851$ sec for $t=250$ mm, that is period decreased by around 8%. From this result we can conclude that for greater building height fundamental time period is less affected by presence of infill walls and walls thickness than lower height building for wall having lower modulus of elasticity.

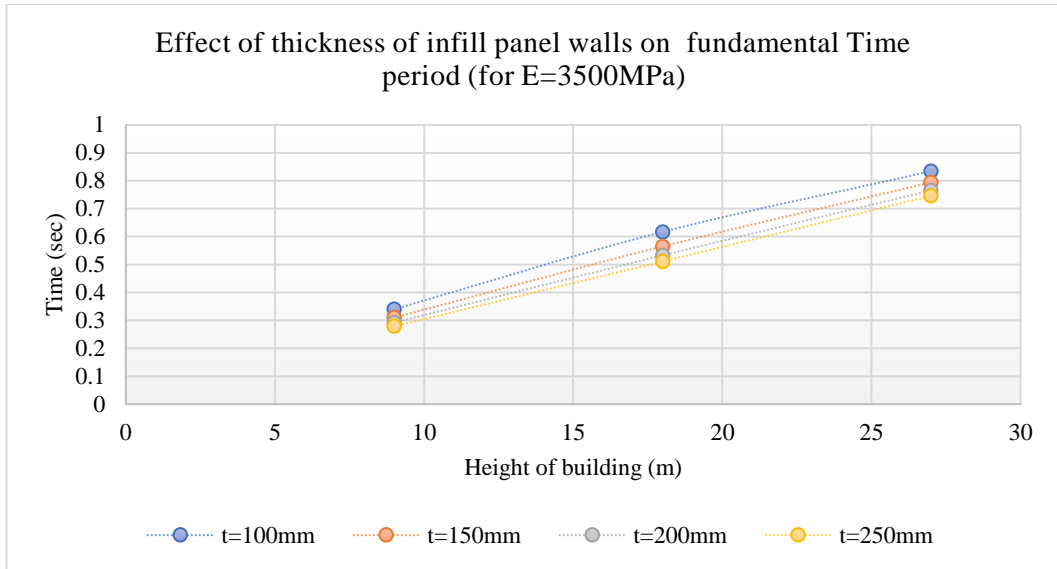


Figure 5.7 Effect of thickness of infill panel walls on fundamental time period (for E=3500MPa)

Here, from figure 5.7, for 9 m height of building having constant modulus of elasticity of infill (3500MPa), time period value is decreased by around 18%. This decreasing ratio is about 17% for 18m height building and around 11% for 27m height building.

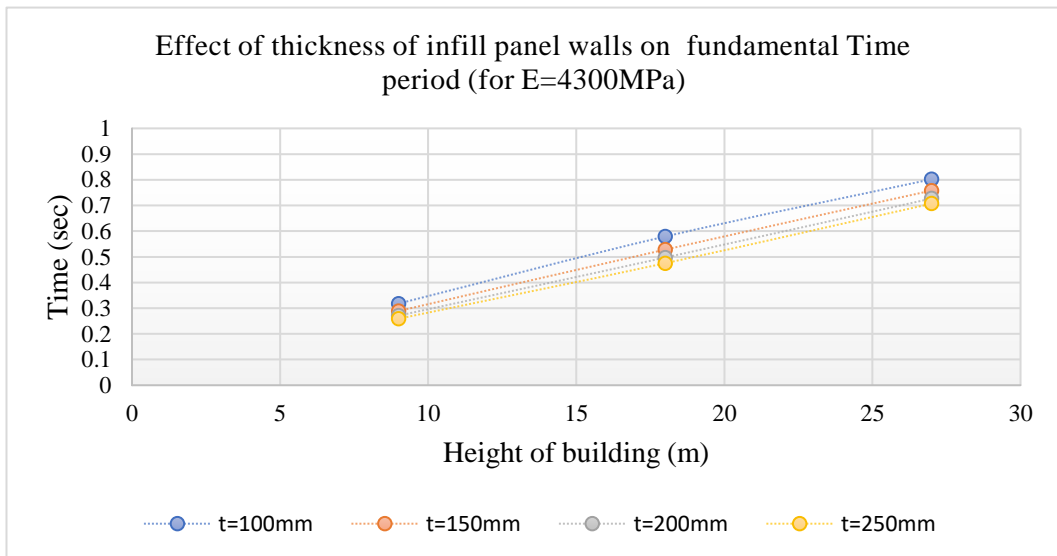


Figure 5.8 Effect of thickness of infill panel walls on fundamental time period (for E=4300MPa)

Similarly from figure 5.8 infill wall having modulus of elasticity of 4300MPa, for 9 m height building, time period value is decreased by around 19%. This decreasing pattern is about 18% for 18m height building and around 12% for 27m height building.

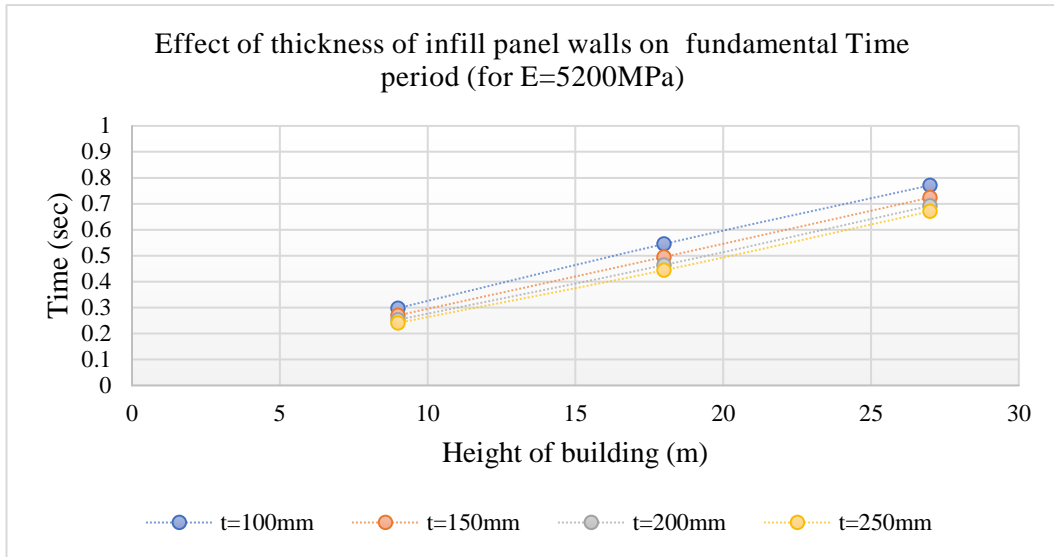


Figure 5.9 Effect of thickness of infill panel walls on fundamental time period (for E=5200MPa)

Again, for constant wall modulus of elasticity of 5200MPa (figure 5.9), for 9 m height building time period values is decreased by around 20% for changing wall thickness from 100mm to 250mm. This decreasing ratio is about 19% for 18m height building and around 13% for 27m height building.

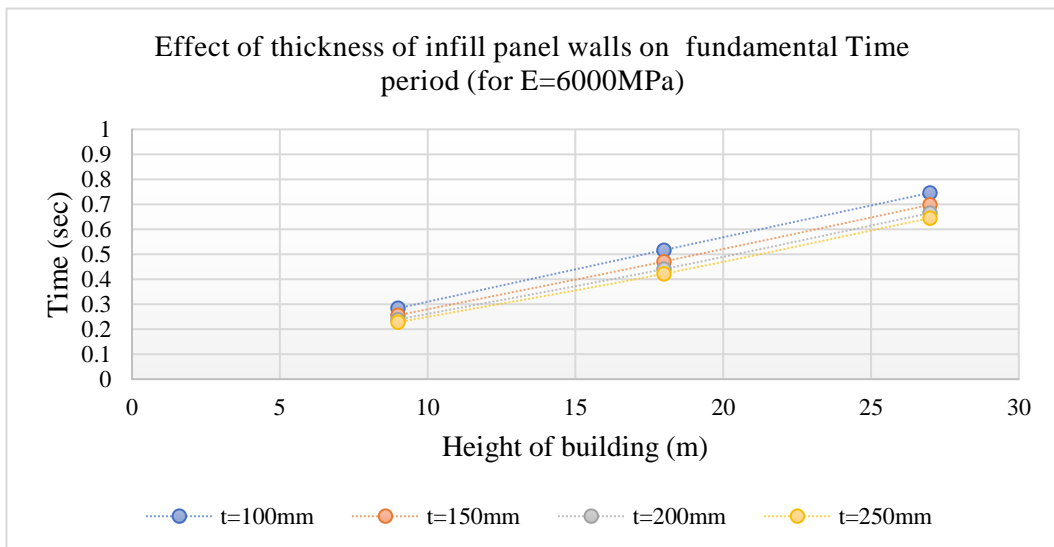


Figure 5.10 Effect of thickness of infill panel walls on fundamental time period (for E=6000MPa)

Results upon analysis shown that, from figure 5.10, for wall with higher modulus of elasticity then their stiffness effect is clearly shown for higher height of building too.

Here for wall having $E=6000\text{MPa}$ for 9m height building time period decreased by around 20% for varying wall thickness from 100mm to 250mm and this value is around 19% for 18m height building and 14% for 27m height building.

Similarly for others considered length of span, same kind of significant variation was found on fundamental time period and which are presented in APPENDIX C and APPENDIX D.

5.4 Regression Analysis

The effect of various considered parameters on the fundamental time period is evaluated after the values of the fundamental time period of different considered 180 building models are obtained (Table 5.3) using the Rayleigh method. After that multiple regression model is conducted through EXCEL software to acquire an approximate equation for fundamental time period which depends on different considered parameters. The height of the building (H), the overall base dimension of the structure (B), the modulus of elasticity of infill wall panels (E), and the thickness of infill wall panels (t) are all considered in the regression analysis.

The adjusted coefficient of determination (adjusted R^2) and standard error are examined for regression mode goodness of fit. Higher value of adjusted coefficient of determination indicates the better fit of data to the obtained regression equation while lower value indicates poorer fit. Smaller value of standard error denotes better fit of data set to the obtained regression equation and higher values of the standard error denotes poorer fit of data set to the obtained regression equation.

5.4.1 Considering fundamental time period as the function of building height, base dimension, modulus of elasticity of infill wall and infill wall thickness

Initially, multiple linear regression analysis was performed on the fundamental period of a building as a function of building height (H), base dimension of the building (B), thickness of infill wall panel (t), and modulus of elasticity of wall panel (E). The proposed expression of fundamental time period as per equation 5.1.

$$T = \alpha \frac{H^\beta D^\gamma}{E^\delta t^\lambda} \quad (5.1)$$

Here, coefficients of regression are α , β , γ , δ and λ .

Equation (5.1) is converted to the form

$$y = a + \beta x_1 + \gamma x_2 + \delta x_3 + \lambda x_4 \quad (5.2)$$

where, $y = \ln(T)$, $a = \ln(\alpha)$, $x_1 = \ln(H)$, $x_2 = \ln(D)$, $x_3 = \ln(E)$, $x_4 = \ln(t)$.

Time period obtained through Rayleigh method and input data set for software for regression analysis are given in Annex-5. From regression analysis, values of regression coefficients are: $\alpha = 0.452$, $\beta = 0.874$, $\gamma = 0.333$, $\delta = 0.284$ and $\lambda = 0.164$. Thus, from equation (5.1):

$$T = 0.452 \frac{H^{0.874} D^{0.333}}{E^{0.284} t^{0.164}} \quad (5.3)$$

The value of coefficient of determination (adjusted R^2) as 0.993 and the standard error as 0.033, which shows the good fit of data. Thus equation (5.3) gives the analytical expression of the fundamental time period of buildings as function of height of building, base dimension, infill wall thickness and modulus of elasticity of infill wall panel.

Figure (5.11) shows the plot of obtained time period from Rayleigh method vs period obtained from proposed equation (5.3) for considered buildings. Here figure shows that plotted data are shows linear relation so proposed equation (5.3) gives better prediction of the fundamental period.

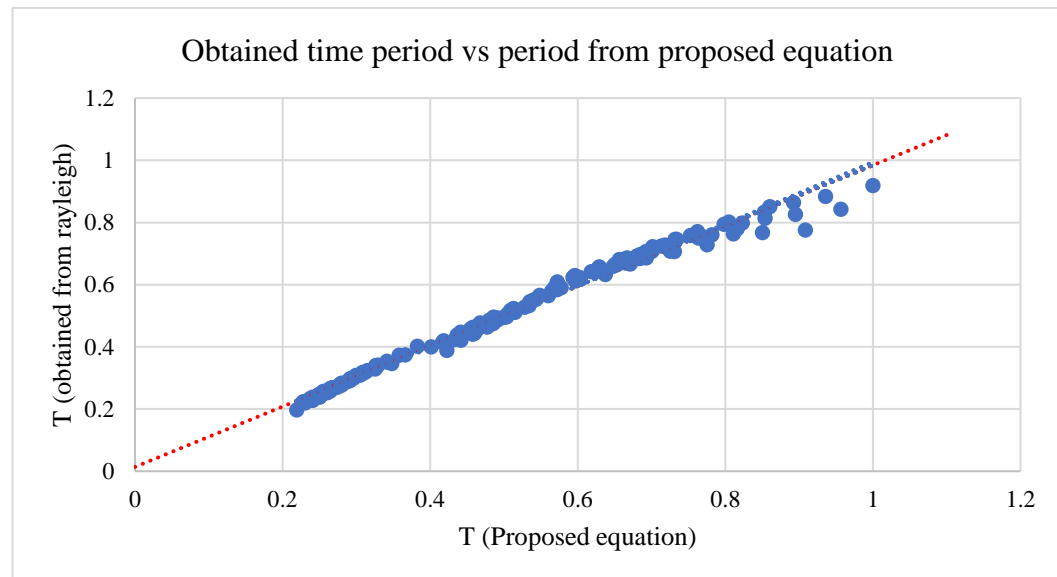


Figure 5.11 Plot of obtained time period from Rayleigh method vs period from proposed equation (5.3)

5.4.2 Considering fundamental time period as the function of building height, modulus of elasticity of infill wall and infill wall thickness

Another regression analysis is performed using the fundamental time period as a function of building height, infill wall thickness, and infill wall modulus of elasticity. The proposed expression is of the form as per equation 5.4.

$$T = \alpha \frac{H^\beta}{E^\delta t^\lambda} \quad (5.4)$$

Here, coefficients of regression are α , β , δ and λ .

The equation (5.4) is converted to the form

$$y = a + \beta x_1 + \delta x_2 + \lambda x_3 \quad (5.5)$$

where, $y = \ln(T)$, $a = \ln(\alpha)$, $x_1 = \ln(H)$, $x_2 = \ln(E)$, $x_3 = \ln(t)$.

Time period obtained through Rayleigh method and input data set for software for regression analysis are given in Annex-5. From regression analysis, values of regression coefficients are: $\alpha = 0.987$, $\beta = 0.874$, $\delta = 0.284$ and $\lambda = 0.164$. Thus, from equation (5.4):

$$T = 0.987 \frac{H^{0.874}}{E^{0.284} t^{0.164}} \quad (5.6)$$

The value of coefficient of determination (adjusted R^2) as 0.985 and the standard error as 0.051, which also shows the good fit of data. Thus equation (5.6) gives the analytical expression of the fundamental time period of buildings as function of building height, infill wall thickness and modulus of elasticity of infill wall panel.

Figure (5.12) shows the plot of obtained time period from Rayleigh method vs period obtained from proposed equation (5.6) for considered buildings data. Here figure shows more dispersion of period data.

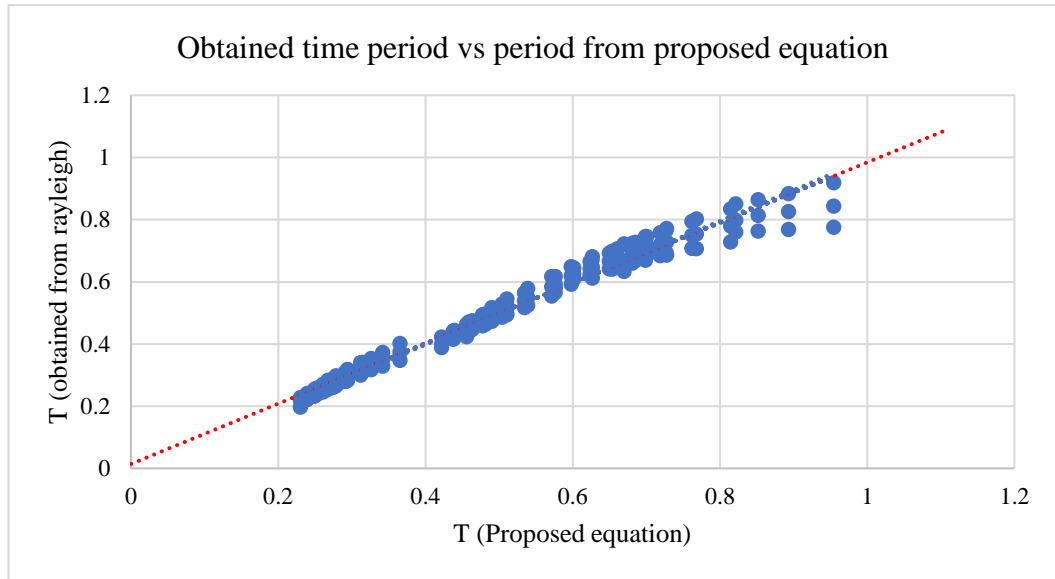


Figure 5.12 Plot of obtained time period from Rayleigh method vs period from proposed equation (5.6)

5.4.3 Considering fundamental time period as the function of height of building and base dimension of building

Similarly, another regression analysis was done to find a relationship between fundamental period as a function of building height and base dimension. The following is the proposed expression as per equation 5.7.

$$T = \alpha H^\beta D^\gamma \quad (5.7)$$

Where, α , β and γ are the regression coefficients.

