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CRITICAL EVALUATION AND COMPARISON OF DIFFERENT SEISMIC CODE PROVISIONS

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ABSTRACT: The main objective of this study is to critically evaluate and compare some section of the current seismic design provisions, which deals with the specification of seismic design forces on buildings. The code provisions reviewed and compared are the Uniform Building Code (UBC), 1994 editions, The Criteria for Earthquake Resistant Design Standards Institutes (IS), 1984 editions, the National Building Code of Canada (NBC), 1995 editions, the Building Standard Law of Japan (BSLJ), 1987 editions. Different parameters such as zone factor, importance factor, structural system factor, site geology and soil characteristics, time period etc. which calculates the base shear has been compared and critically evaluated. For the purpose of analysis, moment resisting concrete and steel buildings have been taken into consideration. In case of concrete building special, intermediate, and ordinary moment resisting framed building have been analysed. Limited numerical study has been done with STRAND6 software, to compare code listed time period, base shear distribution with that of modal analysis using UBC (1994) spectra. It has been found that for calculating base shear in the equivalent static methods almost all codes of practices adopt similar definitions for the numerical coefficient of the base shear formula. It appears that further improvement in the equation pertaining to the calculation of time period of the buildings may not be rewarding.

KEYWORDS: Base shear, importance factor, zone factor, time period, structural system factor

INTRODUCTION

The purpose of this study is to critically review and compare some of the current seismic design provisions dealing with the specification of seismic design forces. Emphasis has been given on the equivalent-static-force procedure, as has been describe in the current codes.

The following seismic design provisions have been taken into cognisance in the present study:

a) The Uniform Building Code (UBC), of the International Conference of Building Officials, 1994 editions.
b) The National Building Code of Canada (NBC), of the National Research Council of Canada, 1995 editions.
c) The Criteria for Earthquake Resistant Design of Structures (referred to as IS), of the Indian Standards Institutes, 1984 editions.
d) The Building Standard Law of Japan (BSLJ), of the Ministry of Construction, 1987 editions.

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In general the earthquake design provisions of these four countries can be related to one another. Detail description of these codes is beyond the scope of this work and is available in International Association of Earthquake Engineering (IAEE, 1992). A comparison of the design seismic load, specifically in equivalent-static-load method, has been presented later. The Bangladesh National Building Code (1993) provisions related to seismic design follows those of UBC (1991) and, thus, has not been included in the comparative study here. It is worth pointing out that while in IAEE (1992) earthquake code provisions of 37 countries are available, in this study UBC (1994), NBC (1995) and BSLJ (1987) provisions have been incorporated in view of the fact that these codes have evolved through a very detailed process and the concerned countries experienced seismic forces regularly. The inclusion of IS (1984) in this study is due to the fact that India is the closest to Bangladesh and shares the same tectonic zone. Most of the other codes of IAEE (1992) are either explicitly or implicitly based on UBC (1994) and originates from a country having very little or no major earthquake experience.

BASE SHEAR

All the four codes, included in this study, have adopted the pseudostatic method of analysis. In static procedure, equivalent static forces applied at the storey levels replace the time varying inertia forces. The relative magnitudes of these equivalent static forces are based on simplifying assumptions for mode shapes and mode participation. A comparison of the base shears is the simplest way of comparing the final result. Figure 1 shows base shear coefficient against building period for steel and concrete (ordinary moment resisting frames) structures in the zone of highest seismic action on dense or stiff soil, referred to as soil type 2. A comparison of the base shears of special moment resisting concrete frame with that of intermediate moment resisting concrete frame in the zone of highest seismic action on soil type 2 is shown in Fig. 2. In IS (1984) and NBC (1995) codes the same formula is used to specify the building period. Thus, the base shears specified can be compared directly from the shapes of the curves shown in Figs. 1 and 2. It is noted that for other soil types and zone factors, the amplitude will change but the nature of the curves will remain the same. In view of this, only one zone factor and one soil type have been selected for comparison. Since UBC (1994) and BSLJ (1987) use different formula to determine the building period, the amplitude of the curves cannot be compared directly.

The lateral force provisions of various codes are presented in Table 1 for comparison. It is evident from Table 1 that base shear of an elastic structure, designed following code provisions and subjected to a seismic ground motion, can be characterised by zone factor, importance factor, structural system factor, soil profile dependent numerical coefficient and time period. These factors have been critically evaluated and compared in the following sections.

