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INFLUENCE OF STRUCTURAL PARAMETERS ON SCALING FACTOR FOR SITE SPECIFIC RESPONSE SPECTRUM

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ABSTRACT: In the Response Spectrum Method, the normalized Response Curve provided by building codes needs to be scaled for a site specific use. In this study, for a particular application, the base shear obtained by Response Spectrum Method is equated with that obtained by Equivalent Static Force Method. This establishes a scaling factor, which multiplies the vertical axis of the normalized Response Spectrum Curve for specific application. In this pilot study the relationship of scaling factor with various structural parameters has been obtained using the STRAND6 software. It has been found that scaling factor decreases with the increase of number of bays along the direction of motion, with the increase of concrete strength and with the increase of column stiffness. And scaling factor increases with the increase of bay width, structure height and number of bays transverse to the direction of motion. This leads to the general conclusion that the scaling factor is proportional to the natural time period of the structure and inversely proportional to the stiffness of the structure.

KEYWORDS: Base shear, scaling factor, acceleration coefficient, zone factor, importance coefficient, response factor, site coefficient, time period.

INTRODUCTION

The Dynamic Response analysis by the spectral method is a more accurate method than the Equivalent Static Force Method, suggested by the design codes. The scaling factor for this pseudo-dynamic analysis may be found by equating the base shear obtained from Response Spectrum Method with the design base shear derived from the Equivalent Static Force Method. Though base shear remains same in both the methods but response spectrum analysis provides more accurate distribution of the force over the structure, which is very important to know for the sake of proportioning the structural elements. In Response Spectrum analysis an earthquake excitation of the ground is given in the form of a response spectrum curve (Fig.1) available in the various national codes.

The Response Spectrum Curve also referred as a Spectral Curve or Design Spectrum, is included in building codes as normalized curve. For a site specific application a scaling factor or multiplier, which multiplies the values on the vertical axis of the curve is to be used.

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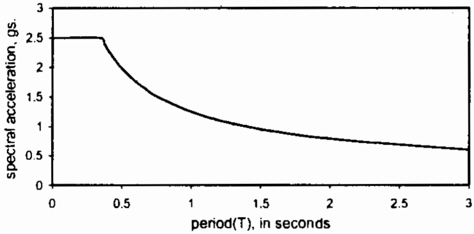

Fig 1. Response Spectrum Curve for damping ratio of 5.0%

The Bangladesh National Building Code (BNBC-93) does not provide a guideline as to how such scaling factor is to be obtained. In a pilot scheme to develop generalized scaling factor, the present paper attempts to identify the parameters, which influence the scaling factor.

DETERMINING THE EXPRESSION FOR THE SCALING FACTOR

The Scaling Factor for a particular site has to take into account the seismicity of the location, importance of the structure, type of the structure, and some other factors. In different national codes, there are different expressions for this scaling factor, which multiplies the vertical axis of the normalized response spectrum for use with a particular structure.

According to Australian Earthquake loading Code (1993) the scaling factor is given by :

$$\text{Scaling Factor(SF)} = a(I/R_f)g \qquad (1)$$

where,

a = acceleration coefficient
I = Importance factor
R_f = Structural response factor
g = gravitational acceleration in units consistent with other data

But in BNBC-93, the Equivalent Static Force Method includes zone coefficient "Z" and site coefficient for soil "S" in its equation for determining the Design Base Shear. So, including the same coefficients in the expression for scaling factor, more generalized scaling factor can be suggested for use with BNBC earthquake loading provisions:

$$SF = a\,(ZIS/R)\,g \qquad (2)$$

where,

a = acceleration coefficient
Z = seismic zone coefficient given in Table 6.2.22 (BNBC-93)
I = structure importance coefficient given in Table 6.2.23 (BNBC-93)

R = response modification coefficient for structural systems given in Table 6.2.24 (BNBC-93)
S = site coefficient for soil characteristics as provided in Table 6.2.25 (BNBC-93)
g = gravitational acceleration in units consistent with other data