The equation (5.7) is converted to the form

$$y = a + \beta x_1 + \gamma x_2 \quad (5.8)$$

Where, $y = \ln(T)$, $a = \ln(\alpha)$, $x_1 = \ln(H)$, $x_2 = \ln(D)$.

Time period obtained through Rayleigh method and input data set for software for regression analysis are given in Annex-5. After conducting regression analysis, values of regression coefficients are obtained as: $\alpha = 0.02$, $\beta = 0.874$, $\gamma = 0.333$. Thus, from equation (5.8):

$$T = 0.02 H^{0.874} D^{0.333} \quad (5.9)$$

From regression analysis, the value of coefficient of determination (adjusted R^2) as 0.9069 and the standard error as 0.127. Thus equation (5.9) gives the analytical

expression of the fundamental period of buildings which is function of building height and base dimension of building.

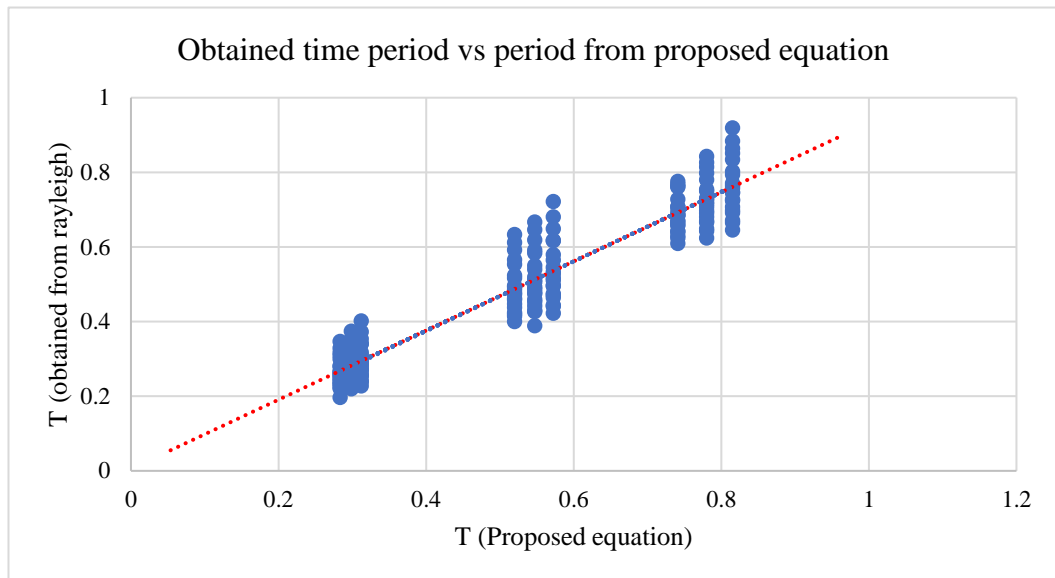


Figure 5.13 Plot of obtained time period from Rayleigh method vs period from proposed equation (5.9)

Figure (5.13) shows the plot of obtained time period from Rayleigh method vs period obtained from proposed equation (5.9) for considered buildings data.

5.4.4 Considering fundamental time period as the function of height of building

Regression analysis was again conducted between fundamental time period and height of building only. The expression of fundamental period as function of building height only is expressed as per equation 5.10.

$$T = \alpha H^\beta \quad (5.10)$$

Where, α and β are the regression coefficients which depend upon the building properties. For conducting regression analysis equation (5.10) is converted to the form

$$y = a + \beta x_1 \quad (5.8)$$

In which $y = \ln(T)$, $a = \ln(\alpha)$, $x_1 = \ln(H)$.

Input data sets for analysis are taken from Annex-5 and from regression analysis, values of unknown coefficients are $\alpha = 0.04$, $\beta = 0.874$. Thus, height dependent equation of fundamental time period considering effect of infill wall as per equation 5.11.

$$T = 0.04 H^{0.874} \quad (5.11)$$

Value of coefficient of determination (adjusted R^2) as 0.898 and the standard error as 0.133. It is seen that decreased in adjusted R^2 value and increase in the value of standard error than other equations.

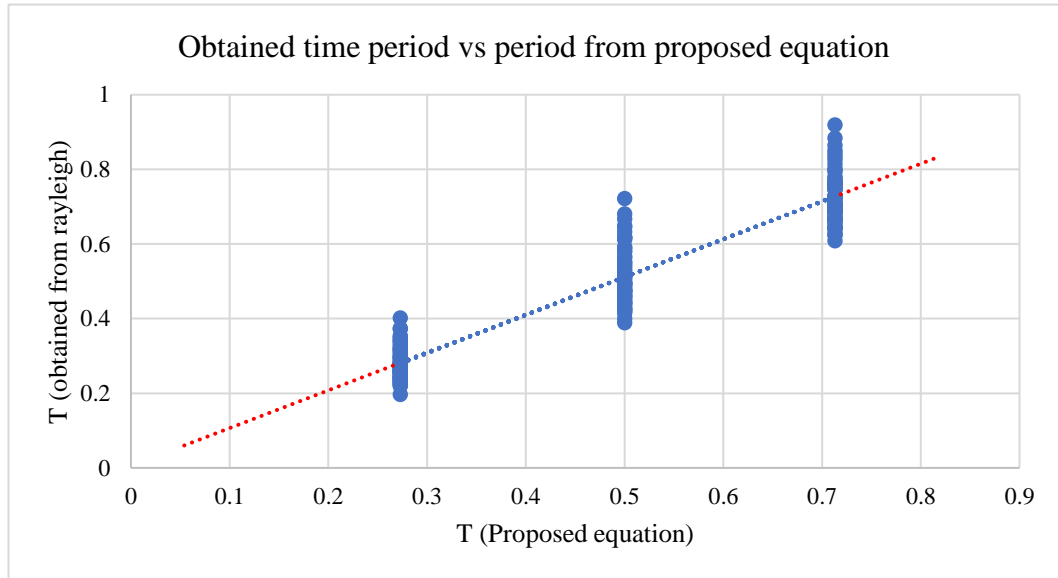


Figure 5.14 Plot of obtained time period from Rayleigh method vs period from proposed equation (5.1)

Figure (5.14) shows the plot of obtained time period from Rayleigh method vs period obtained from proposed equation (5.11) for considered buildings data. Figure shows largely dispersion of period.

Here from different regression analysis, the value of standard error is lower for equation (5.3) than other equations. Thus, the fundamental time period equation as proposed in equation (5.3), which deepens upon building height, base dimension of building, infill wall thickness and modulus of elasticity of infill wall panel, is best fitted among others. Also, period and height depended relation of equation (5.11) have higher value of coefficient of determination (adjusted R^2). Which shows that time period is not fully dependent on the height of building but also the stiffness of infill wall plays considerable role in fundamental period of building.

5.5 Comparisons between computed time period calculated from Rayleigh method with period obtained through proposed equations and others empirical equations

For comparison of the fundamental time period using proposed analytical equations, different Irregular shaped real buildings are chosen. For sample data: real building 1 (APPENDIX F) have following properties: storey number of 3, having 4 bays and storey height of 3m. The column section is of size 350mm*350mm and the beam section is 300mm*230mm. The average wall thickness was taken as 150mm and modulus of elasticity of infill wall was 2700MPa. Here, for real building 1, obtained Rayleigh time period is 0.334sec for x- direction and 0.312sec for y-direction. Time period obtained from height, base dimension, modulus of elasticity and thickness dependent proposed equation is 0.292sec and 0.298sec for x and y direction respectively. Here difference between Rayleigh time period and that obtained from proposed empirical equation is very low. That is proposed empirical equation gives period value nearer to the value of fundamental time period determined through Rayleigh method. Similarly, other proposed equation gives satisfactory period compared to Rayleigh method.

The time period values obtained through Rayleigh method is compared with obtained analytical equation and others empirical equations are shown in Table (5.4) and Table (5.5). For other real buildings, building parameters and plans are shown in APPENDIX F.

Table 5. 4 Comparison of period obtained from proposed empirical equations with Rayleigh method

| <i>Here, H is the height of building in meter, E is modulus of elasticity of infill wall and t is the thickness of infill wall panel. Tray indicates Rayleigh period and Temp indicates period obtained from empirical formula. T_x and T_y period in x and y directions. All values are in second.</i> | | | | | | | | | | | |
|---|----|--------------------|--------------------|------|-----|------------------------|----------------|----------------|----------------|----------------|----------------|
| Real building | H | Base Dimension | | E | t | Empirical Equation (1) | | Rayleigh Time | | Tray-Temp | |
| | | X-dir ⁿ | Y-dir ⁿ | | | T _x | T _y | T _x | T _y | T _x | T _y |
| 1 | 9 | 8.425 | 8.950 | 2700 | 150 | 0.292 | 0.298 | 0.334 | 0.312 | 0.042 | 0.013 |
| 2 | 15 | 9.150 | 8.680 | 2700 | 150 | 0.470 | 0.462 | 0.556 | 0.554 | 0.086 | 0.092 |
| 3 | 6 | 10.515 | 10.973 | 2700 | 150 | 0.221 | 0.224 | 0.284 | 0.236 | 0.063 | 0.012 |
| 4 | 12 | 10.515 | 7.924 | 2700 | 150 | 0.405 | 0.368 | 0.442 | 0.499 | 0.037 | 0.130 |
| 5 | 6 | 10.360 | 7.920 | 2700 | 150 | 0.220 | 0.201 | 0.229 | 0.314 | 0.010 | 0.113 |
| 6 | 6 | 7.010 | 11.430 | 2700 | 150 | 0.193 | 0.227 | 0.278 | 0.248 | 0.085 | 0.021 |
| 7 | 15 | 7.518 | 10.769 | 2700 | 150 | 0.440 | 0.496 | 0.556 | 0.553 | 0.116 | 0.057 |
| 8 | 9 | 8.534 | 8.534 | 2700 | 150 | 0.294 | 0.294 | 0.381 | 0.413 | 0.087 | 0.119 |

Here, comparison results of Table (5.4) show that for real buildings, proposed empirical equations 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 (2019) in his research. Also, these absolute difference period values are identical to comparison results of Aninthaneni P. and Dhakal R. (2016) in their research works. Thus, proposed equation gives satisfactory estimation of fundamental period. Here buildings 1-5 have irregular shape with constant three number of bays in both direction (X & Y) but buildings (6-8) have irregular in shape with unequal number of bays in horizontal direction thus, they have little more difference in period between period obtain through Rayleigh method and empirical equation. Also, real building is constructed based on old codal provision so that structural is more flexible thus, obtained Rayleigh period is litter more than period given by proposed equation. But for practical application proposed equation gives the fundamental time period close to the fundamental period obtained using the Rayleigh method.

Table 5. 5 Comparison of different empirical equations

| <i>Here, T₁, T₂, T₃ and T₄ are proposed empirical equations. T_{ray} is the fundamental period obtained from Rayleigh method. T_x and T_y period in x and y directions. All values are in second.</i> | | | | | | | | |
|---|-------------------|----------------|-------------------|----------------|-------------------|----------------|-------------------|----------------|
| Empirical Equations | Real Building (1) | | Real Building (2) | | Real Building (3) | | Real Building (4) | |
| | T _x | T _y | T _x | T _y | T _x | T _y | T _x | T _y |
| Rayleigh time period (T _{ray}) | 0.334 | 0.312 | 0.556 | 0.554 | 0.284 | 0.236 | 0.442 | 0.499 |
| $T_1 = 0.452 \frac{H^{0.874} D^{0.333}}{E^{0.284} t^{0.164}}$ | 0.292 | 0.298 | 0.470 | 0.462 | 0.221 | 0.224 | 0.405 | 0.368 |
| $T_2 = 0.987 \frac{H^{0.874}}{E^{0.284} t^{0.164}}$ | 0.314 | 0.314 | 0.491 | 0.491 | 0.220 | 0.220 | 0.404 | 0.404 |
| $T_3 = 0.02H^{0.874}D^{0.333}$ | 0.277 | 0.283 | 0.446 | 0.438 | 0.210 | 0.213 | 0.384 | 0.350 |
| $T_4 = 0.04 H^{0.874}$ | 0.273 | 0.273 | 0.427 | 0.427 | 0.191 | 0.191 | 0.351 | 0.351 |
| T _{NBC/NZS(Ultimate)} = 1.25*0.075*H ^{3/4} | 0.487 | 0.487 | 0.751 | 0.751 | 0.359 | 0.359 | 0.604 | 0.604 |
| T _{ASCE-7/BNBC} = 0.0466*H ^{0.9} | 0.329 | 0.329 | 0.521 | 0.521 | 0.228 | 0.228 | 0.426 | 0.426 |
| T _{IS/Eurocode} = 0.075*H ^{3/4} | 0.390 | 0.390 | 0.572 | 0.572 | 0.288 | 0.288 | 0.484 | 0.484 |
| T _{Pakistan} = 0.0731*H ^{3/4} | 0.380 | 0.380 | 0.557 | 0.557 | 0.280 | 0.280 | 0.471 | 0.471 |
| T _{BSLJ} = H (0.02+0.01α) | 0.18 | 0.18 | 0.300 | 0.300 | 0.120 | 0.120 | 0.240 | 0.240 |
| T _{A. Kocak} = 0.026H ^{0.9} | 0.188 | 0.188 | 0.297 | 0.297 | 0.130 | 0.130 | 0.243 | 0.243 |
| T _{Goel & Chopra} = 0.023H ^{0.9} | 0.166 | 0.166 | 0.263 | 0.263 | 0.115 | 0.115 | 0.215 | 0.215 |
| T _{J. C. Rimal} = .03H ^{0.82} D ^{0.766} B ^{-0.784} | 0.393 | 0.390 | 0.637 | 0.408 | 0.334 | 0.547 | 0.590 | 0.426 |
| T _{R. Shrestha} = 0.05*H ^{0.75} | 0.260 | 0.260 | 0.381 | 0.381 | 0.192 | 0.192 | 0.322 | 0.322 |

Here, table 5.5 and table 5.6 shows that time period obtained through proposed equations are very closed to period calculated from Rayleigh method. Latest NBC code doesn't consider the effect of infill so that NBC / NZS (ultimate) code gives period

value more than that period calculated from Rayleigh method. Period obtained from ASCE-7 and BNBC codes closed to proposed equation and which are very closed to fundamental period calculated from Rayleigh method.

Table 5 6 Comparison of different empirical equations

| <i>Here, T_1, T_2, T_3 and T_4 are proposed empirical equations. T_{ray} is the fundamental period obtained from Rayleigh method. T_x and T_y period in x and y directions. All data are in second.</i> | | | | | | | | |
|--|-------------------|-------|-------------------|-------|-------------------|-------|-------------------|-------|
| Empirical Equations | Real Building (5) | | Real Building (6) | | Real Building (7) | | Real Building (8) | |
| | T_x | T_y | T_x | T_y | T_x | T_y | T_x | T_y |
| Rayleigh time period (T_{ray}) | 0.229 | 0.314 | 0.278 | 0.248 | 0.556 | 0.553 | 0.381 | 0.413 |
| $T_1 = 0.452 \frac{H^{0.874} D^{0.333}}{E^{0.284} t^{0.164}}$ | 0.220 | 0.201 | 0.193 | 0.227 | 0.440 | 0.496 | 0.294 | 0.294 |
| $T_2 = 0.987 \frac{H^{0.874}}{E^{0.284} t^{0.164}}$ | 0.220 | 0.220 | 0.220 | 0.220 | 0.491 | 0.491 | 0.314 | 0.314 |
| $T_3 = 0.02 H^{0.874} D^{0.333}$ | 0.209 | 0.209 | 0.183 | 0.216 | 0.418 | 0.471 | 0.279 | 0.279 |
| $T_4 = 0.04 H^{0.874}$ | 0.191 | 0.191 | 0.191 | 0.191 | 0.427 | 0.427 | 0.273 | 0.273 |
| $T_{NBC/NZS(Ultimate)} = 1.25 * 0.075 * H^{3/4}$ | 0.359 | 0.359 | 0.359 | 0.359 | 0.715 | 0.715 | 0.487 | 0.487 |
| $T_{ASCE-7/BNBC} = 0.0466 * H^{0.9}$ | 0.228 | 0.228 | 0.228 | 0.228 | 0.521 | 0.521 | 0.329 | 0.329 |
| $T_{IS/Eurocode} = 0.075 * H^{3/4}$ | 0.288 | 0.288 | 0.288 | 0.288 | 0.572 | 0.572 | 0.390 | 0.390 |
| $T_{Pakistan} = 0.0731 * H^{3/4}$ | 0.280 | 0.280 | 0.280 | 0.280 | 0.557 | 0.557 | 0.380 | 0.380 |
| $T_{BSLJ} = H(0.02 + 0.01\alpha)$ | 0.120 | 0.120 | 0.120 | 0.120 | 0.300 | 0.300 | 0.180 | 0.180 |
| $T_{A. Kocak} = 0.026 H^{0.9}$ | 0.130 | 0.130 | 0.130 | 0.130 | 0.297 | 0.297 | 0.188 | 0.188 |
| $T_{Goel \& Chopra} = 0.023 H^{0.9}$ | 0.115 | 0.115 | 0.115 | 0.115 | 0.263 | 0.263 | 0.166 | 0.166 |
| $T_{J. C. Rimal} = .03 H^{0.82} D^{0.766} B^{-0.784}$ | 0.330 | 0.421 | 0.245 | 0.245 | 0.548 | 0.548 | 0.397 | 0.397 |
| $T_{R. Shrestha} = 0.05 * H^{0.75}$ | 0.192 | 0.192 | 0.192 | 0.192 | 0.381 | 0.381 | 0.260 | 0.260 |

Here, $T_{R. Shrestha}$, is period equation proposed by Ramila Shrestha and Sudip Karanjit (2017) based on real experimental data of 31 real sample buildings of Kathmandu valley. They proposed height dependent equation as $T=0.05 * H^{0.75}$ based on their experimental works. Here fundamental period of real sample buildings obtained from their equation is almost equal to period obtained from height dependent proposed equation (5.11), $T=0.04 * H^{0.874}$. Thus, these proposed analytical equations give fundamental period closed to fundamental period equation given by real experimental works. Thus, proposed equation gives satisfactory estimation of fundamental period.