NBC (1995) includes an extra factor in its code provisions. This factor, called calibration factor U, is applied to maintain the design base shears at the same level of proportion for buildings with good to excellent capability of resisting seismic load consistent with the force modification factor R, as reported by Uzumeri (1995).

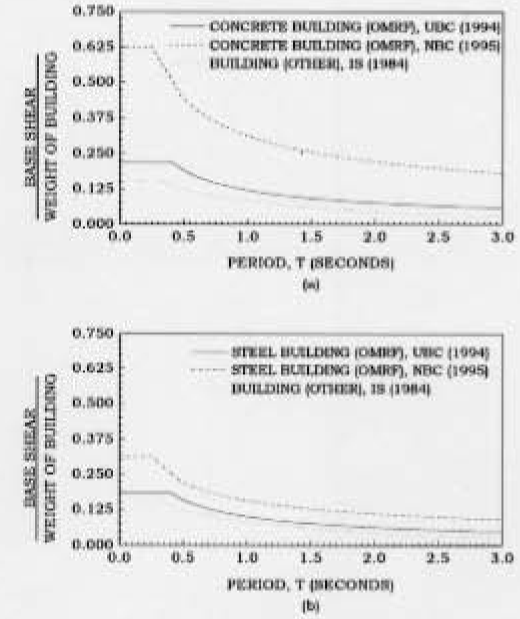

Fig 1. Base Shear coefficient versus building period for (a) ordinary moment resisting concrete buildings and (b) ordinary moment resisting steel buildings

C_0 and A_i are two extra factors BSLJ (1987) includes in its code. C_0 is the standard shear coefficient, which should not be less than 0.2 and 1.0 for moderate earthquake motions and for severe earthquake motions, respectively. A_i is the lateral shear distribution factor, which should be determined by the fundamental natural period and the weight distribution of the buildings, as shown in Fig. 3.

ZONE FACTOR

The term Z is a zone factor, intended to take into account the fact that geographic areas generally differ from each other with regards to the likelihood of earthquakes and also with probable frequency and intensity. Tables 2 to 4 show the zone factors prescribed by various

Table 1 Terms used in UBC (1994), NBC (1995), IS (1984), and BSLJ (1987) for seismic loads.

	Equivalent Term in Four Different Standards			
	UBC (1994)	**NBC (1995)**	**IS (1984)**	**BSLJ (1987)**
Base Shear Formula	$\frac{ZIC}{R_W} W$	$vSIFW\left(\frac{U}{R}\right)$	$KC\beta I\alpha_0 W$	$ZR_tA_iC_0W$
Zone Factor	Z = seismic zone factor.	v = zonal velocity ratio.	α_0 = basic horizontal seismic coefficient.	Z = seismic hazard zoning coefficient.
Importance Factor	I = importance factor depending on occupancy requirements.	I = importance factor.	I = a factor depending upon the soil foundation system.	-
Structural System Factor	R_w = numerical coefficient depending on basic structural system.	R = Force modification factor.	K = performance factor depending on the structural framing system and brittleness or ductility of construction.	-
Numerical Coefficient Depend Upon Soil Profile	$C = \frac{1.25S}{T^{2/3}}$ S = site coefficient for soil characteristics. T = time period of structure.	S = seismic response factor function of fundamental natural period. F= foundation factor depend on soil type and depth.	C = a coefficient defining the flexibility of structure with the increase in number of storeys depending upon fundamental time period T.	R_t = design spectral coefficient, which depends on soil profile and fundamental natural period of the buildings.
Eff. weight of Structure	W = total dead load and applicable portion of other loads.	W = total dead load and applicable portion of live load.	W = total dead load + appropriate amount live load.	W = sum of dead load and applicable portion of live load.
Soil Foundation Factor	-	-	β = a coefficient depending upon the soil-foundation system.	-

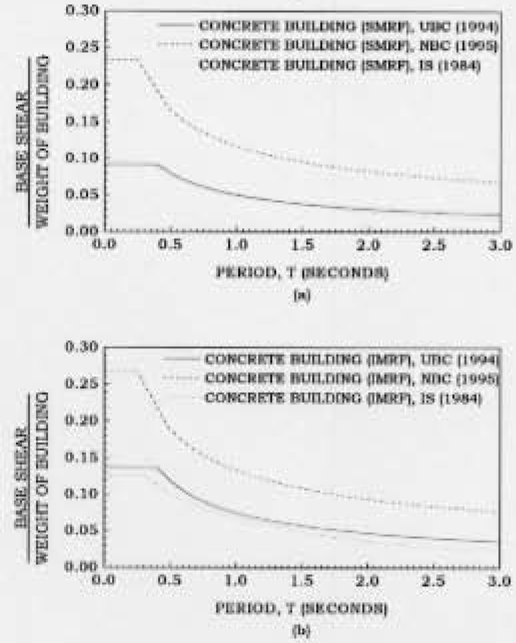

Fig 2. Base Shear coefficient versus building period for concrete (a) special moment resisting frames and (b) intermediate moment resisting frames.

