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BAY EFFECT ON PERIOD OF FRAMED BUILDINGS

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ABSTRACT : Uniform Building Code (UBC) provides approximate formula for evaluation of period of regular building frames for earthquake resistant design by equivalent static force method. The formula expresses period solely as function of structure height. In order to study the influence of other parameters such as bay width and number of bays on period, model frames are analyzed by modal analysis technique using computer software ANSYS. Periods of model frames are plotted against width of bays and their numbers in plan. Period is found to increase with increase in bay width and decrease with increase in number of bays along the direction of motion. Whereas an increase in number of bays transverse to direction of motion causes the period to increase. The approximate UBC-94 formula can not recognize these effects and yields lower values of period than modal analysis. As a result, UBC formula leads to conservative evaluation of earthquake forces.

KEY WORDS: Period, modal analysis, earthquake, base shear, bay width, mass, stiffness.

INTRODUCTION

Frames are the most widely used structural system in building practice. Design codes recommend equivalent static force method for earthquake resistant design of such structures upto certain height. The method suggests calculation of base shear and distribution of this quantity as earthquake forces over the height of the structure. Uniform Building Code (International Conference of Building Officials 1994) proposes evaluation of base shear as product of structure weight and other factors. According to the code, the base shear is inversely proportional to fundamental period of vibration in seconds.

For moment resisting regular concrete frame structures, UBC-94 provides an approximate formula for evaluation of period. The approximate formula describes period as a function of building height only. According to modal analysis technique, however, frequency and hence period of a structure are functions of its stiffness and mass properties. It is anticipated, therefore, the building period would be influenced in addition to height by the width and number of bays of frames, as these would affect the stiffness.

In this paper, period of several model framed buildings are evaluated by modal analysis procedure using high level computer software ANSYS

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(ANSYS User's Manual 1996). Influence of bay width and number of bays of frames on period are studied. Results are compared with those obtained by using approximate code formula.

BASE SHEAR AND PERIOD BY UBC-94

According to UBC-94, base shear V is given by

$$V = \frac{ZIC}{R_W} W \tag{1}$$

where, Z = seismic zone factor

I = importance factor

W = total seismic dead load

R_w = response modification factor

$$C = \frac{1.25S}{T^{2/3}} \geq 0.075 R_w \tag{2}$$

≤ 2.75

S = site coefficient

T = *fundamental period of vibration*

For regular moment-resisting concrete frames, deforming freely, the code permits evaluation of period by using approximate formula

$$T = 0.03 h_n^{3/4} \tag{3}$$

where, h_n = building height in ft above base

MODAL ANALYSIS OF FRAMES FOR PERIOD

The complete dynamic equilibrium of a MDOF structure is given by

$$[m]\{v\} + [c]\{v\} + [k]\{v\} = \{p(t)\} \tag{4}$$

where, [m] = mass matrix

[c] = damping matrix

[k] = stiffness matrix

{p (t)} = load vector

{v } = acceleration vector

{v } = velocity vector

{υ } = displacement vector

For free vibration of an undamped MDOF frame structure, Eq. 4 simplifies to

$$[m]\{v\} + [k]\{v\} = \{O\} \tag{5}$$

For a nontrivial solution of the above equations it can be shown (Clough and Penzien 1993) that the following determinant equation must satisfy

$$\left\| [K] - \omega^2 [m] \right\| = 0 \tag{6}$$

where, ω^2 represents the frequencies of the N modes of vibration which are possible in the system.

ANSYS, however, solves the problem by extracting eigenvalues which represent frequencies and eigenvectors which represent mode shapes.

The vector made up of the entire set of modal frequencies, arranged in sequence, is the frequency vector $\{\omega\}$. For the real, symmetric, positive definite mass and stiffness matrices which pertain to a stable frame structure, all frequencies will be real and positive. The lowest among these, ω_1 will correspond to the first mode. The fundamental period, T of the frame structure can then be determined as

$$T = \frac{2\pi}{\omega_1} \tag{7}$$

SELECTION OF MODEL FRAMES

Group A

In order to study the effect of number of bays on period, 6 storied and 12 storied framed buildings are selected. Each type contains frames having 2 to 5 bays along the direction of motion and 2 to 4 bays transverse to the direction of motion [Fig. 1]. Thus a total of 24 model frames will be analyzed for fundamental period. The other parameters for the selected models are shown in Table 1.

