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# Influence of Geometrical Parameters on the Fundamental Time Period of Masonry Structure

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**Abstract**

The fundamental time period of vibration is one of the foremost important parameters for the seismic design of structures. The fundamental time period is reliant on the mass, strength, and stiffness of the structure but their actual dependency on the geometric parameter is still a matter of study. The influence of the geometric parameter for masonry building is studied. Finite Modelling Element procedure is used to model several masonry buildings and to find their corresponding fundamental time period based on Rayleigh Method and code-based equations. Finally, the influence of selected geometric parameter is expressed in terms of an equation that is formulated based on the regression analysis of output data.

**Keywords**

Fundamental Time Period, Masonry, Rayleigh's Method, Code-Based Emperical Equations

## 1. Introduction

Fundamental Time Period or Natural Period 'T' is an inherent property of a structure. It is the time period of the structure when it is subjected to un-damped free vibration. The determination of the natural period of vibration of a structure is a foremost important procedure in earthquake resistant design and assessment. This property is dependent on the mass, strength, and stiffness of the structure and is affected by many factors such as structural regularity, base dimension, sectional dimensions, etc. For the seismic design of the structure, the period of vibration will not be known a priori and thus seismic design codes employ simplified equations to relate the fundamental period to the height of the building considered. These equations have usually been obtained by regression analysis on the periods of vibration measured during earthquakes. In this context, the present study focuses on the actual influence of geometrical parameters namely; base dimension and height on the fundamental time period of regular masonry buildings, to propose empirical equations to relate the fundamental time period as the function of these selected parameters.

## 2. Existing Code Based Provision for Time Period

Building codes generally consider the natural period as a necessary parameter to estimate the structure response coefficient. Therefore, the empirical formula should be based on the general properties of the buildings, which could be known before a preliminary analysis, such as building height H or dimensions D. A general form of an empirical formula introduced for the fundamental time period is as follow:

$$T(H,D) = aH^bD^c \tag{1}$$

Meanwhile, most of the codes mention the following expression for calculation of fundamental time period of structures:

$$T = C_t h_n^m \tag{2}$$

where, $h_n$ is the height of the building, and $C_t$ is a numerical coefficient.

According to Bangladesh National Building Code (BNBC):2015 [1] Building Code of Pakistan, Seismic Provisions:2007 [2] The value of $C_t$ as 0.048 and m as 0.75 for other systems including masonry structures taking the total height of building in meters. National Structural Code of the Philippines:2010[3] .The value of $C_t$ as 0.0488 and m as 0.75 for other systems including masonry structures taking the height of building in meters According to Euro code 8:2004. [4] Ontario Building Act, Canada:2014[5] Dubai Municipality Building Act:2013.[6] The fundamental lateral period for shear wall and other structures including masonry structures Ta, in the direction under consideration shall be determined as above equation taking, $C_t$ as 0.05 and m as 0.75 . Building Standard Law in Japan (BSLJ) 1981 [7] the fundamental natural period of the building, T, is determined using the relation

$$T = H(0.02 + 0.01\alpha) \quad (3)$$

where H is the height of the building in m and $\alpha$ is the ratio of the total height of steel construction to the height of the building ($\alpha$ = 0 for concrete and structures other than steel) IS1893 (Part 1):2002 [8] and Nepal National Building Code NBC 105:1994 [9] provide a different equation for determination of the fundamental natural period for all other structures including masonry structures,

$$T = \frac{0.09H}{\sqrt{d}} \quad (4)$$

where, H is the total height of the main structure in meters and d is the maximum base dimension of the building in meters in a direction parallel to the applied seismic force. Spain; Norma de Construcción Sismorresistente: Parte general y edificación (NCSE 02-2009) (Eng. transl.-Construction Standard: Earthquake resistant: General part and building (NCSE 02) [10] recommend unique equation than other codes for determination of Fundamental Time Period $T_F$ for Buildings with brick or brick factory walls

$$T_F = 0.006H/\sqrt{H}(2L + H)/\sqrt{L} \quad (5)$$

Being: H Building height, above ground, in meters,L Dimension in the building plan, in the direction of the oscillation, in meters.

## 3. Description and Methodology

For this study, the modelling of 25 selected building models is set up on finite element software to find the quantitative effect of Base Dimension and total height of building on the fundamental time period of building. The fundamental periods for all the selected buildings calculated using Rayleigh method as well as code-based empirical equations. Then after, the qualitative and quantitative influence of selected geometric parameters on the fundamental time period is analyzed. Finally, the approximate formulation of the fundamental time period based on the selected geometric parameters is proposed.