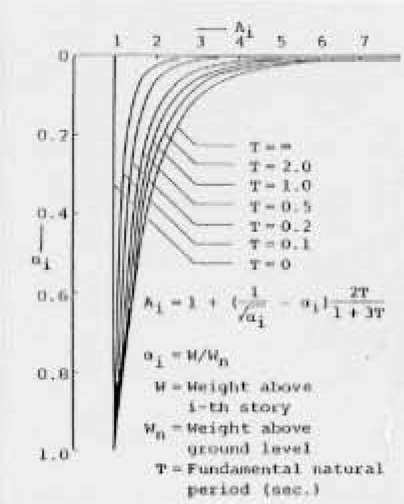

Fig 3 Lateral shear distribution factor A_i. (BSLJ, 1987.)

code provisions under discussion. These zone factors cannot be compared with each other since the seismicity of an area, for zoning purpose, is determined primarily by the historical record of earthquakes and the location, length, and estimated activity of earthquake faults in the region concerned. If there is little or no likelihood of earthquake the value of Z might be taken as zero. Ordinarily any seismic code that employs a zone factor is used in conjunction with a map showing the geographical extent of each zone of a particular seismic intensity.

It must be stressed that seismic zone of a country is not a static endeavour. The philosophy of changing seismic zone is necessary. This should be guided by the changing ideas on the methodology of analysis, available data and improved knowledge of the tectonic of the country. The changes are reflected in the refinements in the knowledge of the location and the arial extent of tectonic features and their correlation with particular seismic events.

It is expected that the increasing refinements taking place in the various approaches, all over the world, to the quantitative seismic evaluations should be reflected in the preparation of the future zone maps of Bangladesh. It should be realised that for obtaining complete information on the seismic status of a country, it is necessary to have a much larger coverage of seismological network than what is currently existing in this country.

Table 2 Seismic Zone Factor of Uniform Building Code, UBC (1994).

Zone	1	2A	2B	3	4
Z	0.075	0.15	0.20	0.30	0.40

Table 3 Definitions of Seismic Zones of Canada, NBC (1995).

Acceleration-Related or Velocity-Related Seismic Zone, Z_a, Z_v	Range of Peak Horizontal Ground Acceleration, g, or Peak Horizontal Ground Velocity, m/s, for 10% Probability of exceedence in 50 years		Zonal Acceleration Ratio, a Zonal Velocity Ratio, v
	Equal to	Less than	
0	0.00	0.04	0.00
1	0.04	0.08	0.05
2	0.08	0.11	0.10
3	0.11	0.16	0.15
4	0.16	0.23	0.20
5	0.23	0.32	0.30
6	0.32 or greater		0.40

Table 4 Values of Basic Seismic Coefficients and Seismic Zone Factors in Different Zones of India, IS (1984).

Zone No	Basic Horizontal Seismic Coefficient
I	0.01
II	0.02
III	0.04
IV	0.05
V	0.08

IMPORTANCE FACTOR

The importance factor *I* establish higher seismic design factors for facilities deemed essential to public welfare and should remain functional for use after a major earthquake. It should be recognised that higher force levels alone do not necessarily improve seismic performance. Experience indicates that independent design review, program of testing and inspection, and involvement of the engineer in the construction process result in a higher standard of structural performance. In addition, it is being recognised that specific damage control measures are a better means of achieving improved performance in lieu of the *I* factor. It should, however, be evaluated that whether special design and construction review/inspection/observation, can provide the same level of overall seismic performance that was intended by the increase load. Thus, giving due care and attention to the factors mentioned above might be more effective than relying solely on increased design force levels. Additional levels of protection might be achieved by providing additional energy dissipation capacity, redundancy in lateral force resisting system, special detailing for damage control, construction quality assurance, and by increasing design force levels.

