Volume-6,Issue-2 (Sep-16)
ISSN (O) :- 2349-3585

Study On Fundamental Natural Time Period of Buildings Resting On Slopes

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Abstract – Fundamental natural time period (T) of a building was estimated using empirical formula by most of the seismic codes in worldwide. As per IS 1893:2002, T is a function of height and dimensions of the building. However, the formula specified in the existing code was not suitable for buildings on slopes, which are irregular in both horizontal and vertical plains as they have non-uniform column height and is also torsional coupled. So, this study helps in providing a better correlation for estimating T by performing regression analysis for numerically measured periods of different building models on slopes. Various cases of slope building in 2D with G+3 to G+7 stories and bays 3 to 5 along with slope varying angles (15°, 30°, 45° and 60°) with fixed as well as pinned supports were studied using SAP 2000(v16) and compared with the time periods of the same found using equation given in IS 1893:2002. In the present study, an attempt was made to establish correlation between the time period as per IS code and a slope coefficient to obtain approximate time period of slope building. It had been found that the time period increased with the increase in slope angle and the number of bays. It was also noticed that the time period was increased when pinned support was used. An empirical formula depending on the slope angle was developed for the same and it can be used in predicting T for any plan dimension. The improved formula was found to have low significant difference between the obtained formula and the real behavior of the buildings.

Keywords— Fundamental natural time period, Buildings resting on Slopes, Restrains, Alpha formula, Regression Analysis

INTRODUCTION

In recent years, population has been increased drastically and due to which cities and towns started spreading out. Due to this reason many buildings are being constructed in hilly areas. India has a large coastal line which is covered with mountains and hills. Most of the hilly areas in India come under the seismic zone II, III and IV zones in such case building built on sloping grounds are highly vulnerable to earthquake. This is due to the fact that the columns in the ground floor differ in their heights according to the slope of the ground. Columns on one end are short and on other end are long, due to which they are highly vulnerable. Generally, hill buildings are different from those in plains; they are very irregular and unsymmetrical in horizontal and vertical planes and torsion ally coupled. Hence, they are susceptible to severe damage when affected by earthquake ground motion. Past earthquakes [2] [e.g. Kangra (1905), Bihar- Nepal (1934 & 1980), Assam (1950), Tokachi-Oki-Japan (1968), Uttarkashi-India (1991)], have proved that buildings located near the edge of stretch of hills or sloping ground suffered severe damages. Such buildings have stiffness and mass varying along the vertical and horizontal planes, resulting center of rigidity and center of mass do not coincide on various floors. Such buildings requires torsional analysis; in addition to lateral forces under the action of earthquakes. Fundamental natural time period (T) is an inherent property of every building. It is essential to obtain the same at design stage for ensuring the accurate calculation of design base shear. As per IS 1893:2002, the fundamental natural time period is a function of height and base dimensions of the building. The time period formula given by Goel and Chopra (1997) [6] which is adopted in most of the seismic codes suggest that it is not ideal for buildings resting on slopes. Indian subcontinent being under seismic threat includes 60% of its land mass, which admits the risk of population living in this area. If focused on north and north east India, the sloppy terrain doubles the risk. To understand the seismic safety of buildings on slopes, the finding of fundamental natural period is a challenging task. In this paper, numerical studies are carried out to find the fundamental natural period of a building resting on slope. This is done by performing regression analysis on several buildings and expressions are derived for natural period of buildings resting on hill slopes. The study includes the influence of story heights and bay dimensions i.e., various cases of slope building with G+3 to G+7 stories along with slope angles varying from (15°, 30°, 45° and 60°) are studied and correlated with the time period as per IS code with some slope coefficient to obtain approximate time period of slope building.

Modelling and Analysis

For calculating the constant valve (α) different cases (each of two dimensional G+3 to G+7 building models with fixed as well as pinned supports on varying slope angles i.e., 15°, 30°, 45° and 60° and with are designed and analysed as per code IS 456:2000 in SAP 2000 - V16, respectively. A few assumptions made to reduce the complexity in calculation of fundamental time period of sloped building are listed below:

a) Buildings without infill

b) Time period along slope direction

c) Buildings are symmetrical

d) 2dimensional models

A. Material Properties

Grade of concrete: M30

Grade of steel: Fe415

B. Structural Geometry

Size of beam : 300x300mm

Size of column: 450x450mm

Slab thickness : 120mm

Bay width : 3m

Story height : 3m

Plinth height : 1.5m

C. Loads

Dead Load:

Typical floor : 27kN/m

Top roof : 13.5KN/m

Live Load:

Typical floor : 3kN/m

Top roof : 1.5KN/m

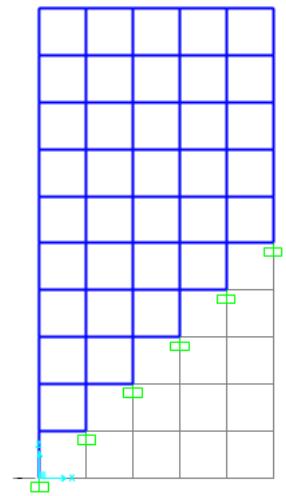


Fig.1. 45° sloped 5bay building with fixed support

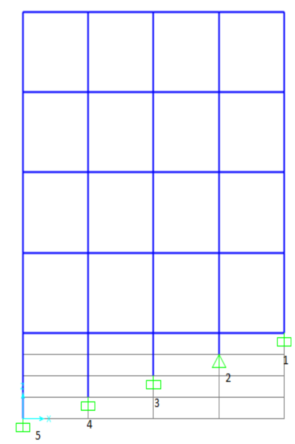
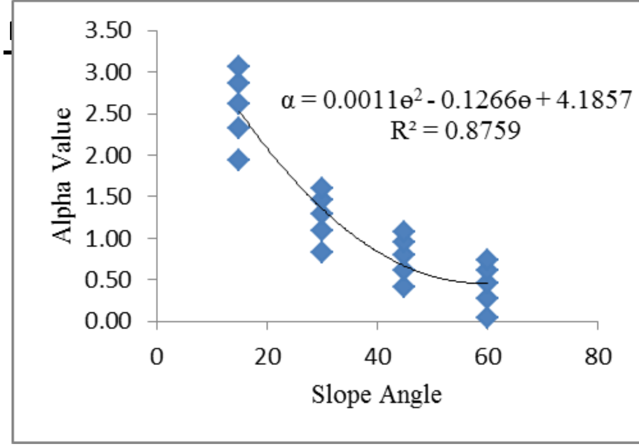


Fig.2. 15° sloped 4bay building with one pinned support

In present study a linear modal analysis is performed on each model and their fundamental natural time periods are calculated. The obtained numerical T is used to calculate the value of α for a building with same plan dimensions but with varying heights. Regression analysis is done for the obtained α value with a best curve fitting. This process is repeated for cases and their respective plots are obtained. A comparative study on time periods obtained from SAP 2000 and formula in IS 1893:2002 code shows a considerable variation in the time periods of the buildings. The error percentage reaches more than 100%. Hence, it is necessary to improve the current code formula which depends only on the height of the building. From the values obtained, it was seen that the time period increased with the increase in number of bays, number of stories and the increase in slope angle. This proved that the



time period depends on bay number, story number and slope angle. Hence, it proved that there is a necessity in improving the current code formula which depends only on the height of the building. Therefore an attempt is made to correlate the current code formula with a slope coefficient to obtain an improved formula. Also, the time period for buildings with fixed support is less compared to time period for buildings with hinged support.

Correlation of time period for buildings on slopes

It is an attempt to correlate the code formula with a slope coefficient, so as to obtain the approximate formula for building on slope surfaces. As per the code IS 1893-2002, for the buildings without infill's the fundamental time period is given as

$$T=0.075\ H^{0.75} \qquad (1)$$

So, for the buildings resting on slope, the column height is considered as the average height of all columns and a coefficient/parameter with respect to the angle (i.e., trigonometric function) is added to the existing empirical formula. The assumed general empirical form can be formulated as below:

$$T=0.075\ (H_{average})^{0.75}\ (1+\sin\theta)^{\alpha} \qquad (2)$$

Where, $H_{average}$= (c1+c2+c3+c4)/4

θ = angle of slope

The numerical time period measured is used to calculate the effective α value for various cases such as 2D buildings with bays of 3, 4 and 5 with G+3 to G+7 stories each of 3m having fixed and pinned supports, the best fit curves are plotted by performing regression analysis. The value of α can be calculated as below:

$$\alpha = \frac{\log\left(\frac{T}{0.075\ (H_{average})^{0.75}}\right)}{\log(1+\sin\theta)} \qquad (3)$$

Results and Discussions

Regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. Once the regression equation is constructed it can be checked using the coefficient of determination (R) which always lies between 0 - 1. The value closer to '1' is more accurate. Regression analysis was done for the obtained α value with a best curve fitting. This process is repeated for all cases and their respective plots are obtained. Figure 3, figure 4 & figure 5 are some of the plots obtained.