### 3.1 Building Parameters and Material Properties

The building used in the study are of various base dimension and storied unreinforced brick masonry. Brick in cement sand mortar (1:4) is considered as the major load-bearing wall. The thickness of the wall is 350 mm and the reinforced concrete slab is of thickness 125mm. D represents the Base Dimension; H represents the height of the building. Base Dimension ;4,6,8,10,12 in base specify that Base Dimension is 4,6,8,10,12 meters (m) respectively. Height of Building ;1,2,3,4,5 in height specify that height is 2.438,4.877,7.315,9.754,12.192 meters (m) respectively. Window and Doors are arranged to maintain 15 percentage opening. Modeling of 25 selected building models setup on Finite element software D: Base Dimension, H: Height of building is considered as a parameter to study of the fundamental time period.

Material Proprties are taken to be : For Masonry Modulus of Elasticity 2703.2 MPa ,Shear Modulus 915.1 MPa,Specific weight of masonry 19 KN/$m^3$, Poisson's Ratio 0.32 ,Compressive Strength 2.4 MPa .the concrete taken is of grade which has the modulus of elasticity 15000MPa and the Poisson's ratio of 0.2. The unit weight of the concrete is taken as 25kN/$m^3$.[11]

### 3.2 Modeling of buildings

Brick masonry building with cement sand mortar having various pretended plan dimensions are considered for the study of the quantitative effect of geometric property in the fundamental period of the buildings. Finite element analysis software CSI-ETABSv17 is used. Only a linear static method is used for design due to its relevancy for the Rayleigh Method. The building is assumed to have a hinge connection at the plinth level. Building considered herein have equal length in both horizontal directions. Floor slabs are assumed to be rigid in their plane. More than FEM defined self-weight of member DL, LL, EL -Dead load, Live load, and earthquake loads are assigned to our models.

For the design of the building models, different load combinations are taken as recommended in Indian Standards.

Seismic weight includes the total dead load of the structure and a fraction of the live load assigned to the structure. In this study, 25 percentages of the live load is considered to be included in the seismic weight along with the dead load. Linear and elastic finite element model was run for the Lateral load corresponding to the various basic seismic coefficient for various code based provisions

### 3.3 Rayleigh method

Rayleigh's energy method of estimating the natural frequencies of vibrating systems is a well-established technique in engineering science. For linear elastic analysis, the Rayleigh method is known to provide a satisfactory approximation of fundamental periods of structures [12].The expression for finding fundamental time period using the Rayleigh method is as follows:

$$T = 2\pi \sum_{i=1}^{n} W_i d_i^2 / g \sum_{i=1}^{n} F_i d_i \tag{6}$$

where, di, Fi, and Wi are the horizontal displacement of the center of mass, displacing force, and seismic weight at level i respectively.This data are obtained on based of FEM modelling.

## 4. Results and Discussion

For this study, the Modelling of 25 selected building models is set up on Finite element software to find the quantitative effect of Base Dimension and Height of building on the fundamental time period of building. The fundamental periods for all the selected buildings calculated using Rayleigh method as well as code-based empirical equations After that, the qualitative and quantitative influence of selected geometric parameters on the fundamental time period is analyzed. Finally, the approximate formulation of the fundamental time period based on the selected geometric parameters is proposed.

### 4.1 Influence of the height of the building on the fundamental time period

Most of the code considered in the literature expresses their fundamental period equation of masonry buildings as the function of the height of the building. So, without a doubt this parameter influences the fundamental period of the building most. In this research, buildings ranging from 1 to 5 stories with a height ranging from 2.438m to 12.192m were considered. For the study of height effects on fundamental time period; three code based emperical equations are selected and the value obtained from this code based formulation is analyzed along with the fundamental time period obtained from the Rayleigh method.

Europe: Euro code 8(2004)

$$T = 0.05H^{\frac{3}{4}} \tag{7}$$

Bangladesh: BNBC-2015

$$T = 0.048H^{\frac{3}{4}} \tag{8}$$

Philippines: NSCP 2010

$$T = 0.0488H^{\frac{3}{4}} \tag{9}$$

Typical example shows the calculated values of the fundamental period of buildings with various height having all other parameters same. These values are presented in graphical form as:

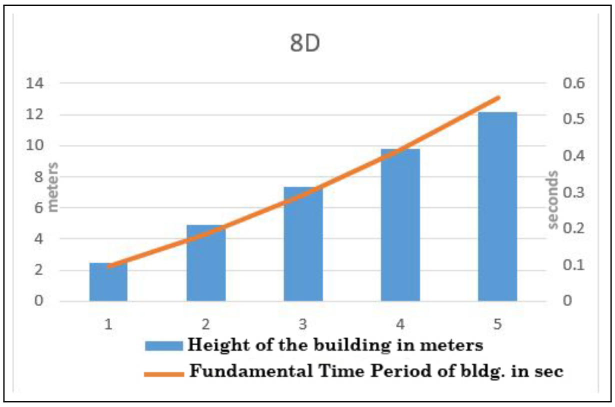


**Figure 1:** Clustered Column showing the variation of the fundamental time period of buildings with variation in Height keeping base dimension constant (8D)