Past earthquakes have repeatedly demonstrated that good structural performance depends on good design. Damages in several past earthquakes were found to be due to poor compliance to the details of construction specifications. Better performance can be obtained if the design engineer visits the construction site, because he or she is most familiar with the design details and, thus, will more easily detect non-compliance with the construction specifications. These site visits do not constitute detailed inspections and do not supplant any aspect of the testing and inspection by the quality assurance plan and its requirements.

As has been noted in every past earthquake, including the recent Northridge (1994) event, much of the damage can be attributed directly to the construction not complying with the construction specifications and the code. By reviewing the testing and inspection reports, as construction progresses, the design engineer has the opportunity to detect any early non-compliance with the quality assurance program and the construction specifications, and can take steps to have such non-compliance corrected and prevented in later stages of construction.

From the above discussion, it becomes clear that the role of importance factor may be made less significant if design detailing could be ensured in the code of practice. It has been observed that UBC (1994) in its recent version give lower values of importance factor than UBC (1985) and other present day codes of practice. Only BSLJ (1987) does not include any importance factor. Table 5 lists the important factor of different codes of practice.

Table 5 Importance factor range of UBC (1994), NBC (1995), IS (1984), and BSLJ (1987) codes.

Country	Range of Importance Factor
UBC (1994)	1-1.25
NBC (1995)	1-1.50
IS (1984)	1-1.50
BSLJ (1987)	-

STRUCTURAL SYSTEM FACTOR

It would, in most cases, be economically prohibitive to design a building so that it remains elastic at all levels of earthquake ground motions. A fundamental tenet of seismic design is that yielding is allowed to accommodate seismic loading as long as such yielding does not impair the vertical load capacity of the structure. In other words, damage is allowed in the maximum expected earthquake loading case only if it does not pose a significant probability of the structure's collapse. The utilisation of design based on linear analysis methods is reconciled with the allowance of damage from inelastic response by using base shears for linear design that are reduced by a factor from those that would be expected to occur in the fully elastic structure. This factor is called structural system factor and a main feature of the equivalent static method of various codes. This factor represents the ability of the structural system to accommodate loads and dissipate energy more than its allowable stress limit without collapse. In Table 6, the values of structural system factor of various codes have been listed for most ductile as well as usual structures. The ratio of this coefficient for most ductile building to usual building is in the range of 4 to 0.45. The ratio being maximum in NBC (1995) and minimum in BSLJ (1987).

Table 6 Structural system factor of UBC (1994), NBC (1995), IS (1984), and BSLJ (1987) codes.

Code	Coefficient	Most ductile	Usual structure
UBC (1994)	$1/R_w$	$R_w = 12$	$R_w = 4$
NBC (1995)	$1/R$	$R = 4$	$R = 1$
IS (1984)	K	$K = 1.0$	$K = 1.60$
BSLJ (1987)	D_s	$D_s = 0.25$	$D_s = 0.55$

SITE GEOLOGY AND SOIL CHARACTERISTICS FACTORS

Local geology and soil characteristics influence the ground motions at a site. The significance of this influence varies essentially from nil to a very large values. Example may be cited of the Mexico City earthquake of September, 1985, where the lake-bed amplified motions were substantially larger compared to adjacent rock sites, as reported in ATC 3-06 (1978). The three codes under appraisal namely UBC (1994), NBC (1995), and BSLJ (1987), propose an equation for site geology and soil characteristics. In this equation a site coefficient related to the site soil dynamic characteristics is used. The curves have been plotted using such equations of UBC (1994), NBC (1995), BSLJ (1987) and compiled with the curve available for IS (1984) in Fig. 4. Softer soils amplify the response of the site to ground motion and increase the width of the spectrum. Use of the simple approach should be avoided for very soft soils, such as San Francisco bay mud. A site specific soil investigation should be considered where soft soil conditions are encountered.

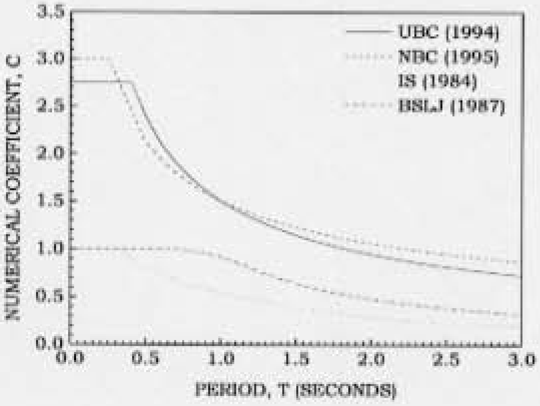

Fig 4. Numerical coefficient C versus structure time period for various codes for soil type 2.