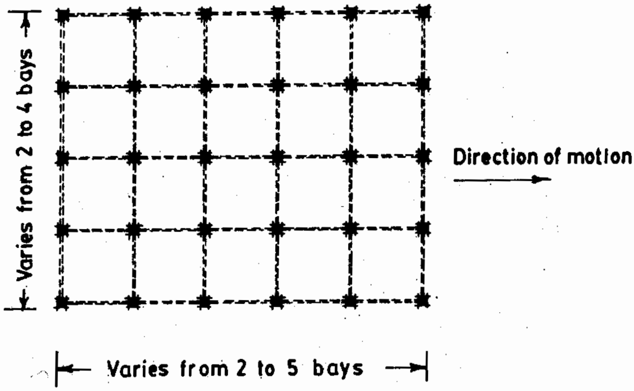


Fig. 1. Plan of Models of Group A for Investigating Effect of Number of Bays on Period

Table 1. Values of Frame Parameters

Parameters	Values
Modulus of Elasticity	2.07×10^6 kN/m^2
Density of Concrete	23.56 kN/m^3
Width of Bays	5.0 m
Story Height	3.2 m
Size of Columns	0.5 m × 0.5 m
Size of Beams	0.35 m × 0.5 m
Thickness of Slab	0.15 m

Group B

For studying the effect of bay width on period, 6 and 12 storied framed buildings are selected. Each type contains models with 3 ×3, 4×4 and 5×5 bays in plan [Fig. 2]. All data shown in Table 1 remain unchanged for the models except the width of bays. For each model, the bay width is varied from 5 m to 7 m at a rate of 0.5 m.

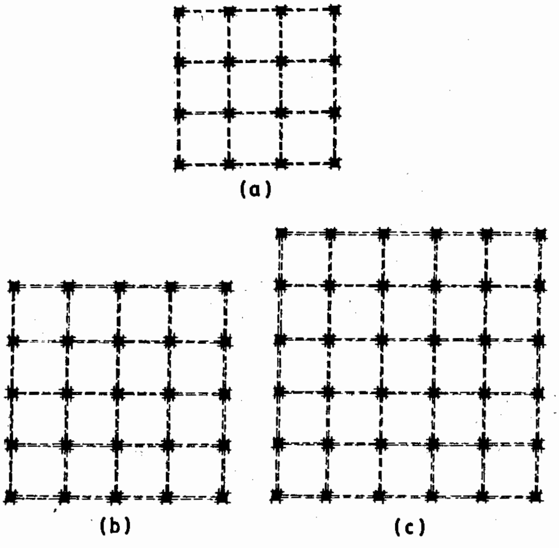
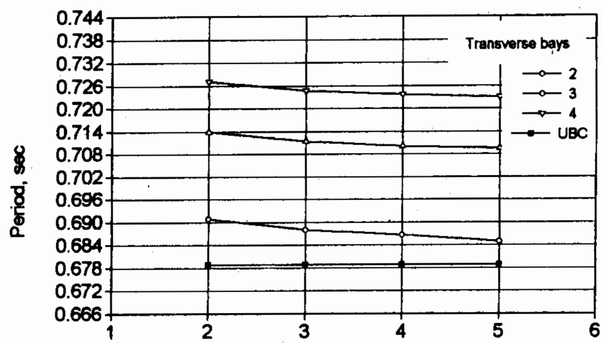


Fig. 2. Plans of Models of Group B for Investigating Effect of Bay Width (a) 3x3 Bays (b) 4x4 Bays (c) 5x5 Bays

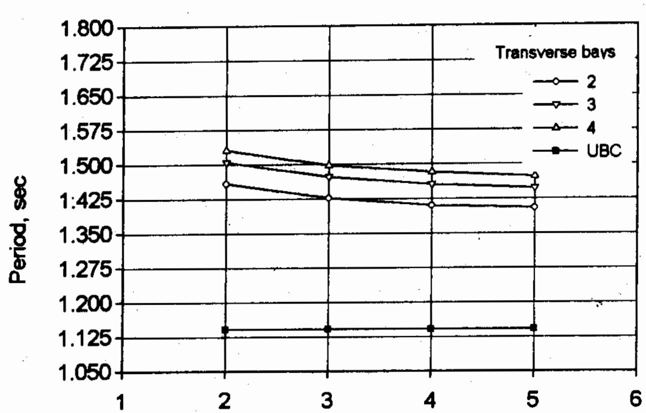
EFFECT OF NUMBER OF BAYS

Periods of the models of Group A are computed by modal analysis using ANSYS. The periods of 6 story models are plotted against number of bays along the direction of motion in Fig. 3. For 12 story models identical relationships are plotted in Fig. 4. The same relationships corresponding to approximate UBC-94 formula are also plotted in Figs.3 & 4. In both the figures, the top three curves correspond to models with 2,3 and 4 numbers of transverse bays. The bottom most curve represents UBC-94 formula.