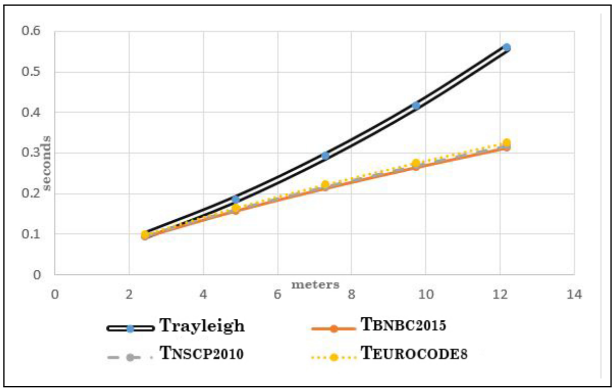


**Figure 2:** Variation of the fundamental time period of buildings with variation in height

Based on the above data from the analysis, it is seen that the calculated fundamental period of the buildings increases with the increase in height. As the height of the building increases, the mass of the building increases but not the stiffness. Thus, the flexibility of the building increases with an increase in the height which causes the fundamental period to increase. So, with an increase in the height, the value of the fundamental period increases. It is seen that, in most cases, the values of the fundamental period as given by the code-based empirical expressions are lower than those calculated by the Rayleigh method which was accordance to with research of William Jacobs. [13] Also, as can be observed from the figure above, the difference between the values of the fundamental period obtained by the Rayleigh method and the empirical equations is smaller for smaller heights of the building but when the height of the building increases, the difference between them becomes larger. Thus, the code-based empirical expressions for the fundamental time period are more accurate for low-rise buildings. Also, since the values of fundamental period calculated by code-based equations in most cases are lower than those calculated by the Rayleigh method, this clearly shows that the code-based period-height formulae tend to underestimate the fundamental periods of buildings. As can be seen from the figure above, the time period value provided by Europe: Euro Code 8(2004), Philippines: NSCP 2010, Bangladesh: BNBC is comparatively even lower in descending order.

### 4.2 Influence of the Base dimension on the fundamental time period

Some of the codes considered in the literature express their fundamental period equation of masonry buildings as the function of the base dimension of the building. So, without a doubt this parameter influences the fundamental period of the building somehow.

The modal analysis performed in this research shows the following tendency in the modification in the time period with an increase in base dimension keeping height constant.

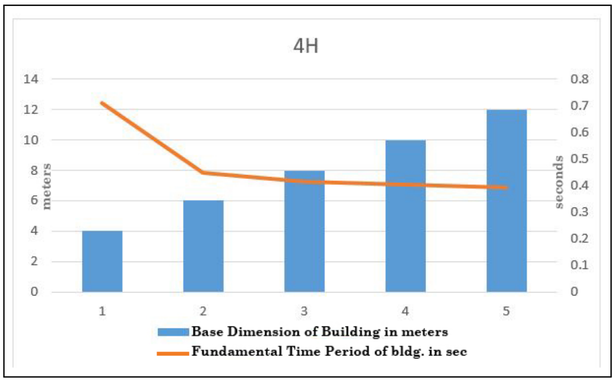


**Figure 3:** Clustered Column showing the variation of the fundamental time period of buildings with variation in base dimension keeping height constant (4H)

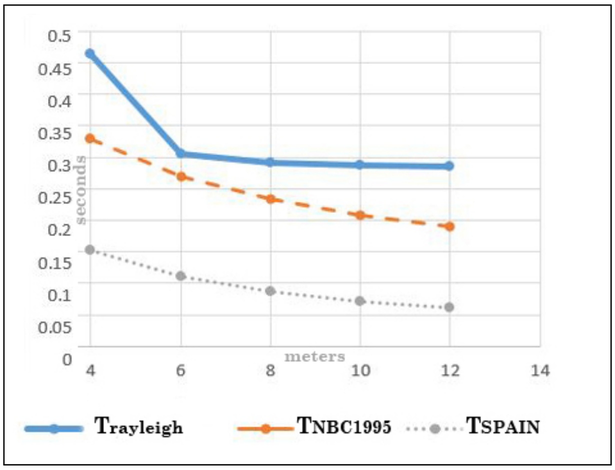


**Figure 4:** Variation of the fundamental time period of buildings with variation in base dimension

## 5. Formulation from Analysis

Regression Analysis is performed now to show how fundamental time period of the considered building models are obtained from the Rayleigh method are related to its parameters height of the building(H), base dimension(D). Furthermore, the approximate equation for the fundamental time period is developed by performing a regression analysis. For the goodness of fit of the regression model, the coefficient of determination is checked out. The coefficient of determination ($R^2$) measures the proportion of variation in the dependent variable that can be predicted from the set of independent variables in a multiple regression equation. When the regression equation fits the data well, $R^2$ will be large (i.e., close to 1); and vice versa.