SOIL FOUNDATION FACTOR

Earthquake lateral forces are affected by different types of foundation systems and by variation of ground motion due to various types of soil. The seismic provisions of the IS (1984) incorporate foundation effects by assigning values to a foundation factor β, depending on soil type and types of foundations systems. It is worth noting that this factor has not been incorporated in UBC (1994), NBC (1995), and BSLJ (1987). Inclusion of such parameters in future versions of these codes may be considered only after a detail study on its usefulness.

TIME PERIOD

All codes listed in IAEE (1992) advocate the equivalent static force method for earthquake resistant design of structure upto a certain height. The equivalent static methods adopt seismic coefficient concept for earthquake resistant design of structures to calculate the base shear. Such coefficients are usually fixed on the basis of the recent studies of earthquake engineering based on the spectral analysis of earthquakes. In examining the factors which define the seismic coefficient, attention has to be paid to the evaluation of the response coefficient of the structures. The response coefficient of the structures depends on the natural period of their vibration. Time period of structure should be calculated using the structural properties and deformation characteristics of resisting elements (stiffness and mass characteristics of the structure). Precise determination of the period, as needed in base shear calculation, often constitutes certain difficulties. In the preliminary design when the structural proportions are not known, period may only be determined approximately. Even when a structure is finalised in geometry and proportion, time consuming precise period calculation may not be wise, economically. It may be possible to calculate time period of structures with great accuracy, but since the response spectra is not sensitive to small changes in time period of structures, there is very little need to determine structure time period precisely. Calculation of overall base shear diminishes with increasing building period, as shown in Figs. 1 and 2. Thus, calculation of time period should be such that the value falls in the lower range, resulting in higher value of base shear. A refined calculation of time period leads to its higher values, as shown later, resulting in lower values of base shear. Codes of practice take these factors into account and propose approximate formula for the determination of period of structure. The formula proposed by codes for the determination of period is usually very simple. The empirical formulas of UBC (1994), NBC (1995), IS (1984), and BSLJ (1987) for estimating the natural periods of buildings are tabulated in Table 7 along with the definitions of various variables as defined by various codes.

It is evident from Table 7 that various codes use similar equations for periods. A total of four independent formula could be identified from these codes. They are given below as Eqns. 1 to 4. The definitions of the relevant variables are already given in Table 7.

Formula I: $T = 0.1n$ (1)

Formula II: $T = C_t(h_n)^{1/4}$ (2)

Formula III: $T = hn\ (0.02 + 0.01\ \alpha)$ (3)

Formula IV: $T = \frac{.09h_n}{\sqrt{D_s}}$ (4)

Equations 1 to 4 are intended to provide conservative approximation of period of structures. Figures 5 a, b show the variation of different formulas for the time period of steel (IMRF) and concrete (SMRF) buildings, respectively, against building height.

LIMITATIONS OF CODE PROVISIONS

The main restriction that has been imposed by different codes to the use of equivalent static methods is structural height. In every code regular and irregular structures of certain height can be analysed by equivalent static load method. Table 8 lists height restrictions imposed by different codes.

Table 7 Period estimates of UBC (1994), NBC (1995), IS (1984), and BSLJ (1987) codes.

Code	Formula Suggested
UBC (1994)	$T = C_t (h_n)^{3/4}$ h_n = height in feet above the base to Level n. C_t = 0.035 for steel moment resisting frames C_t = 0.030 for reinforced concrete moment resisting frames and eccentrically braced frames. C_t = 0.020 for all other buildings.
NBC (1995)	T = 0.1N (lateral force resisting system consists of a moment resisting space frame) $T = \frac{.09h_n}{\sqrt{D_s}}$ (other structures) N = total number of storeys above exterior grade to level "n". h_n = height above the base (i = 0) to level "n" in meters. D_s = maximum base dimension of building in meters in direction parallel to the applied seismic force.
IS (1984)	T = 0.1n (moment resisting frames without bracing or shear walls for resisting the lateral loads) $T = \frac{.09H}{\sqrt{d}}$ (all others) n = number of storeys including basement storeys. H = total height of the main structure of the building in meters. d = maximum base dimension of building in metres in direction parallel to the applied seismic force.
BSLJ (1987)	$T = h\,(0.02 + 0.01\,\alpha)$ T = the fundamental natural period of the building in seconds. h = the height of the building in meters. α = the ratio of the total height of stories of steel construction to the height of the building.