Number of boys along the direction of motion

Fig. 3. Effect of Numbers of Bays on Period of 6 Story Frames



Number of boys along the direction of motion

Fig. 4. Effect of Numbers of Bays on Period of 12 Story Frames

The top curves show that the period decreases with an increase in number of bays along the direction of motion. However, with an increase in number of bays transverse to the direction of motion the period increases. UBC-94 formula, on the other hand, yields a curve invariant of number of bays along any direction. Also UBC-94 formula yields lower period than that obtained by modal analysis. The difference widens with decrease in number of bays along the direction of motion or with increase in number of bays transverse to direction of motion. The difference becomes more prominent for higher storied structures. Hence, UBC-94 formula leads to more and more conservative evaluation of base shear with increasing number of stories.

EFFECT OF BAY WIDTH

Models described in group B are analyzed by modal analysis technique for period. The period-bay width relationships for 6 storied and 12 storied structures are plotted in Figs. 5 and 6 respectively. The top three curves in both the figures correspond to period obtained by modal analysis for 3x3, 4x4 and 5x5 bay structures in plan. The bottom most curve corresponds to approximate UBC-94 formula. Curves obtained through modal analysis show that the period of a structure increases as the bay width increases.UBC-94 formula, however, yields a curve invariant of width of bays. It may be further observed from the figures that the magnitude of the period obtained through modal analysis is higher than the magnitude of period defined by UBC-94 formula. The difference widens with increasing bay width and increasing number of stories.

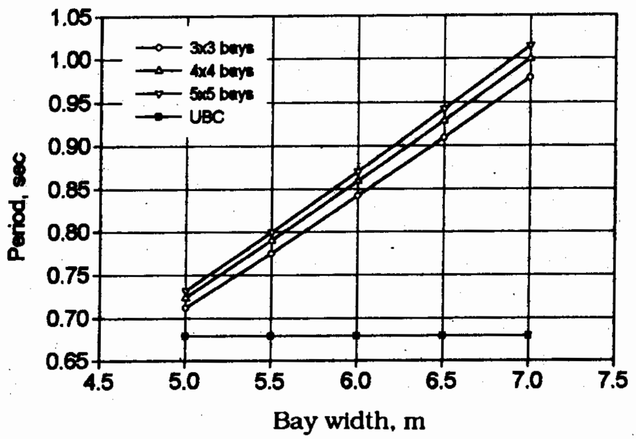
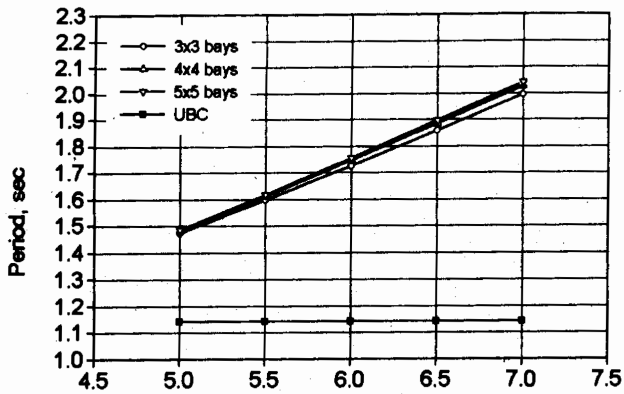


Fig 5. Effect of Bay Width on Period of 6 Story Frames



Bay width, m

Fig 6. Effect of Bay Width on Period of 12 Story Frames

CONCLUSIONS

Approximate formula for evaluation of period proposed by UBC-94 is invariant of structure parameters other than height. The modal analysis for period shows that the width and number of bays of a frame structure have substantial influence on period. The period increases with increasing bay width and increasing number of bays transverse to direction of motion. However, the period decreases with increasing number of bays in the direction of motion.

Period has been found to increase with an increase in number of stories or structure height. Evaluation of period by approximate UBC-94 formula has been found to lead to more conservative evaluation of base shear.

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NOTATIONS

C	numerical coefficient depending on period and site characteristics
[c]	damping matrix
h_n	building height in ft above base
I	importance factor
[k]	stiffness matrix
[m]	mass matrix
{p(t)}	load vector
R_w	response modification factor
S	site coefficient
T	fundamental period of vibration
V	base shear
{v}	displacement vector
{v}	velocity vector
{v}	acceleration vector
W	total seismic dead load
Z	seismic zone factor
{ω}	frequency vector
ω_1	lowest frequency