The expression in Eq.(2) has been used all through this work. For a particular structural system of defined importance the expression for the scaling factor in a specific earthquake zone of known soil characteristics depends on only one variable, which is acceleration coefficient, "a".

i.e. $SF \propto a$ (3)

So, once the acceleration coefficient for a particular structural model for a known I, Z, R and S can be determined, then the SF of that model for any zone and importance or for any structural system or soil characteristics can be obtained by simple transformation.
For the purpose of present study, following values of the factors have been used:

I = 1.00, for standard occupancy structures
Z = 0.15, for seismic zone 2
R = 12, special moment resisting frame(SMRF) for concrete
S = 1.0, for soil type S_1

Using the Eq.(2) for SF :

$$SF = a^*g\ (0.15^*1.0^*1.0)/12 \quad (4)$$

As SI units have been used in this study so taking gravitational acceleration $g = 9.81 m/s^2$, finally we get expression for acceleration coefficient:

$$a = SF\ /\ 0.122625 \quad (5)$$

Once "a" for a particular model has been obtained SF of that model for different I, Z, R or S is obtained by the expression:

$$(SF)_{new} = a\ (ZIS/R)_{new}\ .g \quad (6)$$

From the above discussion, it is clear that for a particular I, Z, R or S, Scaling Factor is dependent only on acceleration coefficient "a", so the influence of structural parameters on SF is nothing but influence on acceleration coefficient "a" for a specific site and structural system. So, influence of structural parameters on "a" is investigated next.

Relationship Between Acceleration Coefficient and Structural Stiffness

Hossain (1997) has demonstrated the effect of structure parameters on natural time period of the structure. It has been established in the paper that if change of structure parameters increases the stiffness of the structure, then the time period of the structure decreases and vice-versa.

In the present paper the influence of structure parameters on scaling factor has been studied. As stated earlier, for a particular structural system of defined importance and of a specific earthquake zone of known soil characteristics, scaling factor depends only on acceleration coefficient, and therefore in the remaining part of this paper influences of various parameters on acceleration coefficient have been studied.

PARAMETERS CONSIDERED

A number of regular three-dimensional structures up to 5 story have been modeled using STRAND6 finite element package. All the models used in this study, except those used to obtain influence of number of bays on acceleration coefficient, are beamless structures with 2 bays transverse to the direction of motion and 3 bays along the direction of motion. The values of parameters, in general, applicable for all models are given in Table 1. The range of parameters considered in this study are tabulated in Table 2.

Table 1. Material Properties and Related Data

Sl. No.	*Parameters*	*Values*
1	Modulus of Elasticity	25.1 x 10^6 kN/m^2
2	Density of Concrete	23.57 kN/m^3
3	Width of the Bay	6.1 m.
4	Story Height	3.05 m.
5	Size of Columns	0.3m x 0.3m. (0.46m x 0.46m, with beam models)
6	Size of Beams	0.4m x 0.46m.
7	Thickness of Slab	0.13m.

Table 2. Range of Parameters Considered

Sl. No.	*Parameter*	*Range or values*
1	Number of bays in either direction	3 to 6
2	Number of bays parallel or transverse to the direction of motion in structures having equal number of bays in both direction	1 to 3
3	Width of bays	3.05m,4.57m, 6.1m
4	Stiffness of columns (EI/L)	3886 kN-m, 5923 kN-m, 8672 kN-m
5	Cylinder strength of concrete	$21 N/mm^2$,$24 N/mm^2$, $28 N/mm^2$
6	Number of stories	1 to 5

EFFECT OF STRUCTURE PARAMETERS ON SCALING FACTOR

Effect of Number of Bays

For studying the effect of number of bays on the acceleration coefficient, models of increasing number of bays in one direction and in both directions simultaneously have been considered.

The effect of number of bays either along or transverse to the direction of motion have been studied. For increase of number of bays, along the direction of motion two transverse bays are kept fixed. Bay numbers are varied from 3 to 6. Figure 2 and Figure 3 show the models of variation of number of bays with the direction of motion.