Table 8 Height restriction imposed by UBC (1994), NBC (1995), IS (1984), and BSLJ (1987) codes.

Code	Structural height restriction (m)
UBC (1994)	73.15
NBC (1995)	-
IS (1984)	90
BSLJ (1987)	60

NUMERICAL ANALYSIS OF BUILDING

In order to perform the numerical analysis a typical beam column framed structure has been selected. The typical floor plan of the building that was selected for this study is shown in Fig. 6. Base shear of the building which has been calculated for different time periods using the software STRAND6 (1996) has been selected as the criterion for comparison. Response spectrum analysis method has been used here. For the purpose of spectral analysis, base acceleration has been applied to the direction parallel to the short planar dimension of the building. Natural frequencies of buildings have been calculated

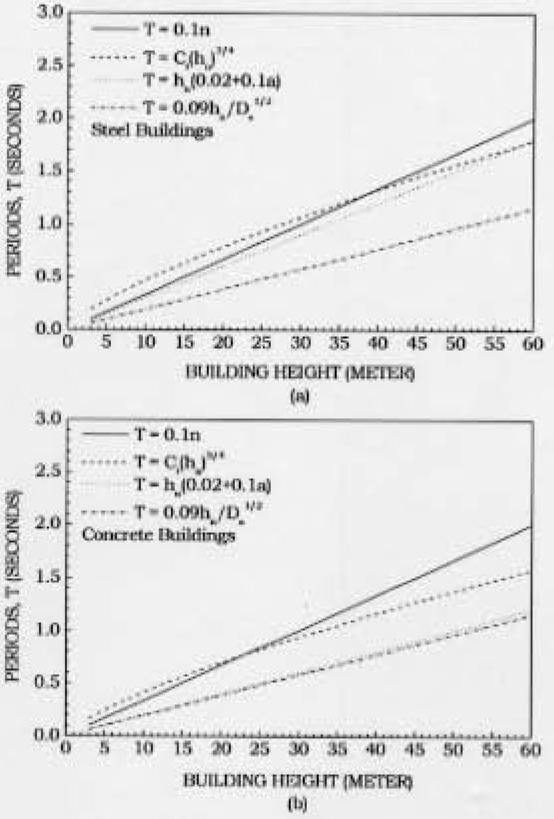

Fig 5. Building height versus fundamental natural period of vibration for (a) steel buildings and (b) concrete buildings.

considering short direction, long direction and the building as a whole. When short or long direction analyses were performed, degrees of freedom of other directions were kept restrained. This has been done to minimise the computer running time. Short direction of the building has been used for further analyses. The importance factor (*I*) and the zone factor (*Z*) have been taken equal to 1.0 and 4.0, respectively, for the purpose of response spectrum analysis. The value of R_w = 12 has been used in the analysis. Square-root-sum of the squares (SRSS) and Complete Quadratic Combination (CQC) methods have been used for combination of modes to get the maximum spectral ordinate. In the present study CQC method with 5 percent of critical damping has been considered for mode combination.

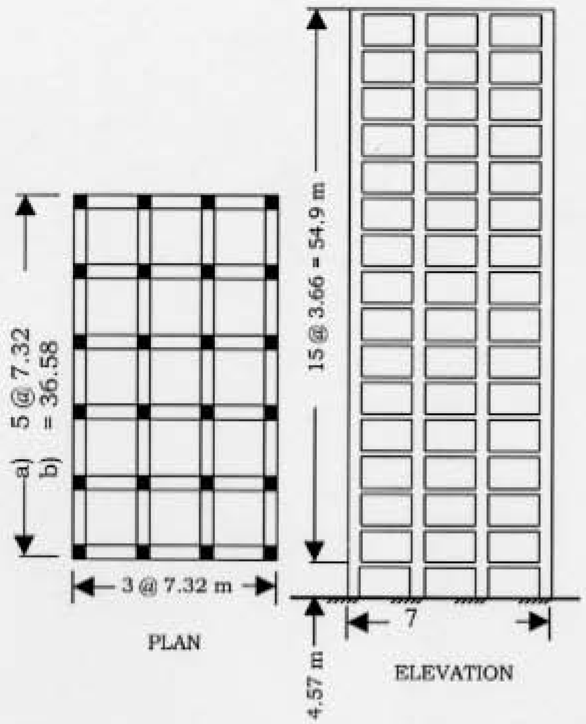

Fig 6. Typical plan and elevation of moment resisting concrete building.