5.6 Effect of proposed equations on the base share

According to NBC: 105:2020, the horizontal base shear (V) at the base of the building, in considered direction shall be calculated as:

considered direction shall be calculated as per equation 5.13.

$$V = C_d(T_1) * W \quad (5.13)$$

Where, $C_d(T_1)$ is the horizontal base shear coefficient which is different for ultimate limit state and serviceability limit state, and W is the seismic weight of the structure.

Here, $C_d(T_1)$ is related to elastic site spectra which is determined for both ultimate limit state and serviceability limit state separately. These elastic site spectra for both condition is related to the spectral shape factor, $C_h(T)$ which is defined in clause (4.1.2) of code. The spectral shape factor, $C_h(T)$ for the relevant soil type shall be obtained for equivalent static method, for modal response spectrum method and nonlinear time history analysis method.

Now for soil type D and for equivalent static method, fundamental period of considered buildings (3-9 storey) lies between 0 to 2sec. For this case the spectral shape factor, $C_h(T)$ is 2.25 (constant value). Thus, for an equivalent static method and soil type D, change in fundamental period due to effect of infill does not change the horizontal base shear.

Again, for soil type D and, for modal response spectrum method and nonlinear time history analysis.

For calculated fundamental period less than 0.5sec

$$C_h(T) = 1 + 1.25 * \frac{T}{0.5} \quad \text{if, } T < 0.5\text{sec.}$$

For calculated fundamental period between 0.5sec to 2.0sec

$$C_h(T) = 2.25$$

Here, for soil type D and, for modal response spectrum method and nonlinear time history analysis, change in fundamental period due to effect of infill may change the horizontal base shear.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1 Introduction

The purpose of this thesis was to investigate the impact of infill wall stiffness on the fundamental time period of regular RC frame buildings. 180 different regular building models are taken for analysis, with various parameters taken into consideration are as: height of building (9.0m, 18.0m and 27.0m), base dimension of building (3.0m, 3.5m, 4.0m), modulus of elasticity of infill wall panel E (2000MPa, 3500MPa, 4300MPa, 5200MPa and 6000MPa) and thickness of infill walls (100mm, 150mm, 200mm and 250mm). Building models are designed using FEM software ETABS v19. Infilled was analyzed by using the equation given in FEMA as diagonal strut model, It has proven to be the most common and accepted method for dealing with infilled frame analysis by the majority of researchers. After that fundamental time period was calculated using Rayleigh method, which is an energy-based method and finally approximate formulation of fundamental time period of building based on considered parameters are given using regression analysis. After study of results obtained from considered models for considered parameters, a conclusion of the research work was developed.

6.2 Conclusion

The stiffness of the infill wall panels has a significant impact on the building's fundamental time period. For low to medium height of building, infill wall plays more important role on fundamental time period than high rise building. By increasing the modulus of elasticity and thickness of infill wall panel, 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 period of building.

The proposed analytical expressions which include height of building, base dimension, wall thickness and modulus of elasticity shows better results for prediction of fundamental time period of building. Proposed analytical expression based on regression analysis are as:

- i.) Fundamental time period of building which is depend on height of building(H), base dimension of building (D), modulus of elasticity of infill wall panel (E) and thickness of infill wall panel (t) only:

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

- ii.) Fundamental time period of building which is depend on height of building(H), modulus of elasticity of infill wall panel (E) and thickness of infill wall panel (t) only:

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

- iii.) Fundamental time period of building which is depend on height of building(H) and base dimension (D) of building only:

$$T = 0.02 H^{0.874}D^{0.333}$$

- iv.) Fundamental time period of building which is depend on height of building(H):

$$T = 0.04 H^{0.874}$$

Hare, T is the fundamental time period of building in second, H is the height of building in meter, D is the base dimension of building in meter, E is the modulus of elasticity of infill wall panel in MPa and t is the thickness of infill wall in millimeter.

6.3 Recommendations

This thesis only considered regular buildings with three number of equal sized bays in both horizontal directions having constant storey height. Parameters taken into consideration for analysis was height of building, base dimension of building, modulus of elasticity of infill wall panel and thickness of infill wall panels. Further study can be done by considering wider range of height, base dimension, number of bays, varying storey heigh, shear walls, lift core walls and other sets of geometrical parameters. Also, irregular buildings in both plan and elevation can be analyzed. Study of effect of mass and stiffness irregularity can also consider. In this study constant wall thickness for both external and internal wall are considered with fixed 30% opening, detailed study can be done by considering more actual wall thickness for external and internal wall with various opening percentage. Here only analytical study could be done. If,

fundamental time period of real buildings from experimental study could be carried out, the result would be more accurate and realistic. The foundation consideration here is fixed, further detailed study can be done by consideration effect of soil structure interaction. Here infill wall is model as single equivalent diagonal strut model as suggested by FEMA, further study can be done by other methods of infill wall modeling.

REFERENCES

- Al-Chaar, G. (2002). Evaluating Strength and Stiffness of Unreinforced Masonry Infill Structures. *US army corps of engineers, engineering research and development center*,86.
- Amalia, A., & Iranata, D. (2017). Comparative study on diagonal equivalent methods of masonry infill panel. *AIP Conference Proceedings*, 030011.
- Anderson J.C. & Naeim F. (2012). Basic Structural Dynamics. *John Wiley & Sons, Inc.*
- Aninthaneni, P., & Dhakal, R. (2016). Prediction of fundamental period of regular frame buildings. *Bulletin of the New Zealand Society for Earthquake Engineering*, 49, 175-189
- ASCE (2017). Minimum Design loads and Associated criteria for Buildings and other Structures. American Society of Civil Engineering
- Asteris, P., Repapis, C., Tsaris, A., Di Trapani, F., & Cavaleri, L. (2015). Parameters affecting the fundamental period of infilled RC frame structures. *Earthquakes and Structures*, 9, 999-1028.
- Bangladesh National Building Code (BNBC) (2015). Housing Building Research Institute, Bangladesh Standards, and Testing Institution.
- Bhatt, M., Jha, S., & Pradhan, P. (2019). Study on the Effect of Mass and Stiffness Irregularities on Fundamental Period of Infilled RC Framed Buildings. *2nd International Conference on Earthquake Engineering and Post Disaster Reconstruction Planning*.
- Building Code of Pakistan Seismic Provisions (2007). Government of Pakistan Ministry of Housing & Works.
- Clough R.W. & Penzien J. (2015). Dynamics of structure (2nd ed.). *CBS Publishers & distributors Pvt. Ltd.*
- Eurocode 8 (2004). Design of structures for earthquake resistance. European Committee for Standardization.
- FEMA 356 (2000). Prestandard and commentary for the seismic rehabilitation of building. Federal Emergency Management agency, Washington, DC.

- Furtado, A., Vila-Pouca, N., Varum, H., & Arêde, A. (2019). Study of the Seismic Response on the Infill Masonry Walls of a 15-Storey Reinforced Concrete Structure in Nepal. *Buildings*, 9,39.
- Hatzigeorgiou, G., & Kanapitsas, G. (2013). Evaluation of fundamental period of low-rise and mid-rise reinforced concrete buildings. *Earthquake Engineering & Structural Dynamics*, 42(11), 1599-1616.
- Holmes, M. (1961). Steel Frames with Brickwork and Concrete Infilling. *Proceedings of the Institution of Civil Engineers*, 19(4), 473-478.
- IS1893:2016 (2016). Indian Standard Criteria for Earthquake Resistant Design of Structures-Part I: General Provisions and Buildings (Sixth Revision). New Delhi: Bureau of Indian Standards.
- Khan Mahmud Amanat, & Ekramul Hoque (2006). A rationale for determining the natural period of RC building frames having infill. *Engineering Structures*, 28(4), 495-502.
- Kocak, A., & Yıldırım, M. (2011). Effects of Infill Wall Ratio on the Period of Reinforced Concrete Framed Buildings. *Advances in Structural Engineering*, 14, 731-744.
- Kocak, A., Kalyoncuoğlu, A., & Zengin, B. (2013). Effect of infill wall and wall openings on the fundamental period of RC buildings. *WIT Transactions on the Built Environment*, 132, 121-131.
- Liau, T. C. & Kwan K.W. (1992). Nonlinear behavior of non-integral infilled frames
- Mainstone, R.J., Weeks, G.A. (1970). The influence of bounding frame on the racking stiffness and strength of brick walls. *In: Proceedings of the 2nd International Brick Masonry Conference*, Building Research Establishment, Watford, England,165–171.
- Mehmet Metin Kose (2009). Parameters affecting the fundamental period of RC buildings with infill walls. *Engineering Structures*, 31(1), 93-102.
- NBC105:2020 (2020). Nepal National Building Code. Seismic Design of Buildings in Nepal.

- Öz, İ., Senel, S., Palanci, M., & Kalkan, A. (2020). Effect of Soil-Structure Interaction on the Seismic Response of Existing Low and Mid-Rise RC Buildings. *Applied-Sciences, 10*.
- Paulay & M. Priestley, 1992, Seismic Design of Reinforced Concrete and Masonry Buildings. Jhon Wiley & Sons, New York.
- Phaiju, S., & Pradhan, P. (2018). Experimental Work for Mechanical Properties of Brick and Masonry Panel. *Journal of Science and Engineering 5, 51-57*.
- Pradhan, P., Maskey, R., & Pradhan, P. (2012). Composite Behavior of Masonry Partially Infilled Reinforced Concrete Frames. *Building Research Journal, 60, 51-60*.
- Rakesh K. Goel, & Anil K. Chopra (1997). Period Formulas for Moment-Resisting Frame Buildings. *Journal of Structural Engineering, 123(11), 1454-1461*.
- Rimal Jagadish C., (2019), “Fundamental Time Period for seismic Design of Buildings in Nepal”, *MSc. Thesis*, Department of Civil Engineering, Tribhuvan University, Nepal.
- Shrestha, R., & Karanjit, S. (2017). Comparative study on the fundamental time period of RC buildings based on codal provision and ambient vibration test – a case study of Kathmandu Valley. *Journal of Science and Engineering, 4, 31–37*.
- Stafford Smith, B., & Carter, C. (1969). A Method of Analysis for Infilled Frames. *Proceedings of the Institution of Civil Engineers, 44(1), 31-48*.
- The National Building Code (NBC) (1995). National Research Council, Canada.

APPENDIX

APPENDIX A:

Effect of modulus of elasticity (E) of infill wall panel on fundamental time period of regular building (For 3m span length)

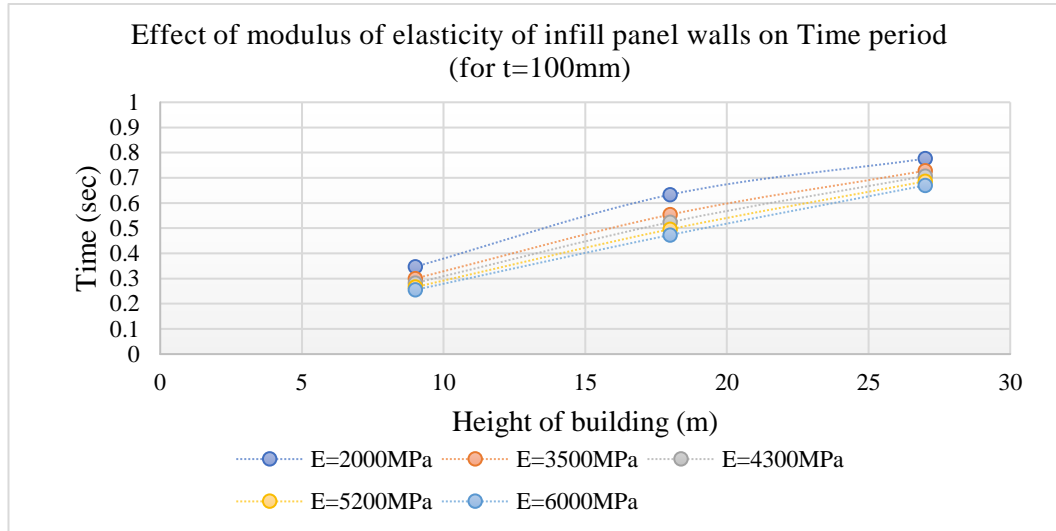


Figure A1 Effect of modulus of elasticity of infill wall panel (t=100mm) on fundamental time period

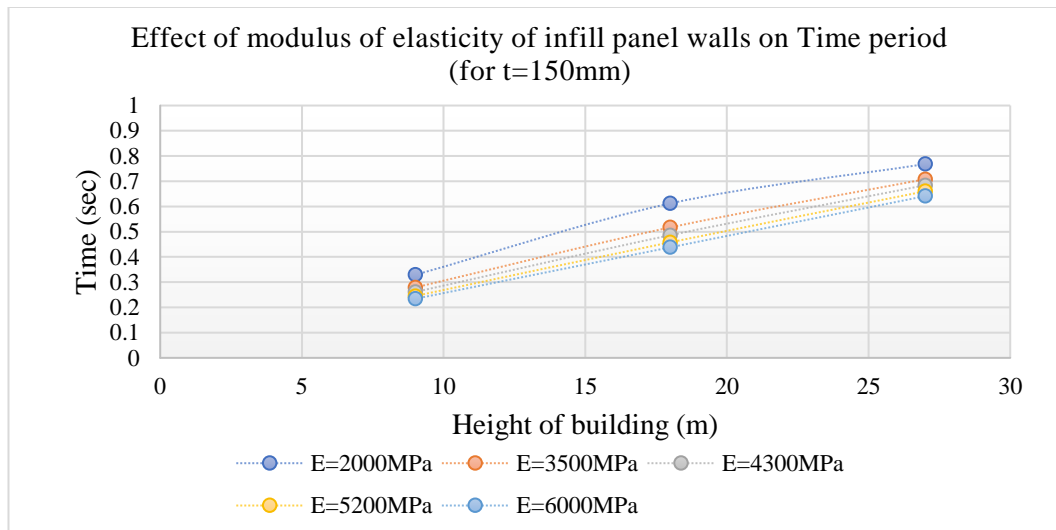


Figure A2 Effect of modulus of elasticity of infill wall panel (t=150mm) on fundamental time period

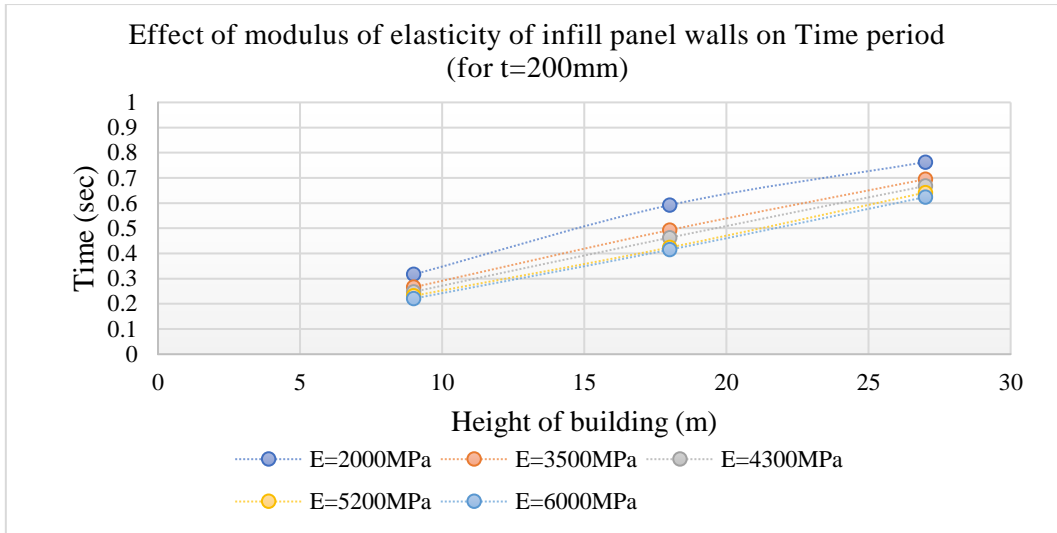


Figure A3 Effect of modulus of elasticity of infill wall panel (t=200mm) on fundamental time period