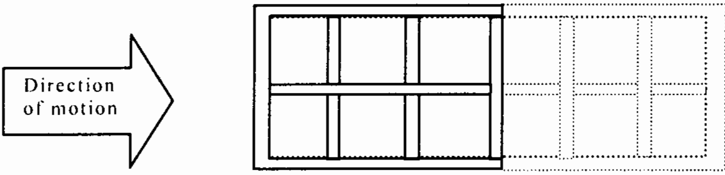

Fig 2. Two bays transverse to the direction of motion and increase of number of bays along the direction of motion

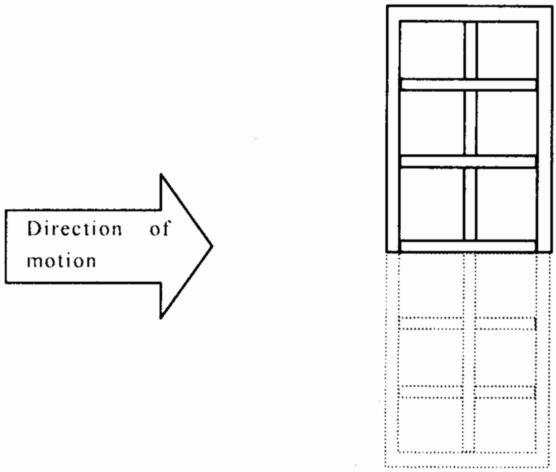

Fig 3. Two bays along the direction of motion and increase of number of bays transverse to the direction of motion

The effects of number of bays on acceleration coefficient for both beam-column structure and beamless structure have been studied and are represented in Fig.4 and Fig.5.

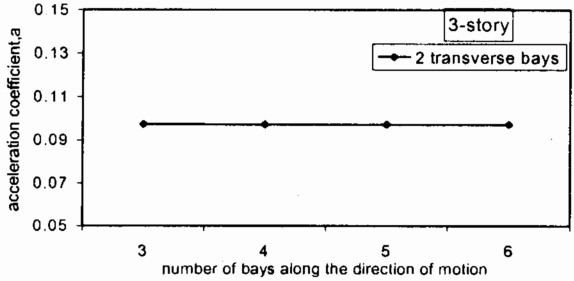

Fig 4. Effect of number of bays along the direction of motion on acceleration coefficient for a beam-column structure.

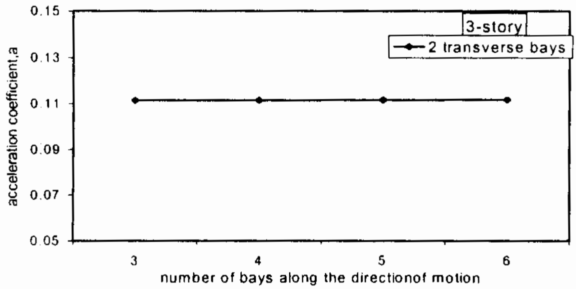

Fig 5. Effect of number of bays along the direction of motion on acceleration coefficient for a beamless structure

The following observations are made from Fig.4 and Fig. 5.

i) As observed in Fig. 4 acceleration coefficient decreases slightly with the increase of number of bays along the direction of motion. This may be explained by the fact that, as the number of bays increases in the direction of motion, the stiffness of the structure in that direction also increases, which leads to a decrease in acceleration coefficient.

ii) For beamless structure acceleration coefficient increases slightly with the increase of number of bays, along the direction of motion. This means stiffness of the building decreases with the increase of number of bays. This can be explained as with the increase of number of bays along the direction of motion, the mass of the structure increases rapidly and the stiffness of the structure also increases in that direction.

The natural time period of the structure is proportional to the mass of the structure and inversely proportional to the stiffness of the structure. The relationship of Fig.5 between number of bays and acceleration coefficient can be explained by the fact that the influence of the mass of structure on natural time period is more than the increase of the stiffness, this leads to an overall increase of natural time period of the structure. The increase of stiffness due to increase in number of bays along the direction of motion is less pronounced in the case of a beamless structure than in the case of a beam-column structure.

However, from Fig. 4 and Fig. 5, it can be seen that the variation of acceleration coefficient with the increase or decrease of number of bays is so small that it carries almost no significance from practical point of view.