DESCRIPTION OF MODEL BUILDING

A typical floor plan and elevation of the building adopted for this study is shown in the Fig. 6. The floor plan and geometry of the building have been adopted from Ghosh and Domel (1992). The columns, beams and slabs have constant cross section throughout the height of the building. Although the uniformity and symmetry used in this example have been adopted primarily for simplicity, these are generally considered to be sound engineering design concept, which should be utilised wherever practicable for seismic design. Although the member dimensions used in the example are within the practical range, the structure itself is a hypothetical one and has been chosen mainly for research purpose. Superimposed dead load has been taken equal to 42.5 psf (2.06 kN). Weight and ultimate crushing strength of concrete have been take as 150 pcf (23.56 kN/m^3) and 4000 psi (27576 kN/m^2), respectively. The member dimensions selected for this design were, beams 24 in. (60.96 cm) wide x 26 in. (66.04 cm) deep in transverse direction, beams 24 in. (60.96 cm) wide x 20 in. (50.8 cm) deep in longitudinal direction, columns-24 in.(60.96 cm) and slabs-7 in. (17.78 cm) thick.

On the basis of the given data and the dimensions of the building, the weights of the floors are listed in Table 9. It should be noted that the building has the same lateral load resisting system in both the principal directions. Thus, the lateral seismic forces will be the same in both the longitudinal and the transverse directions of the building. However, since the building is rectangular rather than square in plan, the lateral shears produced by torsion will most likely not be equal in the two directions. The weight of a typical floor includes that of all the elements located between two imaginary parallel planes passing through the mid height of the columns above and below the floor considered.

Table 9 Individual storey weight for moment resisting concrete frames.

Floor Level	Weight (kN)
1	6800
2	6654
3	6654
4	6654
5	6654
6	6654
7	6654
8	6654
9	6654
10	6654
11	6654
12	6654
13	6654
14	6654
15	6654
16	6543

ANALYSIS SCHEME

For spectral analysis purposes only one direction, that is, short direction of the building have been selected. This directional analysis has been performed by locking the global degrees of freedom of other direction. As spectral acceleration was applied towards the short dimension of the building, the mode shapes transverse to the direction and torsional mode shapes should have no mass participation factor to the final analysis. To validate this, one analyses have been performed taking 16 storey special moment resisting concrete frames keeping all the degrees of freedoms unlocked. The mass participation factors for both the analyses have been listed in Table 10. It is clearly observed from Table 10 that modes perpendicular to the direction of analysis and torsional modes have no participation to final result. Taking this fact into account and to minimise the time of computer run, short direction analysis scheme has been adopted for further analyses, which is expected to produce equally good accuracy of the analytical analysis. Comparing the total mass participation factors as reported, it can be said that total mass participation factor actually increases when the unnecessary modes which have no contribution to the final result, are excluded.

Table 10 Seismic mass participation factors for 16 storey building. (Soil Type II, UBC, 1994, Whole building.)

Mode	Mass Participation Factor (%)
1	0.00
2	82.08
3	0.00
4	0.00
5	10.60
6	0.00
7	0.00
8	3.30
9	0.00
Total Mass Participation Factor	95.98

COMPARISON OF TIME PERIOD

In this section equations prescribed by different seismic codes of practice have been compared with more refined methods of calculating time period. STRAND6 (1996) has been used to calculate the relatively refined time period of building. STRAND6 (1996) used the following Eqn.5 to get eigenvalues, which eventually gave the natural frequency of the building.

$$[K]\{x\} = \chi[M\{x\}] \quad (5)$$

Here, $[K]$ is the banded stiffness matrix, $\{x\}$ is the eigenvector, χ is the eigenvalues and $[M]$ is mass matrix (Consistent and lumped). The building frame shown in Fig. 6 has two predominant directions - short and long. Natural time period for both the directions and considering the whole building has been calculated and plotted in Fig. 7. It is observed from the Fig. 7 that for moment resisting concrete frame these time periods were independent of building direction. For comparison purpose these time periods are plotted again in Fig. 8 with the approximated formulas proposed by various seismic Code provisions. It is clear from the Fig. 8 that time period calculated using relatively refined method is larger than the code specified approximate formulas which eventually produce less spectral ordinate in response spectrum analysis. It emphasises the fact that further refinement in the equation pertaining to the calculation of time period may not be rewarding.