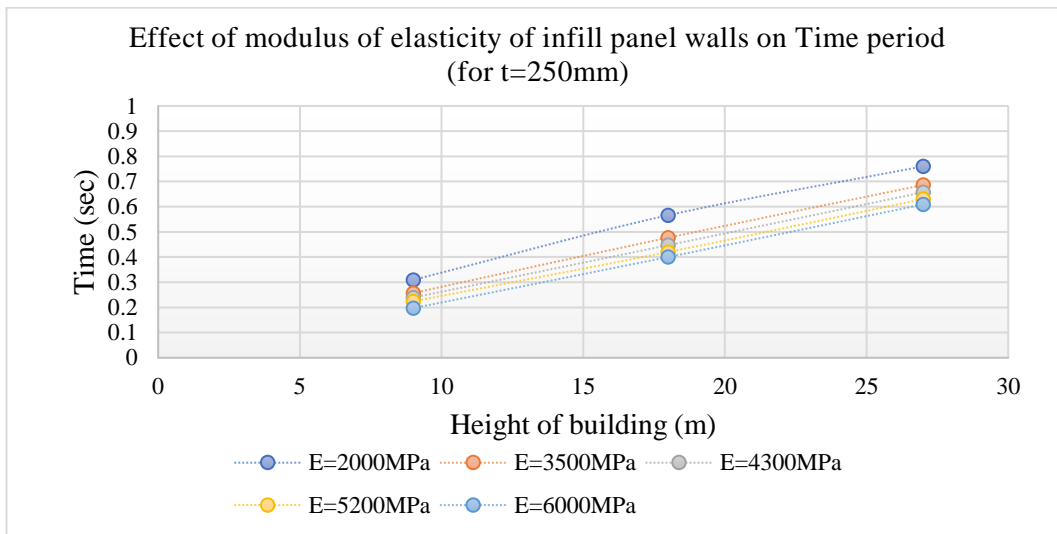


Figure A4 Effect of modulus of elasticity of infill wall panel (t=250mm) on fundamental time period

APPENDIX B:

Effect of modulus of elasticity (E) of infill wall panel on fundamental time period of regular building (For 3.5m span length)

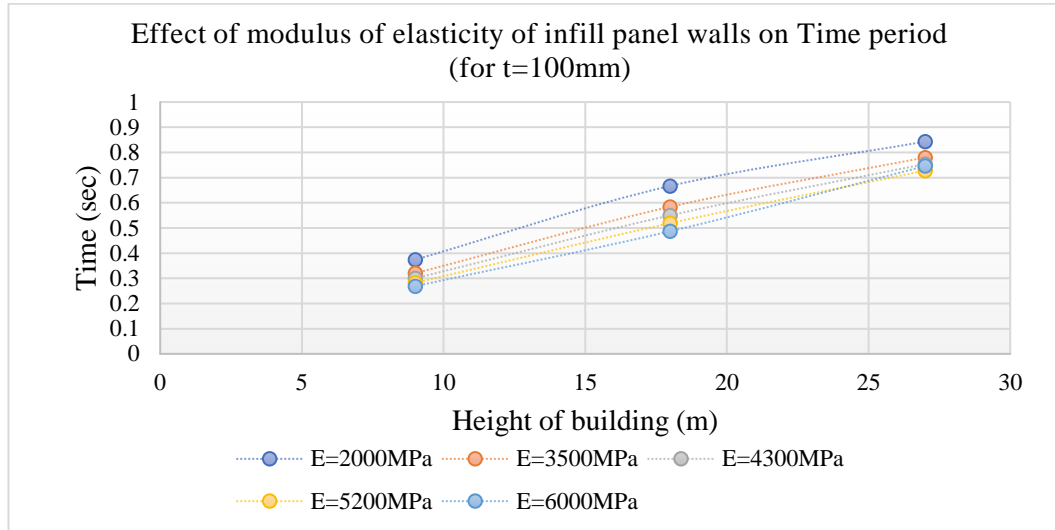


Figure A5 Effect of modulus of elasticity of infill wall panel (t=100mm) on fundamental time period

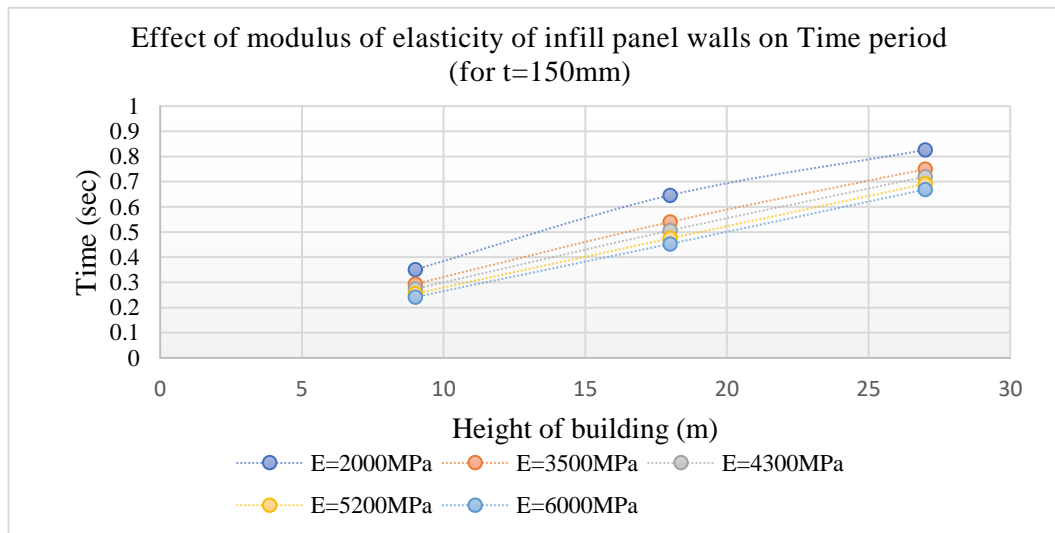


Figure A6 Effect of modulus of elasticity of infill wall panel (t=150mm) on fundamental time period

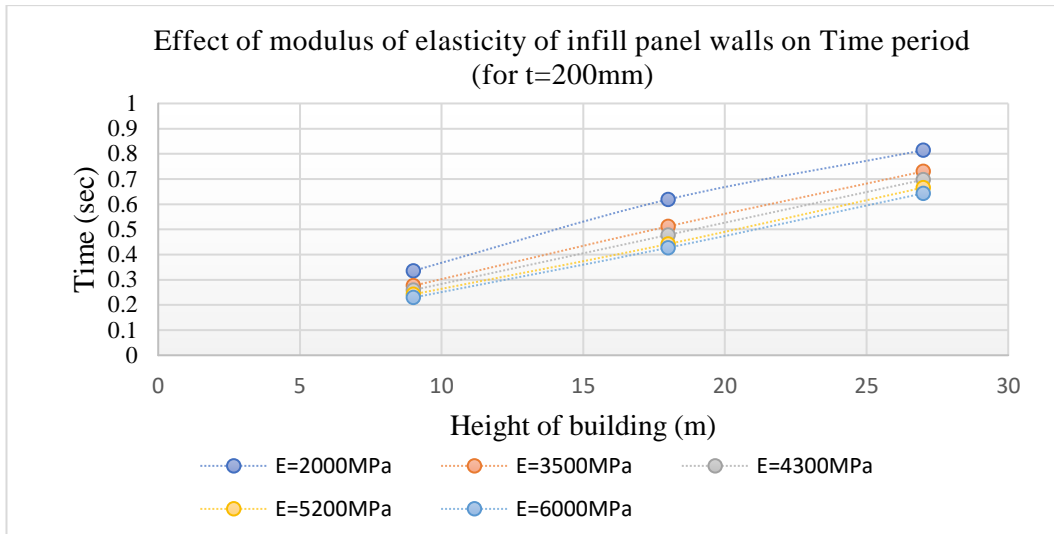


Figure A7 Effect of modulus of elasticity of infill wall panel (t=200mm) on fundamental time period

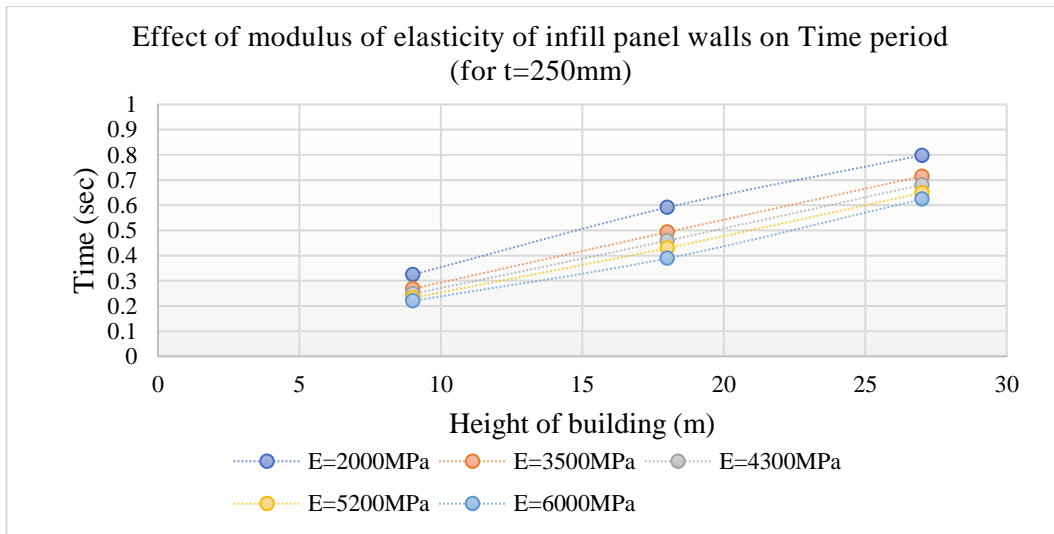


Figure A8 Effect of modulus of elasticity of infill wall panel (t=250mm) on fundamental time period

APPENDIX C:

Effect of thickness of infill wall panel on fundamental time period of regular building (For 3m span length)

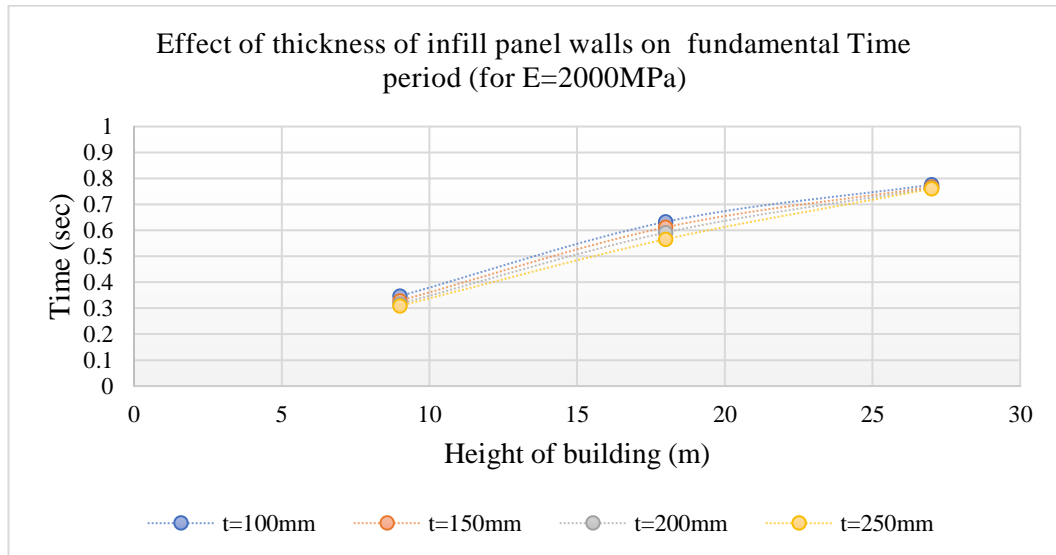


Figure A9 Effect of thickness of infill panel walls on fundamental time period (for E=2000MPa)

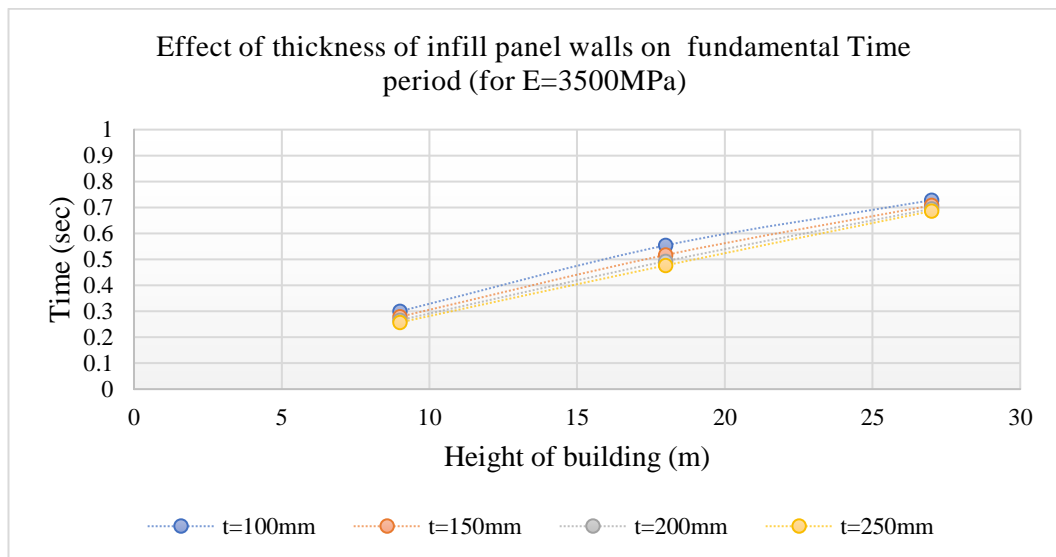


Figure A10 Effect of thickness of infill panel walls on fundamental time period (for E=3500MPa)

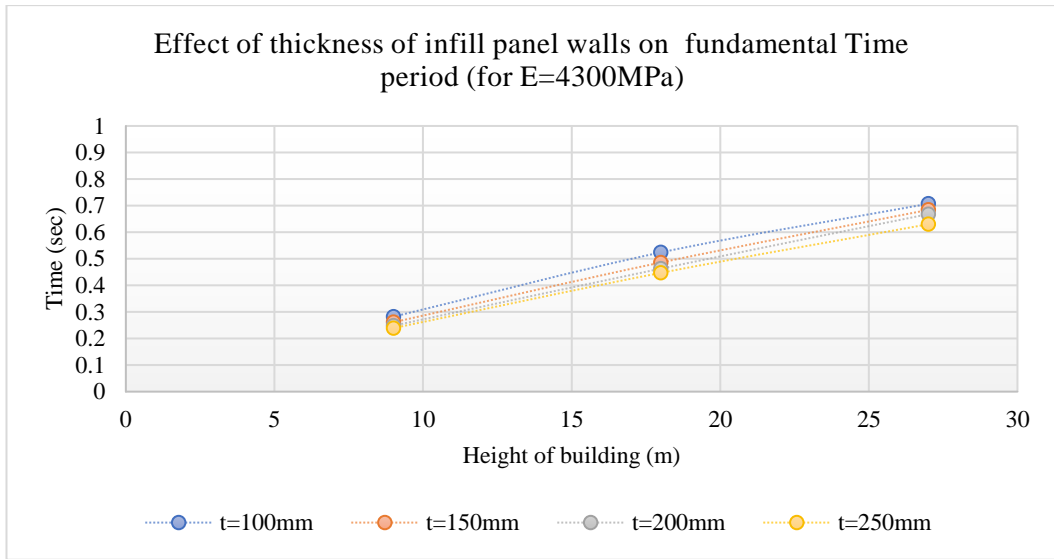


Figure A11 Effect of thickness of infill panel walls on fundamental time period (for E=4300MPa)

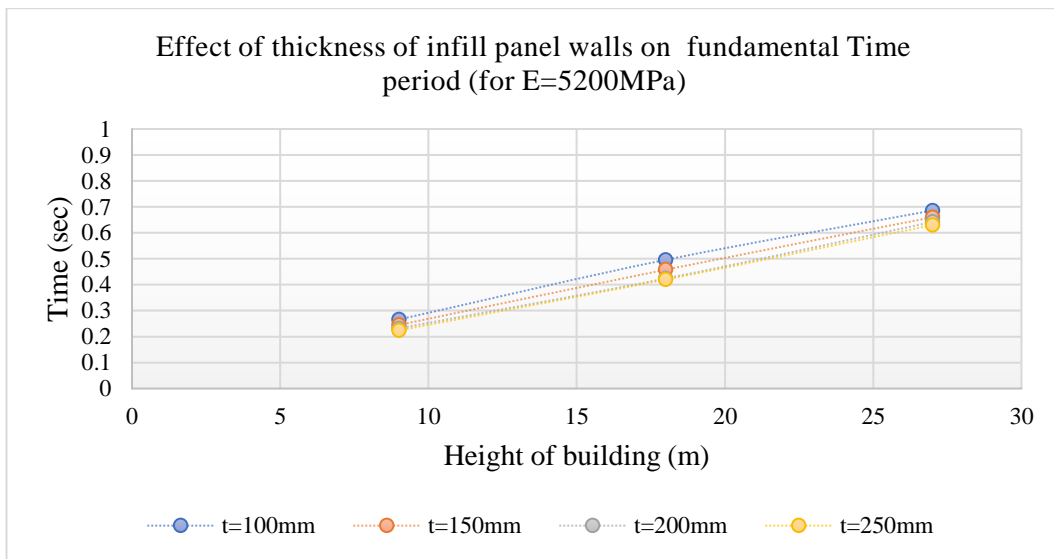


Figure A12 Effect of thickness of infill panel walls on fundamental time period (for E=5200MPa)