The effect of number of bays in transverse direction of motion on acceleration coefficient is plotted in Fig.6. Two numbers of bays along the direction of motion is kept fixed, while three to six bays have been considered in the transverse direction.

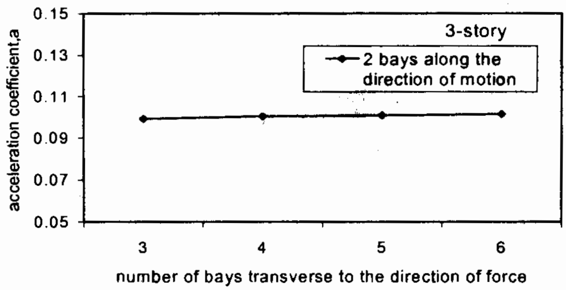

Fig 6. Effect of number of bays perpendicular to the direction of motion on acceleration coefficient

The following observations are made from Fig.6:

The acceleration coefficient increases as the number of bays transverse to the direction of motion increases. Increase of bays transverse to direction of motion adds mass, while the stiffness along the direction of motion remains virtually unaffected. As time period of a structure is proportional to mass (Hossain(1997)), addition of mass leads to increase in period and the relationship here between increase of bays transverse to the direction of motion and acceleration coefficient can be explained similarly.

Figure 7 presents the effect of increase of bays in both directions simultaneously, on acceleration coefficient.

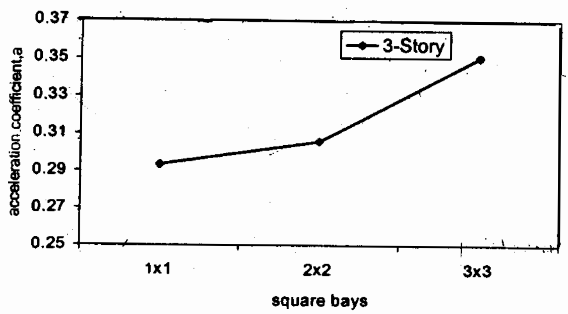

Fig 7. Effect of number of bays on the acceleration coefficient due to increase of bays in both directions

The following observations are made from Fig. 7.

i) The acceleration coefficient for a structure increases with the increase of number of bays in the both the directions simultaneously. This can be explained by the fact that the increase in number of bays, increases both the stiffness and mass of a structure. As time period is directly proportional to mass and inversely proportional to stiffness, increase of stiffness leads to decrease in time period while increase in mass leads to increase in time period. However, influence of mass dominates over influence of stiffness, which leads to a resultant increase in period and the increase of acceleration coefficient in Fig.7 reflects the same explanation.

ii) It is also observed that the rate of increase of acceleration coefficient increases with the increase in number of bays. It can be observed that the increase of acceleration coefficient from bay 2x2 to 3x3 is much higher than from bay1x1 to 2x2. This means as number of bays are increased in both directions simultaneously, increase in mass effect offset in the increase in stiffness effect.

Effect of Bay Width

For studying the effect of bay width on the acceleration coefficient for a structure, models of 3 and 5 story with 2 bays transverse to the direction of motion and 3 bays along the direction of motion are studied and results are plotted in Fig.8 and Fig.9. The bay widths used in these models are 3.05m, 4.57m and 6.1m.

The following observations are made from Fig.8 and Fig. 9.

i) It is seen that the acceleration coefficient increases as the bay width increases. With the increase in bay width, the stiffness of a structure decreases and mass increases. This leads to a increase of structure period. Therefore the increase in acceleration coefficient here can be explained as before.

ii) It can also be observed from the plots that the increase of acceleration coefficient due to increase of bay width is higher with the increase of number of stories. For example, for the increase of bay width from 3.05m. to 4.57m. causes increase in acceleration coefficient of 34.88% for 3 story structure and 37.43% for 5 story structure.