### 5.1 Regression considering fundamental time period as the function of height only

Period-height code expressions are generally of the form

$$T = \lambda H^{\beta} \tag{10}$$

was adopted for the regression where the fundamental time period(T) depends upon the parameter: height(H) . $\lambda$ and $\beta$ are the regression coefficients to be determined. For regression analysis, the above equation is altered to the form of equation as follows:

$$y = a + \beta x \tag{11}$$

where as y,a,x are natural logarithm T, $\lambda$ and H respectively.

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{(n\sum x^2 - (\sum x)^2)}\sqrt{(n\sum y^2 - (\sum y)^2)}} \tag{12}$$

$$\beta = n\sum xy - \sum x \sum y / \sqrt{(n\sum x^2 - (\sum x)^2)} \tag{13}$$

$$a = \sum y/n - \beta \sum x/n \tag{14}$$

From Calculation value of $\lambda$ and $\beta$ are found to be 0.0348 and 1.0893 respectively with $R^2$ is equal to 0.99.

Thus, the empirical expression considering the fundamental time period as the function of the height of the building is given as an equation.

$$T = 0.034H^{1.0893} \tag{15}$$

### 5.2 Regression considering fundamental time period as the function of height, base dimension

The form of equation considered is

$$T = \lambda H^{\beta} D^{\gamma} \tag{16}$$

was adopted for the regression where the fundamental time period(T) depends upon the parameters: height(H) and base dimension or length of the building(D). $\lambda$ , $\beta$ and $\gamma$ are the regression coefficients to be determined.

For regression analysis, the above equation is altered to the form of equation of y on $x_1$ and $x_2$

$$y = a + \beta x_1 + \gamma x_2 \tag{17}$$

where as y,a,$x_1$,$x_2$ are natural logarithm T, $\lambda$ , H and D respectively.

The above equation represents a plane in the three-dimensional coordinate system, it is often called a regression plane. To find the least-squares regression plane a, $\beta$ and $\gamma$ are:

$$\sum y = na + \beta \sum x_1 + \gamma \sum x_2 \tag{18}$$

$$\sum yx_1 = a\sum x_1 + \beta \sum x_1^2 + \gamma \sum x_1 x_2 \tag{19}$$

$$\sum yx_2 = a\sum yx_2 + \beta \sum x_1 x_2 + \gamma \sum x_2^2 \tag{20}$$

From Calculation value of $\lambda$ and $\beta$ and $\gamma$ are found to be 0.09348 and 1.08 and -0.4346 respectively.

Thus, the empirical expression considering the fundamental time period as the function of the height of the building and the base dimension is given as an equation.

$$T = 0.093H^{1.08}D^{-0.4346} \tag{21}$$

## 6. Conclusion

Brick masonry building with cement sand mortar is a common type of building typology in Nepal. The effect of geometrical parameters namely base dimension and height were analyzed by considering twenty-five different building plan configurations. Linear analysis was performed in order to calculate the fundamental time period of the building based on the Rayleigh method. Indian Standards as well as Nepal National Building Codes were used for the analytical process. Following conclusions are drawn from this research:

1. Geometric Parameters: Height and Base Dimension both influence the fundamental time period of masonry building. This study shows that the calculated fundamental period of the buildings increases with the increase in height and decreases with an increase in the base dimension. Within them, Height is likely to have more influence in the fundamental period of the building.

2. The code-based empirical expressions generally underestimate the value of the fundamental time period of masonry buildings. This study shows that the time period value provided by Europe: Euro Code 8(2004), Philippines: NSCP 2010, Bangladesh: BNBC is comparatively even lower in descending order, this code based values are already lower than the time period calculated by modal analysis which shows code is at a conservative approach. Likewise the difference between the values of the fundamental period obtained by the Rayleigh method and the empirical equations is smaller for smaller heights of the building but when the height of the building increases, the difference between them becomes larger. Thus, the code-based empirical expressions for the fundamental time period are more accurate for low-rise buildings.

3. Two Different empirical equations were also proposed by conducting a regression analysis on the selected data by considering the time period as the function of height only and height as well as base dimension.

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