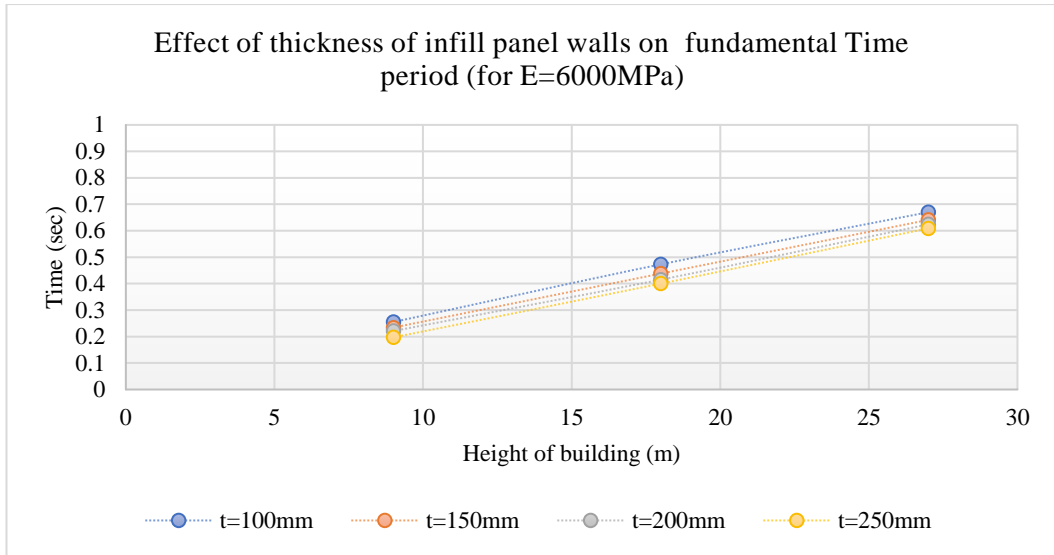


Figure A13 Effect of thickness of infill panel walls on fundamental time period (for E=6000MPa)

APPENDIX D:

Effect of thickness of infill wall panel on fundamental time period of regular building (For 3.5m span length)

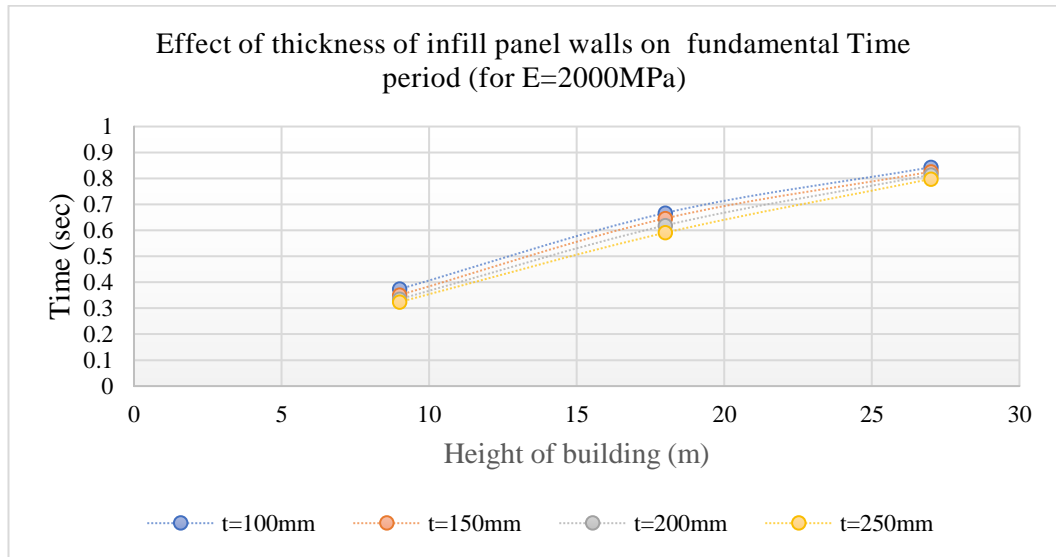


Figure A14 Effect of thickness of infill panel walls on fundamental time period (for E=2000MPa)

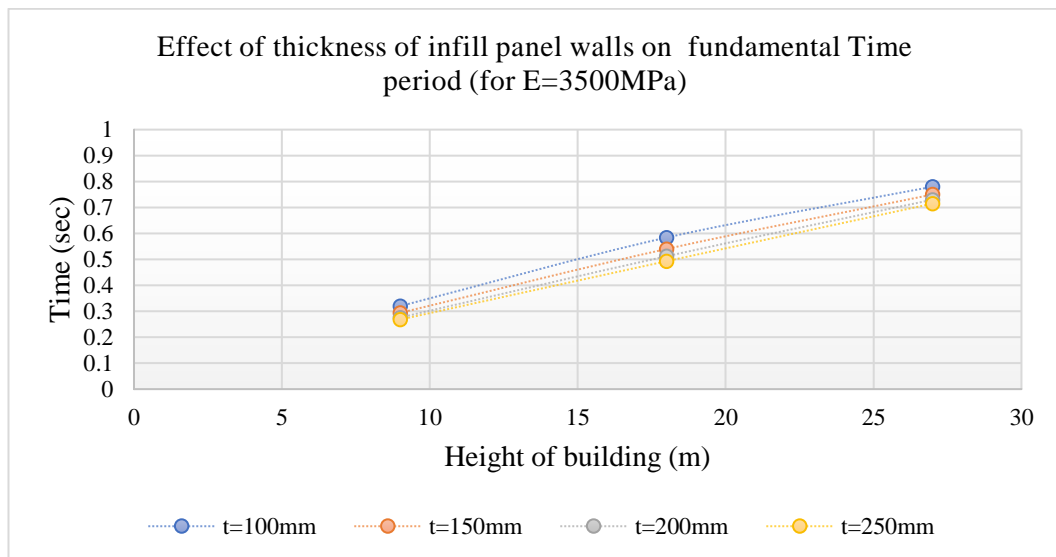


Figure A15 Effect of thickness of infill panel walls on fundamental time period (for E=3500MPa)

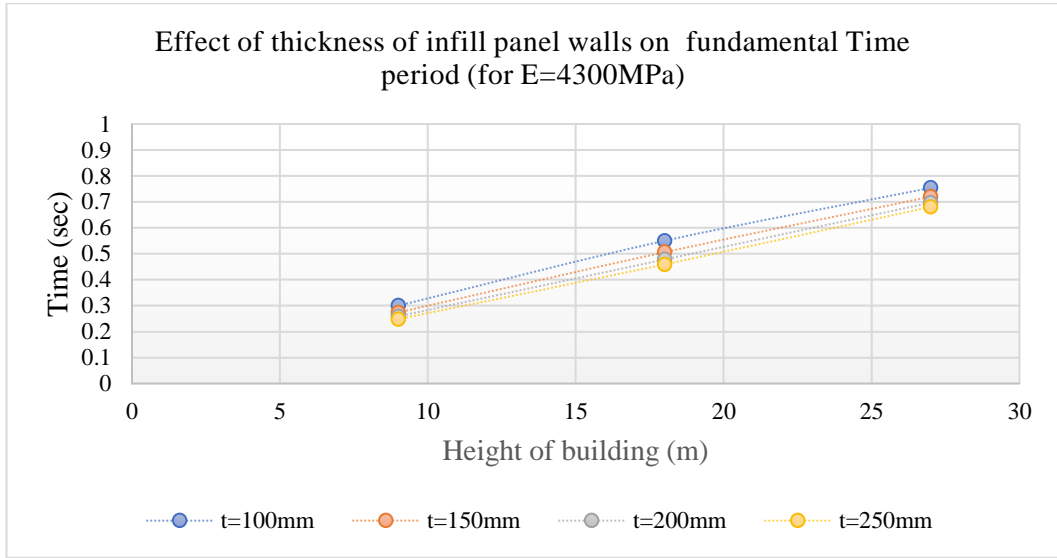


Figure A16 Effect of thickness of infill panel walls on fundamental time period (for E=4300MPa)

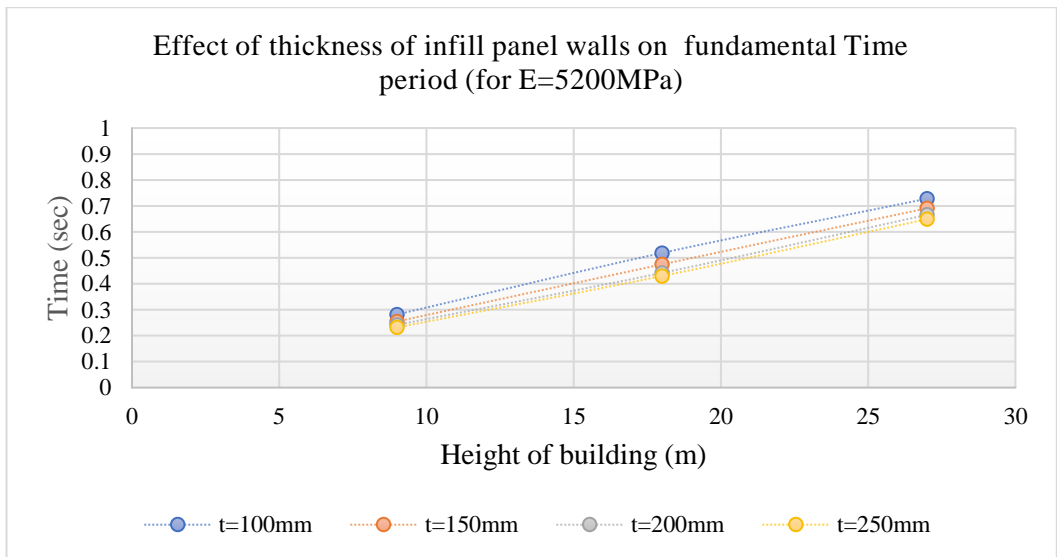


Figure A17 Effect of thickness of infill panel walls on fundamental time period (for E=5200MPa)

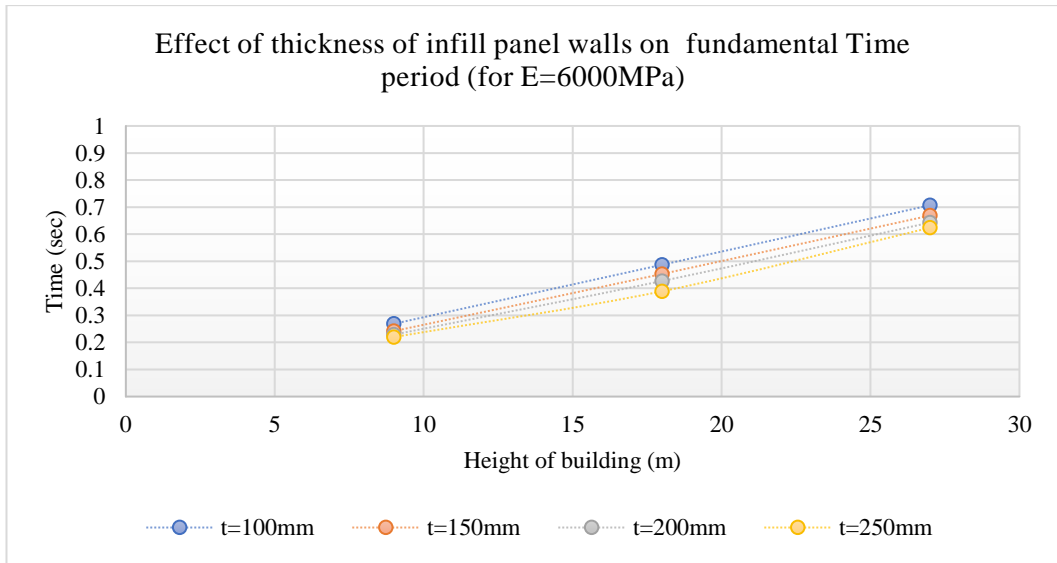


Figure A18 Effect of thickness of infill panel walls on fundamental time period (for E=6000MPa)

APPENDIX E:

Input data sets for regression analysis

Table A1 Input data sets for regression analysis

| <i>Note: Here, H: height of building (m), t: thickness of infill (mm), E: modulus of elasticity of infill (MPa), D: base dimension of building (m)</i> | | | | | | | | | | |
|--|------------|----|-----|------|----|---------|--------|--------|--------|--------|
| S.N. | Time (sec) | H | t | E | D | ln(T) | ln(H) | ln(t) | ln(E) | ln(D) |
| 1 | 0.919 | 27 | 100 | 2000 | 12 | -0.0845 | 3.2958 | 4.6052 | 7.6009 | 2.4849 |
| 2 | 0.834 | 27 | 100 | 3500 | 12 | -0.1815 | 3.2958 | 4.6052 | 8.1605 | 2.4849 |
| 3 | 0.802 | 27 | 100 | 4300 | 12 | -0.2206 | 3.2958 | 4.6052 | 8.3664 | 2.4849 |
| 4 | 0.771 | 27 | 100 | 5200 | 12 | -0.2601 | 3.2958 | 4.6052 | 8.5564 | 2.4849 |
| 5 | 0.746 | 27 | 100 | 6000 | 12 | -0.2930 | 3.2958 | 4.6052 | 8.6995 | 2.4849 |
| 6 | 0.884 | 27 | 150 | 2000 | 12 | -0.1233 | 3.2958 | 5.0106 | 7.6009 | 2.4849 |
| 7 | 0.794 | 27 | 150 | 3500 | 12 | -0.2307 | 3.2958 | 5.0106 | 8.1605 | 2.4849 |
| 8 | 0.758 | 27 | 150 | 4300 | 12 | -0.2771 | 3.2958 | 5.0106 | 8.3664 | 2.4849 |
| 9 | 0.724 | 27 | 150 | 5200 | 12 | -0.3230 | 3.2958 | 5.0106 | 8.5564 | 2.4849 |
| 10 | 0.698 | 27 | 150 | 6000 | 12 | -0.3595 | 3.2958 | 5.0106 | 8.6995 | 2.4849 |
| 11 | 0.864 | 27 | 200 | 2000 | 12 | -0.1462 | 3.2958 | 5.2983 | 7.6009 | 2.4849 |
| 12 | 0.765 | 27 | 200 | 3500 | 12 | -0.2679 | 3.2958 | 5.2983 | 8.1605 | 2.4849 |
| 13 | 0.727 | 27 | 200 | 4300 | 12 | -0.3188 | 3.2958 | 5.2983 | 8.3664 | 2.4849 |
| 14 | 0.692 | 27 | 200 | 5200 | 12 | -0.3682 | 3.2958 | 5.2983 | 8.5564 | 2.4849 |
| 15 | 0.665 | 27 | 200 | 6000 | 12 | -0.4080 | 3.2958 | 5.2983 | 8.6995 | 2.4849 |
| 16 | 0.851 | 27 | 250 | 2000 | 12 | -0.1613 | 3.2958 | 5.5215 | 7.6009 | 2.4849 |
| 17 | 0.746 | 27 | 250 | 3500 | 12 | -0.2930 | 3.2958 | 5.5215 | 8.1605 | 2.4849 |
| 18 | 0.707 | 27 | 250 | 4300 | 12 | -0.3467 | 3.2958 | 5.5215 | 8.3664 | 2.4849 |
| 19 | 0.671 | 27 | 250 | 5200 | 12 | -0.3990 | 3.2958 | 5.5215 | 8.5564 | 2.4849 |
| 20 | 0.645 | 27 | 250 | 6000 | 12 | -0.4385 | 3.2958 | 5.5215 | 8.6995 | 2.4849 |
| 21 | 0.722 | 18 | 100 | 2000 | 12 | -0.3257 | 2.8904 | 4.6052 | 7.6009 | 2.4849 |
| 22 | 0.617 | 18 | 100 | 3500 | 12 | -0.4829 | 2.8904 | 4.6052 | 8.1605 | 2.4849 |
| 23 | 0.579 | 18 | 100 | 4300 | 12 | -0.5465 | 2.8904 | 4.6052 | 8.3664 | 2.4849 |
| 24 | 0.545 | 18 | 100 | 5200 | 12 | -0.6070 | 2.8904 | 4.6052 | 8.5564 | 2.4849 |
| 25 | 0.517 | 18 | 100 | 6000 | 12 | -0.6597 | 2.8904 | 4.6052 | 8.6995 | 2.4849 |
| 26 | 0.681 | 18 | 150 | 2000 | 12 | -0.3842 | 2.8904 | 5.0106 | 7.6009 | 2.4849 |
| 27 | 0.565 | 18 | 150 | 3500 | 12 | -0.5709 | 2.8904 | 5.0106 | 8.1605 | 2.4849 |
| 28 | 0.528 | 18 | 150 | 4300 | 12 | -0.6387 | 2.8904 | 5.0106 | 8.3664 | 2.4849 |
| 29 | 0.495 | 18 | 150 | 5200 | 12 | -0.7032 | 2.8904 | 5.0106 | 8.5564 | 2.4849 |
| 30 | 0.471 | 18 | 150 | 6000 | 12 | -0.7529 | 2.8904 | 5.0106 | 8.6995 | 2.4849 |
| 31 | 0.649 | 18 | 200 | 2000 | 12 | -0.4323 | 2.8904 | 5.2983 | 7.6009 | 2.4849 |
| 32 | 0.533 | 18 | 200 | 3500 | 12 | -0.6292 | 2.8904 | 5.2983 | 8.1605 | 2.4849 |
| 33 | 0.497 | 18 | 200 | 4300 | 12 | -0.6992 | 2.8904 | 5.2983 | 8.3664 | 2.4849 |
| 34 | 0.464 | 18 | 200 | 5200 | 12 | -0.7679 | 2.8904 | 5.2983 | 8.5564 | 2.4849 |
| 35 | 0.441 | 18 | 200 | 6000 | 12 | -0.8187 | 2.8904 | 5.2983 | 8.6995 | 2.4849 |
| 36 | 0.617 | 18 | 250 | 2000 | 12 | -0.4829 | 2.8904 | 5.5215 | 7.6009 | 2.4849 |
| 37 | 0.511 | 18 | 250 | 3500 | 12 | -0.6714 | 2.8904 | 5.5215 | 8.1605 | 2.4849 |