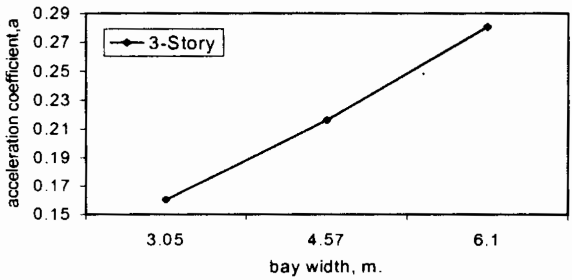

Fig 8. Effect of bay width on acceleration coefficient of a 3 story structure

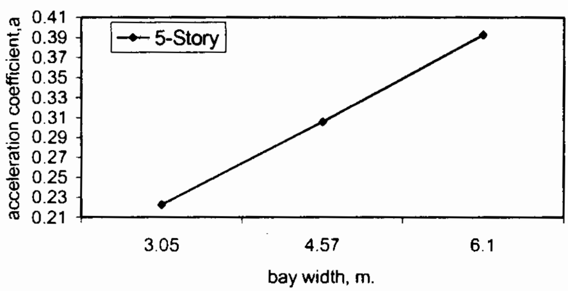

Fig 9. Effect of bay width on acceleration coefficient of a 5 story structure

Effect of Stiffness of Columns

For studying the effect of stiffness of columns on the acceleration coefficient, models of 3 and 5 story with 2 bays transverse to the direction of motion and 3 bays along the direction of motion are studied and results plotted in Fig.10 and Fig.11.

Three different column sizes are used for each of the 3 and 5 story structures, 270mm by 270mm., 300mm. by 300mm and 340mm. by 340mm.. In all the analyses, the column height, h of 3.05m. and modulus of elasticity $E = 25.1x10^6$ kN/m^2 have been kept constant. The stiffness of column is represented by EI/h.

The following observations are made from Fig.10 and Fig. 11.

The curves drawn show that the acceleration coefficient decreases with the increase of stiffness of columns. This can be explained as, with the increases of column stiffness the overall stiffness of the structure increases, causing decrease in acceleration coefficient. The same relationship has been established by Hossain (1997) between time period and stiffness of columns.

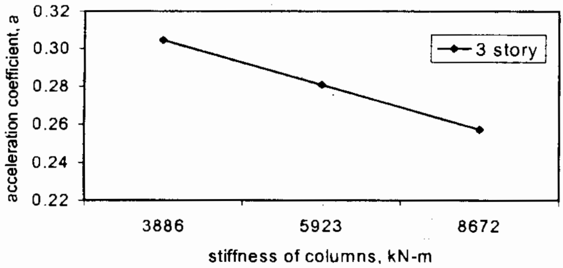

Fig 10. Effect of stiffness of columns on acceleration coefficient of a 3 story

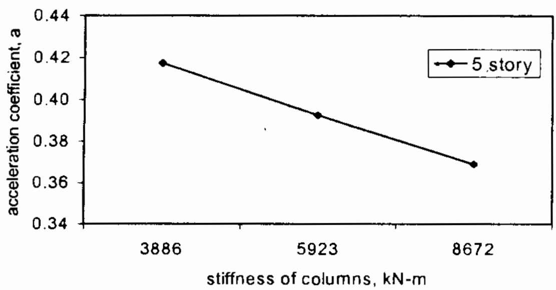

Fig 11. Effect of stiffness of columns on acceleration coefficient of a 5 story structure

Effect of Strength of Concrete

For studying the effect of cylinder strength of concrete on acceleration coefficient, 3 story and 5 story models having cylinder strengths 20.69N/mm^2 (3000psi), 24.13 N/mm^2 (3500psi), and 27.58 N/mm^2 (4000psi) have been used. The models have 2 bays transverse to the direction of motion and 3 bays along the direction of motion. The cylinder strength is taken into account by appropriately modifying the modulus of elasticity using the following relationship:

$E = 4700\sqrt{f'_c}$ *[BNBC-93(1993)]* (8)

Where E is the modulus of elasticity (N/mm^2), f'_c is the cylinder strength (N/mm^2). The moduli of elasticity for the corresponding cylinder strengths are 21.7x10 kN/m^2, 23.5x10^6 kN/m^2 and 25.1x10^6 kN/m^2.
The variation of acceleration coefficient against the cylinder strength is plotted in Fig. 12 and Fig. 13.