Fig 3. α formula for 3bay building obtained from regression analysis

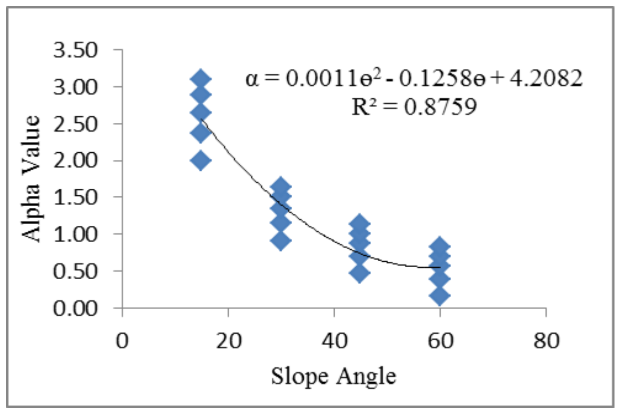


Fig 4. α formula for 4bay building obtained from regression analysis

It has been found that the alpha value decreases with the increase in slope angle. The highest alpha value can be seen for the slope with lowest angle. Also, as the slope angle increases the time period value increases, it increase with the number of story and bay number. Also, in case of fixed support, the time period is said to be minimum, it increases when hinged support are being used.

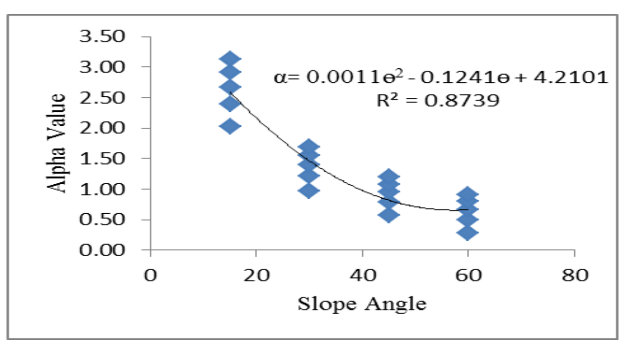


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Fig 5. α formula for 5bay building obtained from regression analysis

The equations obtained for α from different cases, are further reduced to obtain an average equation for the same. The formula arrived through the results of regression analysis for the different cases are visualized in figure 3, 4 and 5. As observed from it, the data falls above or below the best fit curve. Mean (μ) and standard deviations (are calculated to reduce error. The results reported in this paper show a significant difference between the obtained formula and the real behaviour of the buildings. The error percentage considering the time period obtained using the improved formula is much less compared to that obtained from the current code formula. So this improved formula can be used in estimating the time period of buildings resting on slopes.

TABLE 1. OBTAINED ALPHA FORMULA (α) VALUES FOR DIFFERENT CONSIDERED BUILDINGS

Sl No.	Bay No	Value of α
1	3	$\alpha=0.0011\theta^2-0.1250867\theta+4.24548$
2	4	$\alpha=0.0011\theta^2-0.1264923\theta+4.2343846$
3	5	$\alpha=0.0011\theta^2\ 0.127567\theta+4.212128571$

ACCORDING TO BAY NUMBER

TABLE 2. OBTAINED ALPHA FORMULA (α) VALUES FOR DIFFERENT CONSIDERED BUILDINGS

	C1	C2	C3
μ	0.0011	-0.126781929	4.225127711
μ+	0.0011	-0.125449303	4.259288605
μ-	0.0011	-0.128114553	4.190966819

CONCLUSIONS

This study has been supportive in determining effectively the time period of buildings resting on slopes by analyzing building models using SAP. As the buildings resting on slopes are irregular and asymmetrical in both horizontal and vertical plains and is also tensional coupled, the formula specified in the code is not applicable to those buildings. So, it is clearly understood from the study that the fundamental natural period is not only the function of height. The time period obtained for buildings resting on slopes obtained using SAP and formula specified in IS code shows a considerable variation. It is also observed that as the slope angle increases, the time period also increases because of the variation in mass and stiffness. Also, as the bay number increases, the time period also increases accordingly. It is found that when the support condition is changed from fixed to hinged, the time period increases. This proved that the time period depends not only on the height of the build, but also depends on bay number and slope. Therefore an improved formula has been proposed for the buildings resting on slopes based on a slope coefficient. The formula is $T=0.075\ (H_{average})^{0.75}\ (1+\sin\theta)^{\alpha}$, where α value is found out using regression equation. Hence, this study is clearly able to produce an improved empirical formula for calculating the fundamental time period of building resting on slope which is equally valid to regular building as per code. Based on the regression equation, the obtained α value is used to predict the T for any plan dimension.

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