| <i>Note: Here, H: height of building (m), t: thickness of infill (mm), E: modulus of elasticity of infill (MPa), D: base dimension of building (m)</i> | | | | | | | | | | |
|--|------------|----|-----|------|------|---------|--------|--------|--------|--------|
| S.N. | Time (sec) | H | t | E | D | ln(T) | ln(H) | ln(t) | ln(E) | ln(D) |
| 38 | 0.475 | 18 | 250 | 4300 | 12 | -0.7444 | 2.8904 | 5.5215 | 8.3664 | 2.4849 |
| 39 | 0.444 | 18 | 250 | 5200 | 12 | -0.8119 | 2.8904 | 5.5215 | 8.5564 | 2.4849 |
| 40 | 0.422 | 18 | 250 | 6000 | 12 | -0.8627 | 2.8904 | 5.5215 | 8.6995 | 2.4849 |
| 41 | 0.402 | 9 | 100 | 2000 | 12 | -0.9113 | 2.1972 | 4.6052 | 7.6009 | 2.4849 |
| 42 | 0.34 | 9 | 100 | 3500 | 12 | -1.0788 | 2.1972 | 4.6052 | 8.1605 | 2.4849 |
| 43 | 0.318 | 9 | 100 | 4300 | 12 | -1.1457 | 2.1972 | 4.6052 | 8.3664 | 2.4849 |
| 44 | 0.298 | 9 | 100 | 5200 | 12 | -1.2107 | 2.1972 | 4.6052 | 8.5564 | 2.4849 |
| 45 | 0.284 | 9 | 100 | 6000 | 12 | -1.2588 | 2.1972 | 4.6052 | 8.6995 | 2.4849 |
| 46 | 0.373 | 9 | 150 | 2000 | 12 | -0.9862 | 2.1972 | 5.0106 | 7.6009 | 2.4849 |
| 47 | 0.31 | 9 | 150 | 3500 | 12 | -1.1712 | 2.1972 | 5.0106 | 8.1605 | 2.4849 |
| 48 | 0.289 | 9 | 150 | 4300 | 12 | -1.2413 | 2.1972 | 5.0106 | 8.3664 | 2.4849 |
| 49 | 0.27 | 9 | 150 | 5200 | 12 | -1.3093 | 2.1972 | 5.0106 | 8.5564 | 2.4849 |
| 50 | 0.256 | 9 | 150 | 6000 | 12 | -1.3626 | 2.1972 | 5.0106 | 8.6995 | 2.4849 |
| 51 | 0.354 | 9 | 200 | 2000 | 12 | -1.0385 | 2.1972 | 5.2983 | 7.6009 | 2.4849 |
| 52 | 0.292 | 9 | 200 | 3500 | 12 | -1.2310 | 2.1972 | 5.2983 | 8.1605 | 2.4849 |
| 53 | 0.271 | 9 | 200 | 4300 | 12 | -1.3056 | 2.1972 | 5.2983 | 8.3664 | 2.4849 |
| 54 | 0.253 | 9 | 200 | 5200 | 12 | -1.3744 | 2.1972 | 5.2983 | 8.5564 | 2.4849 |
| 55 | 0.239 | 9 | 200 | 6000 | 12 | -1.4313 | 2.1972 | 5.2983 | 8.6995 | 2.4849 |
| 56 | 0.341 | 9 | 250 | 2000 | 12 | -1.0759 | 2.1972 | 5.5215 | 7.6009 | 2.4849 |
| 57 | 0.279 | 9 | 250 | 3500 | 12 | -1.2765 | 2.1972 | 5.5215 | 8.1605 | 2.4849 |
| 58 | 0.259 | 9 | 250 | 4300 | 12 | -1.3509 | 2.1972 | 5.5215 | 8.3664 | 2.4849 |
| 59 | 0.241 | 9 | 250 | 5200 | 12 | -1.4230 | 2.1972 | 5.5215 | 8.5564 | 2.4849 |
| 60 | 0.228 | 9 | 250 | 6000 | 12 | -1.4784 | 2.1972 | 5.5215 | 8.6995 | 2.4849 |
| 61 | 0.843 | 27 | 100 | 2000 | 10.5 | -0.1708 | 3.2958 | 4.6052 | 7.6009 | 2.3514 |
| 62 | 0.78 | 27 | 100 | 3500 | 10.5 | -0.2485 | 3.2958 | 4.6052 | 8.1605 | 2.3514 |
| 63 | 0.754 | 27 | 100 | 4300 | 10.5 | -0.2824 | 3.2958 | 4.6052 | 8.3664 | 2.3514 |
| 64 | 0.728 | 27 | 100 | 5200 | 10.5 | -0.3175 | 3.2958 | 4.6052 | 8.5564 | 2.3514 |
| 65 | 0.707 | 27 | 100 | 6000 | 10.5 | -0.3467 | 3.2958 | 4.6052 | 8.6995 | 2.3514 |
| 66 | 0.826 | 27 | 150 | 2000 | 10.5 | -0.1912 | 3.2958 | 5.0106 | 7.6009 | 2.3514 |
| 67 | 0.75 | 27 | 150 | 3500 | 10.5 | -0.2877 | 3.2958 | 5.0106 | 8.1605 | 2.3514 |
| 68 | 0.72 | 27 | 150 | 4300 | 10.5 | -0.3285 | 3.2958 | 5.0106 | 8.3664 | 2.3514 |
| 69 | 0.691 | 27 | 150 | 5200 | 10.5 | -0.3696 | 3.2958 | 5.0106 | 8.5564 | 2.3514 |
| 70 | 0.669 | 27 | 150 | 6000 | 10.5 | -0.4020 | 3.2958 | 5.0106 | 8.6995 | 2.3514 |
| 71 | 0.814 | 27 | 200 | 2000 | 10.5 | -0.2058 | 3.2958 | 5.2983 | 7.6009 | 2.3514 |
| 72 | 0.73 | 27 | 200 | 3500 | 10.5 | -0.3147 | 3.2958 | 5.2983 | 8.1605 | 2.3514 |
| 73 | 0.697 | 27 | 200 | 4300 | 10.5 | -0.3610 | 3.2958 | 5.2983 | 8.3664 | 2.3514 |
| 74 | 0.666 | 27 | 200 | 5200 | 10.5 | -0.4065 | 3.2958 | 5.2983 | 8.5564 | 2.3514 |
| 75 | 0.643 | 27 | 200 | 6000 | 10.5 | -0.4416 | 3.2958 | 5.2983 | 8.6995 | 2.3514 |
| 76 | 0.798 | 27 | 250 | 2000 | 10.5 | -0.2256 | 3.2958 | 5.5215 | 7.6009 | 2.3514 |
| 77 | 0.715 | 27 | 250 | 3500 | 10.5 | -0.3355 | 3.2958 | 5.5215 | 8.1605 | 2.3514 |
| 78 | 0.681 | 27 | 250 | 4300 | 10.5 | -0.3842 | 3.2958 | 5.5215 | 8.3664 | 2.3514 |
| 79 | 0.649 | 27 | 250 | 5200 | 10.5 | -0.4323 | 3.2958 | 5.5215 | 8.5564 | 2.3514 |
| 80 | 0.624 | 27 | 250 | 6000 | 10.5 | -0.4716 | 3.2958 | 5.5215 | 8.6995 | 2.3514 |

| <i>Note: Here, H: height of building (m), t: thickness of infill (mm), E: modulus of elasticity of infill (MPa), D: base dimension of building (m)</i> | | | | | | | | | | |
|--|------------|----|-----|------|------|---------|--------|--------|--------|--------|
| S.N. | Time (sec) | H | t | E | D | ln(T) | ln(H) | ln(t) | ln(E) | ln(D) |
| 81 | 0.667 | 18 | 100 | 2000 | 10.5 | -0.4050 | 2.8904 | 4.6052 | 7.6009 | 2.3514 |
| 82 | 0.584 | 18 | 100 | 3500 | 10.5 | -0.5379 | 2.8904 | 4.6052 | 8.1605 | 2.3514 |
| 83 | 0.55 | 18 | 100 | 4300 | 10.5 | -0.5978 | 2.8904 | 4.6052 | 8.3664 | 2.3514 |
| 84 | 0.519 | 18 | 100 | 5200 | 10.5 | -0.6559 | 2.8904 | 4.6052 | 8.5564 | 2.3514 |
| 85 | 0.487 | 18 | 100 | 6000 | 10.5 | -0.7195 | 2.8904 | 4.6052 | 8.6995 | 2.3514 |
| 86 | 0.646 | 18 | 150 | 2000 | 10.5 | -0.4370 | 2.8904 | 5.0106 | 7.6009 | 2.3514 |
| 87 | 0.54 | 18 | 150 | 3500 | 10.5 | -0.6162 | 2.8904 | 5.0106 | 8.1605 | 2.3514 |
| 88 | 0.506 | 18 | 150 | 4300 | 10.5 | -0.6812 | 2.8904 | 5.0106 | 8.3664 | 2.3514 |
| 89 | 0.475 | 18 | 150 | 5200 | 10.5 | -0.7444 | 2.8904 | 5.0106 | 8.5564 | 2.3514 |
| 90 | 0.453 | 18 | 150 | 6000 | 10.5 | -0.7919 | 2.8904 | 5.0106 | 8.6995 | 2.3514 |
| 91 | 0.619 | 18 | 200 | 2000 | 10.5 | -0.4797 | 2.8904 | 5.2983 | 7.6009 | 2.3514 |
| 92 | 0.512 | 18 | 200 | 3500 | 10.5 | -0.6694 | 2.8904 | 5.2983 | 8.1605 | 2.3514 |
| 93 | 0.478 | 18 | 200 | 4300 | 10.5 | -0.7381 | 2.8904 | 5.2983 | 8.3664 | 2.3514 |
| 94 | 0.442 | 18 | 200 | 5200 | 10.5 | -0.8164 | 2.8904 | 5.2983 | 8.5564 | 2.3514 |
| 95 | 0.427 | 18 | 200 | 6000 | 10.5 | -0.8510 | 2.8904 | 5.2983 | 8.6995 | 2.3514 |
| 96 | 0.591 | 18 | 250 | 2000 | 10.5 | -0.5259 | 2.8904 | 5.5215 | 7.6009 | 2.3514 |
| 97 | 0.493 | 18 | 250 | 3500 | 10.5 | -0.7072 | 2.8904 | 5.5215 | 8.1605 | 2.3514 |
| 98 | 0.459 | 18 | 250 | 4300 | 10.5 | -0.7787 | 2.8904 | 5.5215 | 8.3664 | 2.3514 |
| 99 | 0.43 | 18 | 250 | 5200 | 10.5 | -0.8440 | 2.8904 | 5.5215 | 8.5564 | 2.3514 |
| 100 | 0.389 | 18 | 250 | 6000 | 10.5 | -0.9442 | 2.8904 | 5.5215 | 8.6995 | 2.3514 |
| 101 | 0.374 | 9 | 100 | 2000 | 10.5 | -0.9835 | 2.1972 | 4.6052 | 7.6009 | 2.3514 |
| 102 | 0.32 | 9 | 100 | 3500 | 10.5 | -1.1394 | 2.1972 | 4.6052 | 8.1605 | 2.3514 |
| 103 | 0.3 | 9 | 100 | 4300 | 10.5 | -1.2040 | 2.1972 | 4.6052 | 8.3664 | 2.3514 |
| 104 | 0.282 | 9 | 100 | 5200 | 10.5 | -1.2658 | 2.1972 | 4.6052 | 8.5564 | 2.3514 |
| 105 | 0.269 | 9 | 100 | 6000 | 10.5 | -1.3130 | 2.1972 | 4.6052 | 8.6995 | 2.3514 |
| 106 | 0.351 | 9 | 150 | 2000 | 10.5 | -1.0470 | 2.1972 | 5.0106 | 7.6009 | 2.3514 |
| 107 | 0.294 | 9 | 150 | 3500 | 10.5 | -1.2242 | 2.1972 | 5.0106 | 8.1605 | 2.3514 |
| 108 | 0.274 | 9 | 150 | 4300 | 10.5 | -1.2946 | 2.1972 | 5.0106 | 8.3664 | 2.3514 |
| 109 | 0.255 | 9 | 150 | 5200 | 10.5 | -1.3665 | 2.1972 | 5.0106 | 8.5564 | 2.3514 |
| 110 | 0.242 | 9 | 150 | 6000 | 10.5 | -1.4188 | 2.1972 | 5.0106 | 8.6995 | 2.3514 |
| 111 | 0.335 | 9 | 200 | 2000 | 10.5 | -1.0936 | 2.1972 | 5.2983 | 7.6009 | 2.3514 |
| 112 | 0.276 | 9 | 200 | 3500 | 10.5 | -1.2874 | 2.1972 | 5.2983 | 8.1605 | 2.3514 |
| 113 | 0.259 | 9 | 200 | 4300 | 10.5 | -1.3509 | 2.1972 | 5.2983 | 8.3664 | 2.3514 |
| 114 | 0.242 | 9 | 200 | 5200 | 10.5 | -1.4188 | 2.1972 | 5.2983 | 8.5564 | 2.3514 |
| 115 | 0.229 | 9 | 200 | 6000 | 10.5 | -1.4740 | 2.1972 | 5.2983 | 8.6995 | 2.3514 |
| 116 | 0.324 | 9 | 250 | 2000 | 10.5 | -1.1270 | 2.1972 | 5.5215 | 7.6009 | 2.3514 |
| 117 | 0.268 | 9 | 250 | 3500 | 10.5 | -1.3168 | 2.1972 | 5.5215 | 8.1605 | 2.3514 |
| 118 | 0.248 | 9 | 250 | 4300 | 10.5 | -1.3943 | 2.1972 | 5.5215 | 8.3664 | 2.3514 |
| 119 | 0.232 | 9 | 250 | 5200 | 10.5 | -1.4610 | 2.1972 | 5.5215 | 8.5564 | 2.3514 |
| 120 | 0.22 | 9 | 250 | 6000 | 10.5 | -1.5141 | 2.1972 | 5.5215 | 8.6995 | 2.3514 |
| 121 | 0.776 | 27 | 100 | 2000 | 9 | -0.2536 | 3.2958 | 4.6052 | 7.6009 | 2.1972 |
| 122 | 0.728 | 27 | 100 | 3500 | 9 | -0.3175 | 3.2958 | 4.6052 | 8.1605 | 2.1972 |
| 123 | 0.707 | 27 | 100 | 4300 | 9 | -0.3467 | 3.2958 | 4.6052 | 8.3664 | 2.1972 |