The following observations are made from the Fig.12 and Fig. 13.

The acceleration coefficient for a structure decreases with the increase of cylinder strength of concrete. This behaviour is consistent with the findings reported earlier, since the increase of cylinder strength actually increases the stiffness of the structure resulting in decrease in acceleration coefficient.

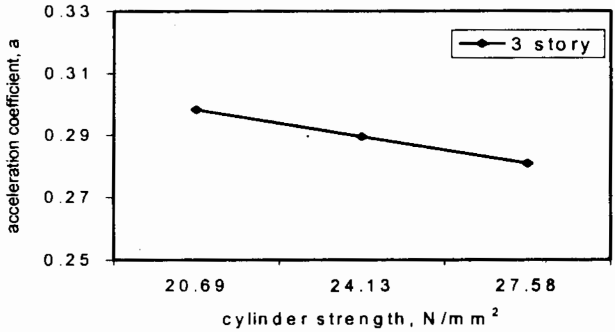

Fig 12. Effect of concrete strength on acceleration coefficient of a 3 story structure

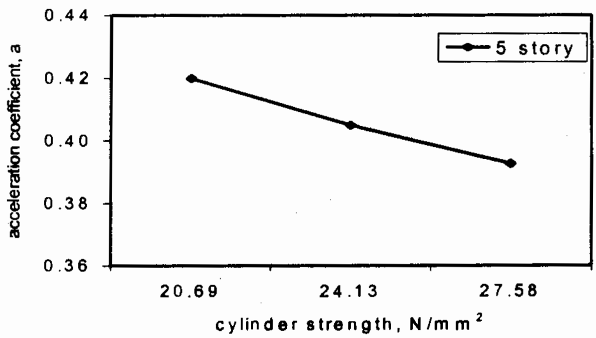

Fig 13. Effect of concrete strength on acceleration coefficient of a 5 story structure

Effect of Number of Stories

For studying the effect of number of stories on the acceleration coefficient models ranging from single story to 5 story have been used. These beamless models with the parameter, given in Table 1, have 2 bays transverse to the direction of motion and 3 bays along the direction of motion.

The acceleration coefficient is drawn against the number of stories in Fig. 14.

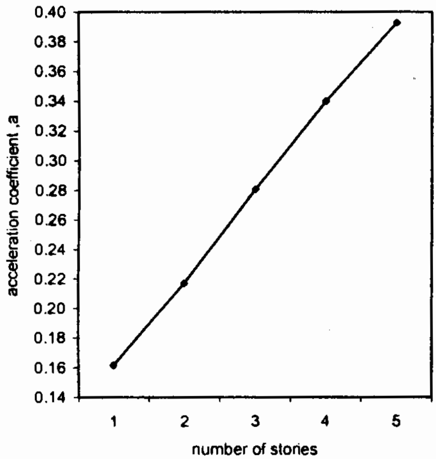

Fig 14. Effect of number of stories on the acceleration coefficient

The following observations are made from the Fig.14

i) The acceleration coefficient of a structure increases as the number of stories increases.

ii) This can be explained as, with the increase of number of stories the mass of the structure increases but stiffness along the direction of motion decreases causing increase of acceleration coefficient. Similar relationship between time period and number of stories of the structure has also been reported [Hossain (1997)).

CONCLUSIONS

A pilot level study for establishing a scaling factor for normalized Response Spectrum for site specific application has been conducted. A formula for obtaining scaling factor has been proposed for use with BNBC earthquake loading provisions.. It has been shown that the scaling factor for a particular structure is proportional to mass of the structure and is inversely proportional to its stiffness. It is felt that further studies are needed for quantitative evaluation of these factors, which will finally establish appropriate scaling factor for various structural configurations.

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NOTATIONS

a = acceleration coefficient
g = gravitational acceleration
I = Structure Importance coefficient
R = Response modification Coefficient for structural systems
R_f = Structural response factor
S = Site coefficient for soil characteristics
SF = Scaling Factor
Z = Seismic Zone Coefficient