| <i>Note: Here, H: height of building (m), t: thickness of infill (mm), E: modulus of elasticity of infill (MPa), D: base dimension of building (m)</i> | | | | | | | | | | |
|--|------------|----|-----|------|---|---------|--------|--------|--------|--------|
| S.N. | Time (sec) | H | t | E | D | ln(T) | ln(H) | ln(t) | ln(E) | ln(D) |
| 124 | 0.686 | 27 | 100 | 5200 | 9 | -0.3769 | 3.2958 | 4.6052 | 8.5564 | 2.1972 |
| 125 | 0.67 | 27 | 100 | 6000 | 9 | -0.4005 | 3.2958 | 4.6052 | 8.6995 | 2.1972 |
| 126 | 0.768 | 27 | 150 | 2000 | 9 | -0.2640 | 3.2958 | 5.0106 | 7.6009 | 2.1972 |
| 127 | 0.708 | 27 | 150 | 3500 | 9 | -0.3453 | 3.2958 | 5.0106 | 8.1605 | 2.1972 |
| 128 | 0.684 | 27 | 150 | 4300 | 9 | -0.3798 | 3.2958 | 5.0106 | 8.3664 | 2.1972 |
| 129 | 0.66 | 27 | 150 | 5200 | 9 | -0.4155 | 3.2958 | 5.0106 | 8.5564 | 2.1972 |
| 130 | 0.641 | 27 | 150 | 6000 | 9 | -0.4447 | 3.2958 | 5.0106 | 8.6995 | 2.1972 |
| 131 | 0.763 | 27 | 200 | 2000 | 9 | -0.2705 | 3.2958 | 5.2983 | 7.6009 | 2.1972 |
| 132 | 0.695 | 27 | 200 | 3500 | 9 | -0.3638 | 3.2958 | 5.2983 | 8.1605 | 2.1972 |
| 133 | 0.668 | 27 | 200 | 4300 | 9 | -0.4035 | 3.2958 | 5.2983 | 8.3664 | 2.1972 |
| 134 | 0.642 | 27 | 200 | 5200 | 9 | -0.4432 | 3.2958 | 5.2983 | 8.5564 | 2.1972 |
| 135 | 0.624 | 27 | 200 | 6000 | 9 | -0.4716 | 3.2958 | 5.2983 | 8.6995 | 2.1972 |
| 136 | 0.76 | 27 | 250 | 2000 | 9 | -0.2744 | 3.2958 | 5.5215 | 7.6009 | 2.1972 |
| 137 | 0.686 | 27 | 250 | 3500 | 9 | -0.3769 | 3.2958 | 5.5215 | 8.1605 | 2.1972 |
| 138 | 0.657 | 27 | 250 | 4300 | 9 | -0.4201 | 3.2958 | 5.5215 | 8.3664 | 2.1972 |
| 139 | 0.63 | 27 | 250 | 5200 | 9 | -0.4620 | 3.2958 | 5.5215 | 8.5564 | 2.1972 |
| 140 | 0.609 | 27 | 250 | 6000 | 9 | -0.4959 | 3.2958 | 5.5215 | 8.6995 | 2.1972 |
| 141 | 0.633 | 18 | 100 | 2000 | 9 | -0.4573 | 2.8904 | 4.6052 | 7.6009 | 2.1972 |
| 142 | 0.554 | 18 | 100 | 3500 | 9 | -0.5906 | 2.8904 | 4.6052 | 8.1605 | 2.1972 |
| 143 | 0.524 | 18 | 100 | 4300 | 9 | -0.6463 | 2.8904 | 4.6052 | 8.3664 | 2.1972 |
| 144 | 0.496 | 18 | 100 | 5200 | 9 | -0.7012 | 2.8904 | 4.6052 | 8.5564 | 2.1972 |
| 145 | 0.473 | 18 | 100 | 6000 | 9 | -0.7487 | 2.8904 | 4.6052 | 8.6995 | 2.1972 |
| 146 | 0.612 | 18 | 150 | 2000 | 9 | -0.4910 | 2.8904 | 5.0106 | 7.6009 | 2.1972 |
| 147 | 0.517 | 18 | 150 | 3500 | 9 | -0.6597 | 2.8904 | 5.0106 | 8.1605 | 2.1972 |
| 148 | 0.486 | 18 | 150 | 4300 | 9 | -0.7215 | 2.8904 | 5.0106 | 8.3664 | 2.1972 |
| 149 | 0.458 | 18 | 150 | 5200 | 9 | -0.7809 | 2.8904 | 5.0106 | 8.5564 | 2.1972 |
| 150 | 0.438 | 18 | 150 | 6000 | 9 | -0.8255 | 2.8904 | 5.0106 | 8.6995 | 2.1972 |
| 151 | 0.592 | 18 | 200 | 2000 | 9 | -0.5242 | 2.8904 | 5.2983 | 7.6009 | 2.1972 |
| 152 | 0.493 | 18 | 200 | 3500 | 9 | -0.7072 | 2.8904 | 5.2983 | 8.1605 | 2.1972 |
| 153 | 0.463 | 18 | 200 | 4300 | 9 | -0.7700 | 2.8904 | 5.2983 | 8.3664 | 2.1972 |
| 154 | 0.424 | 18 | 200 | 5200 | 9 | -0.8580 | 2.8904 | 5.2983 | 8.5564 | 2.1972 |
| 155 | 0.415 | 18 | 200 | 6000 | 9 | -0.8795 | 2.8904 | 5.2983 | 8.6995 | 2.1972 |
| 156 | 0.566 | 18 | 250 | 2000 | 9 | -0.5692 | 2.8904 | 5.5215 | 7.6009 | 2.1972 |
| 157 | 0.477 | 18 | 250 | 3500 | 9 | -0.7402 | 2.8904 | 5.5215 | 8.1605 | 2.1972 |
| 158 | 0.447 | 18 | 250 | 4300 | 9 | -0.8052 | 2.8904 | 5.5215 | 8.3664 | 2.1972 |
| 159 | 0.42 | 18 | 250 | 5200 | 9 | -0.8675 | 2.8904 | 5.5215 | 8.5564 | 2.1972 |
| 160 | 0.4 | 18 | 250 | 6000 | 9 | -0.9163 | 2.8904 | 5.5215 | 8.6995 | 2.1972 |
| 161 | 0.347 | 9 | 100 | 2000 | 9 | -1.0584 | 2.1972 | 4.6052 | 7.6009 | 2.1972 |
| 162 | 0.3 | 9 | 100 | 3500 | 9 | -1.2040 | 2.1972 | 4.6052 | 8.1605 | 2.1972 |
| 163 | 0.282 | 9 | 100 | 4300 | 9 | -1.2658 | 2.1972 | 4.6052 | 8.3664 | 2.1972 |
| 164 | 0.266 | 9 | 100 | 5200 | 9 | -1.3243 | 2.1972 | 4.6052 | 8.5564 | 2.1972 |
| 165 | 0.255 | 9 | 100 | 6000 | 9 | -1.3665 | 2.1972 | 4.6052 | 8.6995 | 2.1972 |
| 166 | 0.329 | 9 | 150 | 2000 | 9 | -1.1117 | 2.1972 | 5.0106 | 7.6009 | 2.1972 |

| <i>Note: Here, H: height of building (m), t: thickness of infill (mm), E: modulus of elasticity of infill (MPa), D: base dimension of building (m)</i> | | | | | | | | | | |
|--|------------|---|-----|------|---|---------|--------|--------|--------|--------|
| S.N. | Time (sec) | H | t | E | D | ln(T) | ln(H) | ln(t) | ln(E) | ln(D) |
| 167 | 0.279 | 9 | 150 | 3500 | 9 | -1.2765 | 2.1972 | 5.0106 | 8.1605 | 2.1972 |
| 168 | 0.261 | 9 | 150 | 4300 | 9 | -1.3432 | 2.1972 | 5.0106 | 8.3664 | 2.1972 |
| 169 | 0.245 | 9 | 150 | 5200 | 9 | -1.4065 | 2.1972 | 5.0106 | 8.5564 | 2.1972 |
| 170 | 0.234 | 9 | 150 | 6000 | 9 | -1.4524 | 2.1972 | 5.0106 | 8.6995 | 2.1972 |
| 171 | 0.317 | 9 | 200 | 2000 | 9 | -1.1489 | 2.1972 | 5.2983 | 7.6009 | 2.1972 |
| 172 | 0.266 | 9 | 200 | 3500 | 9 | -1.3243 | 2.1972 | 5.2983 | 8.1605 | 2.1972 |
| 173 | 0.248 | 9 | 200 | 4300 | 9 | -1.3943 | 2.1972 | 5.2983 | 8.3664 | 2.1972 |
| 174 | 0.232 | 9 | 200 | 5200 | 9 | -1.4610 | 2.1972 | 5.2983 | 8.5564 | 2.1972 |
| 175 | 0.221 | 9 | 200 | 6000 | 9 | -1.5096 | 2.1972 | 5.2983 | 8.6995 | 2.1972 |
| 176 | 0.309 | 9 | 250 | 2000 | 9 | -1.1744 | 2.1972 | 5.5215 | 7.6009 | 2.1972 |
| 177 | 0.257 | 9 | 250 | 3500 | 9 | -1.3587 | 2.1972 | 5.5215 | 8.1605 | 2.1972 |
| 178 | 0.239 | 9 | 250 | 4300 | 9 | -1.4313 | 2.1972 | 5.5215 | 8.3664 | 2.1972 |
| 179 | 0.224 | 9 | 250 | 5200 | 9 | -1.4961 | 2.1972 | 5.5215 | 8.5564 | 2.1972 |
| 180 | 0.197 | 9 | 250 | 6000 | 9 | -1.6246 | 2.1972 | 5.5215 | 8.6995 | 2.1972 |

APPENDIX F:

Typical plan of real buildings

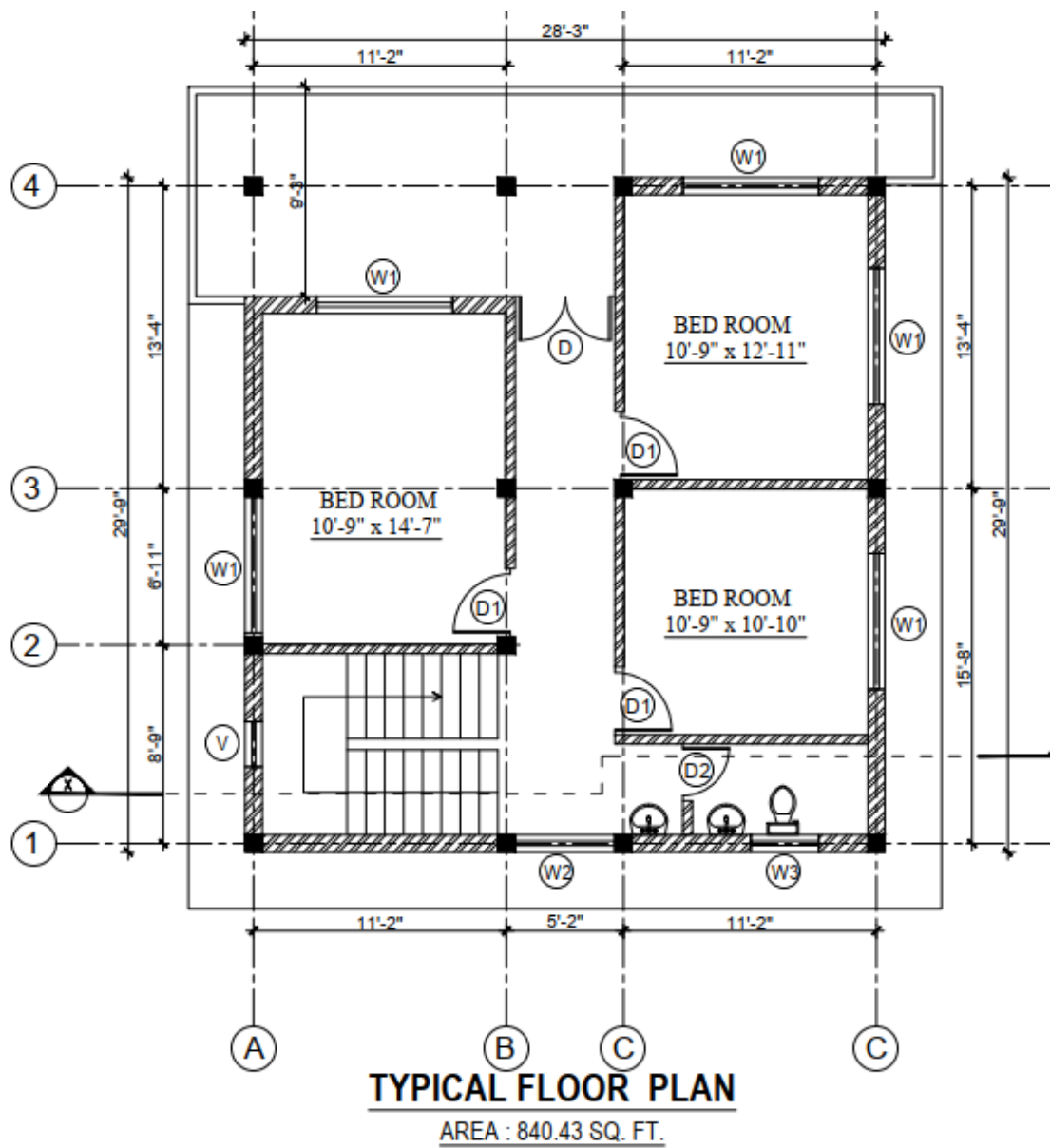
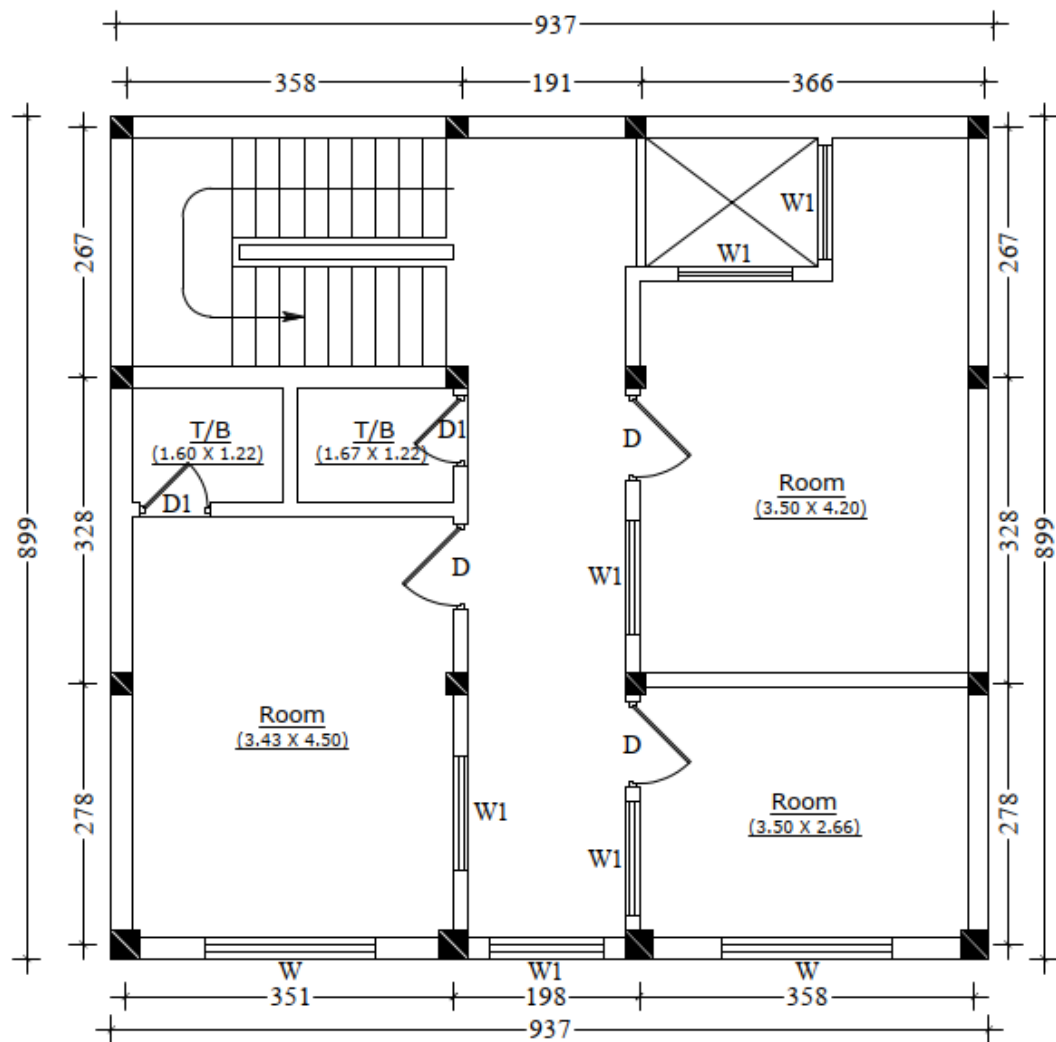


Figure A19 Plan of real building 1

Table A2 Building parameters of real building 1

| Parameters Data | Value |
|-------------------|-------------|
| Number of storey | 3 |
| Grade of concrete | M20 |
| Column size | 350mm*350mm |
| Beam size | 300mm*230mm |
| Slab thickness | 127mm |



Typical Floor Plan

Area = 84.23 sq.m.

Figure A20 Plan of real building 2

Table A3 Building parameters of real building 2

| Parameters Data | Value |
|-------------------|-------------|
| Number of storey | 5 |
| Grade of concrete | M20 |
| Column size | 350mm*350mm |
| Beam size | 300mm*250mm |
| Slab thickness | 127mm |

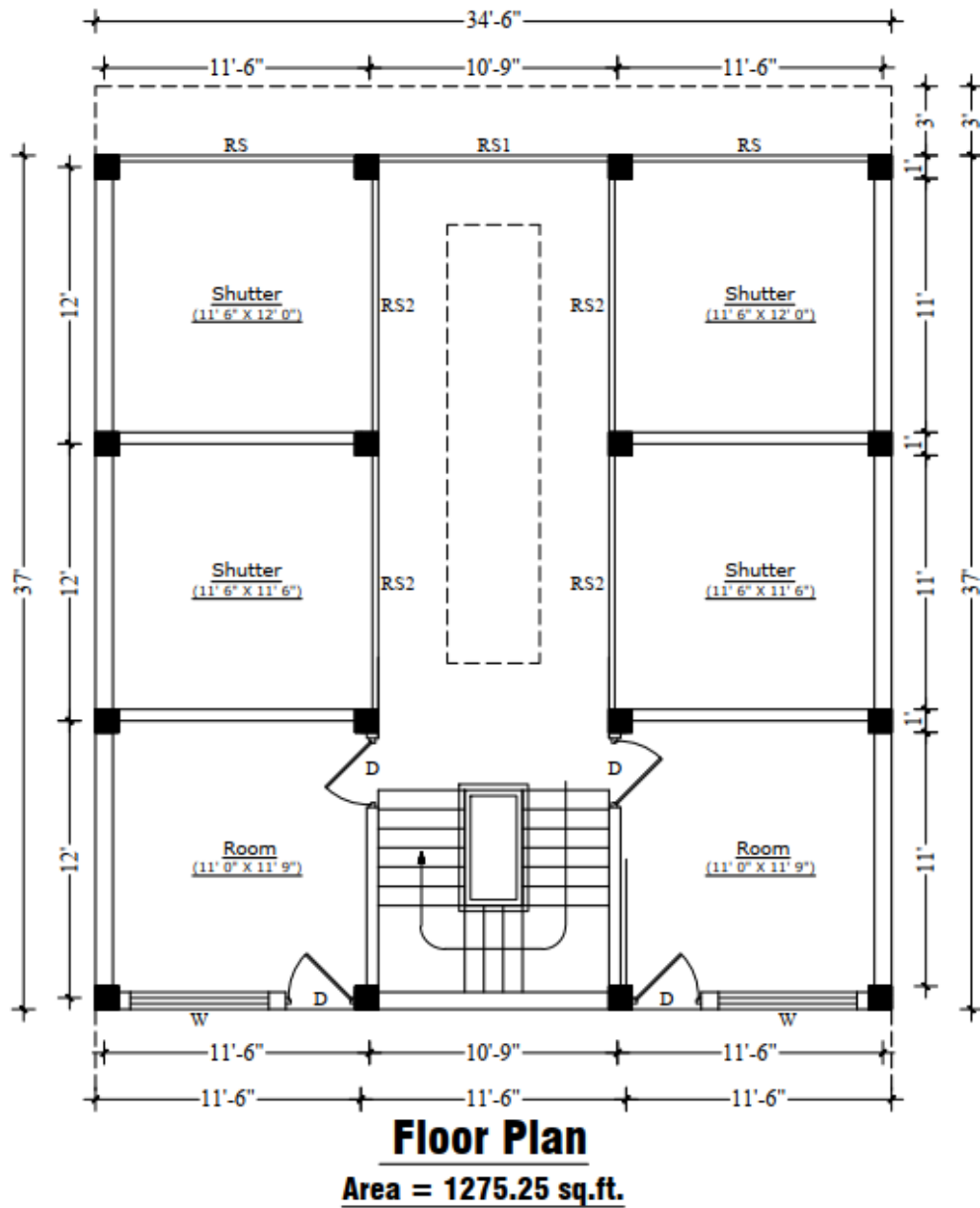
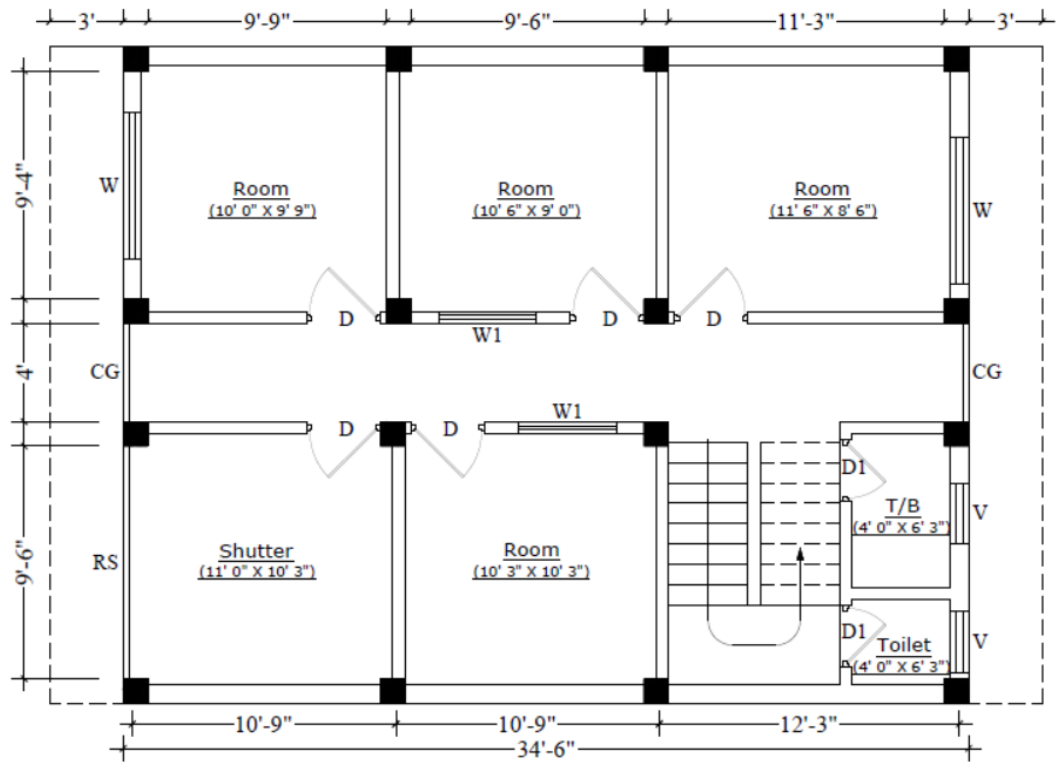


Figure A21 Plan of real building 3

Table A4 Building parameters of real building 3

| Parameters Data | Value |
|-------------------|-------------|
| Number of storey | 2 |
| Grade of concrete | M20 |
| Column size | 300mm*300mm |
| Beam size | 300mm*200mm |
| Slab thickness | 127mm |



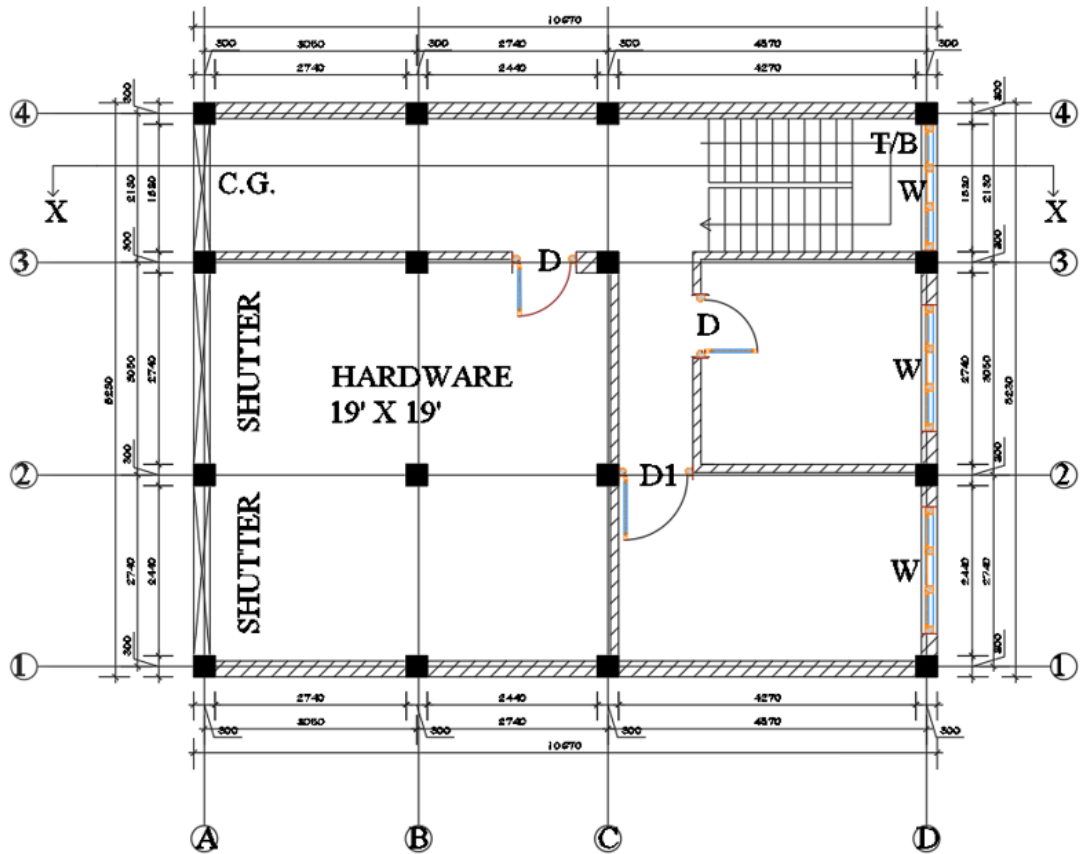
Typical Floor Plan

Area = 888.37 sq.ft.

Figure A22 Plan of real building 4

Table A5 Building parameters of real building 4

| Parameters Data | Value |
|-------------------|-------------|
| Number of storey | 4 |
| Grade of concrete | M20 |
| Column size | 350mm*350mm |
| Beam size | 300mm*230mm |
| Slab thickness | 127mm |



Typical Floor Plan
Plinth Area:- 87.79 sq.m.

Figure A23 Plan of real building 5

Table A6 Building parameters of real building 5

| Parameters Data | Value |
|-------------------|-------------|
| Number of storey | 2 |
| Grade of concrete | M20 |
| Column size | 300mm*300mm |
| Beam size | 300mm*230mm |
| Slab thickness | 127mm |

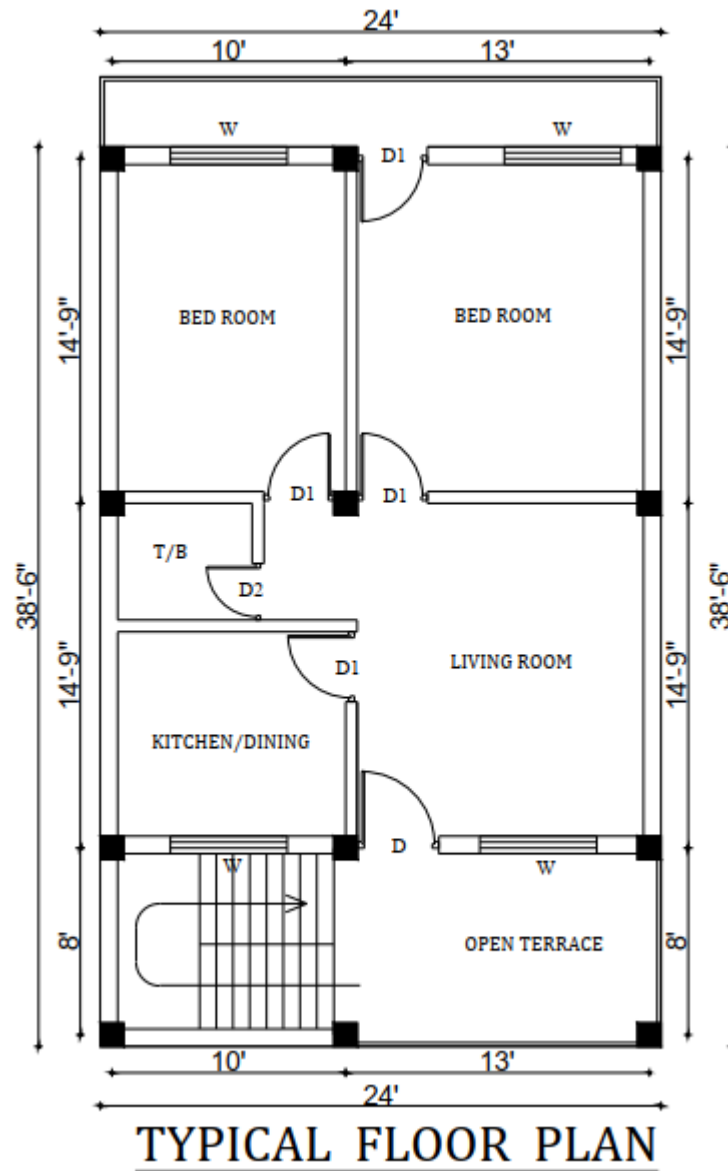


Figure A24 Plan of real building 6

Table A7 Building parameters of real building 6

| Parameters Data | Value |
|-------------------|-------------|
| Number of storey | 3 |
| Grade of concrete | M20 |
| Column size | 350mm*350mm |
| Beam size | 300mm*230mm |
| Slab thickness | 127mm |

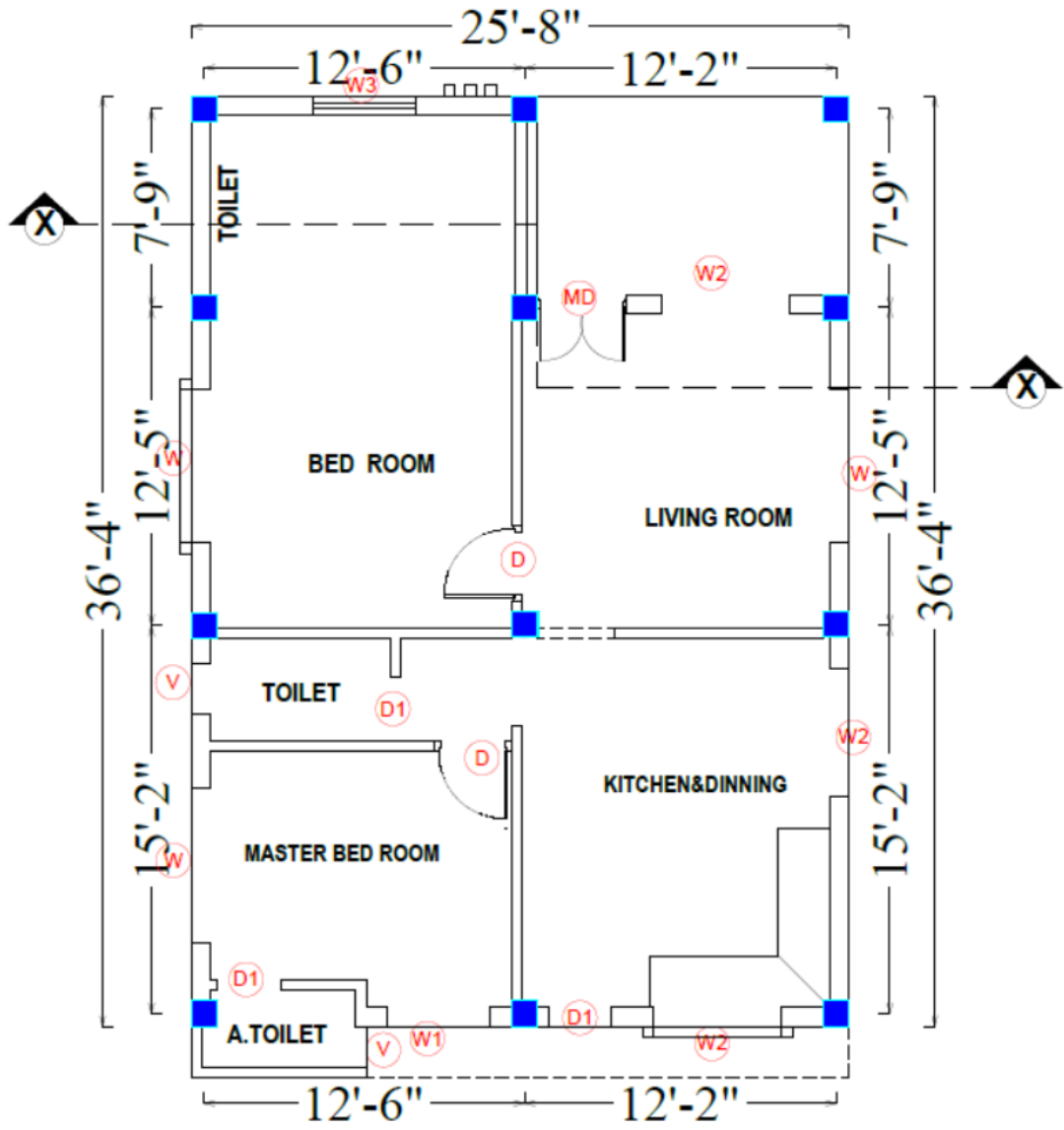
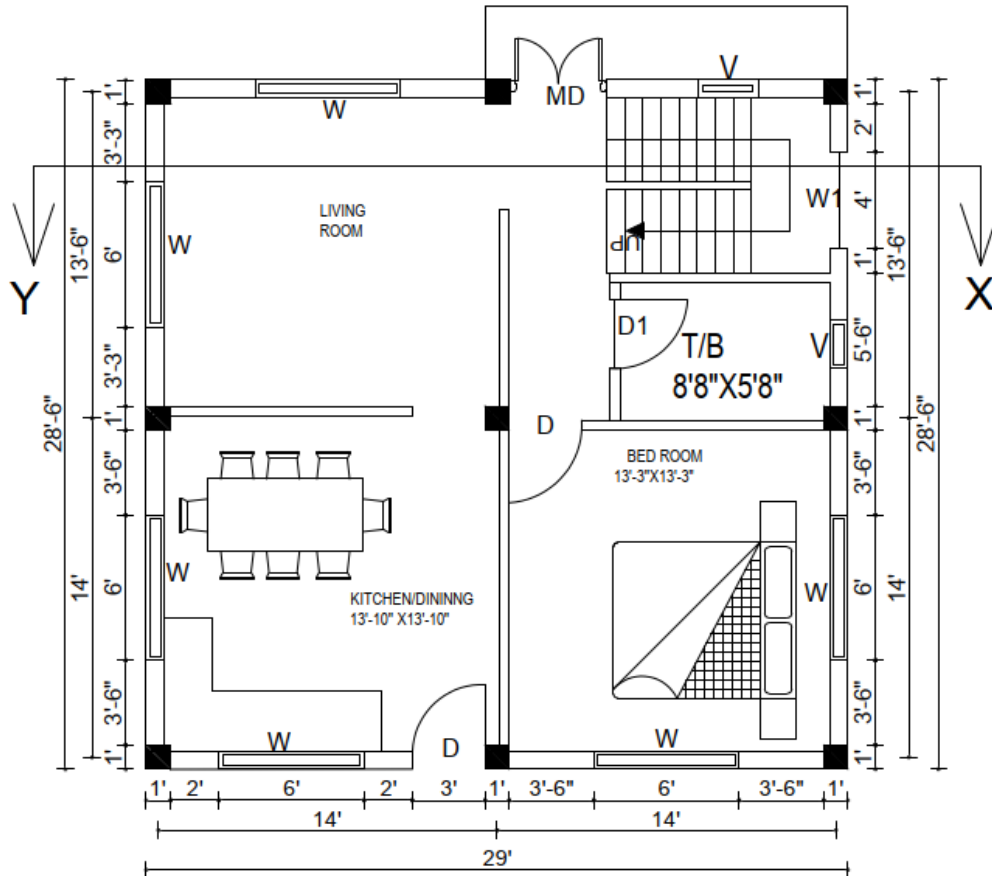


Figure A25 Plan of real building 7

Table A8: Building parameters of real building 7

| Parameters Data | Value |
|-------------------|-------------|
| Number of storey | 2 |
| Grade of concrete | M20 |
| Column size | 300mm*300mm |
| Beam size | 300mm*230mm |
| Slab thickness | 127mm |



TYPICAL FLOOR PLAN
PLINTH AREA= (922.38 SQ.Ft.)

Figure A26 Plan of real building 8

Table A9: Building parameters of real building 8

| Parameters Data | Value |
|-------------------|-------------|
| Number of storey | 3 |
| Grade of concrete | M20 |
| Column size | 300mm*300mm |
| Beam size | 300mm*230mm |
| Slab thickness | 127mm |