COMPARISON OF BASE SHEAR

Efforts have been made to compare the base shear calculated using the code specified response spectra with the static base shear. Response spectrum analysis has been used to calculate the base shear of the moment resisting concrete frame. STRAND6 (1996) has been extensively used to perform these computations.

To calculate the base shear for different time periods, height of the moment resisting concrete frames have been varied from storey one to storey sixteen. Spectral analysis has been done for soil types 2. Base shear for a particular building has been found by summing all the

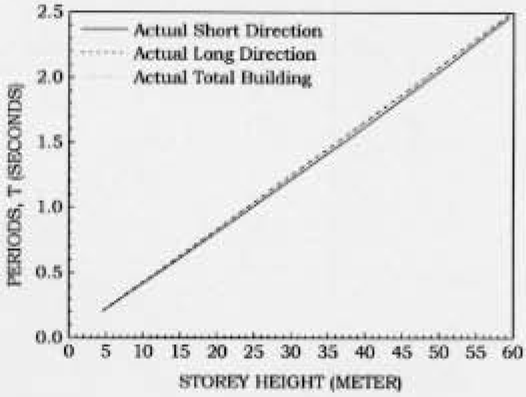

Fig 7. Time period for moment resisting concrete frame considering short, long and total building.

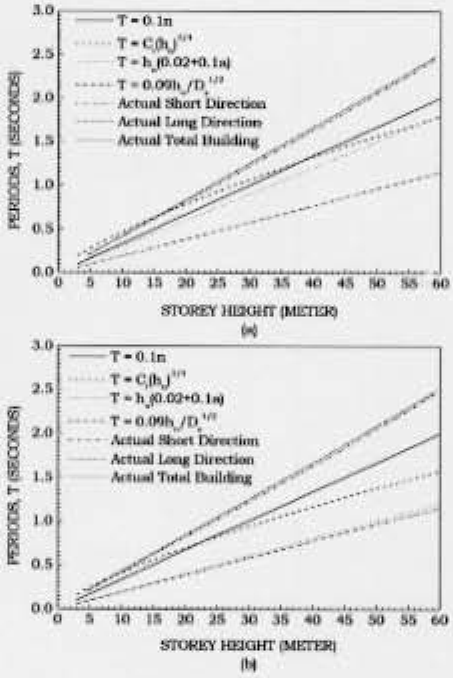

Fig 8. Comparison of more refined method of time period with that of approximate equations propsoed by variouis seismic codes. horizontal

forces of each of the column base for a particular direction. Fig. 9 shows the comparison between code specified base shear and UBC (1994) spectra base shear for soil type 2.

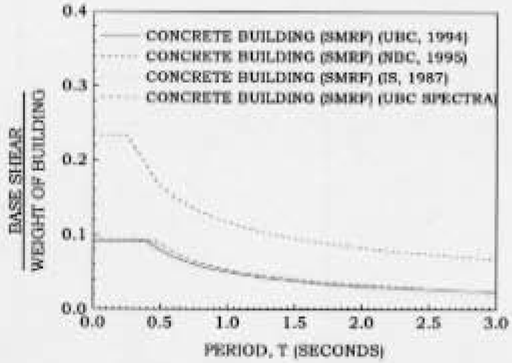

Fig 9. Comparison of base shear coefficient of various codes with UBC (1994) spectra for soil type 2.

COMPARISON OF BASE SHEAR DISTRIBUTION

Base shear distribution has been compared with the corresponding shear distribution proposed by Uniform Building Code (1994). For the purpose of comparison, 16 and 10 storey special moment resisting concrete frames have been selected. In Figs. 10 normalised storey shear is plotted against percent height using UBC (1994) acceleration spectra for soil type 2. Normalised storey shear distribution proposed by UBC (1994) has been included in these figures for comparison. It is observed from these figures that the static storey shear distribution of UBC (1994) adopt linear formula which is absent in spectral solution. It can be said that, further improvement of storey shear distribution can be done for future adoption in seismic codes.

CONCLUDING REMARKS

Almost all the codes, considered here, adopt a similar definition for the various coefficients in the equation of the base shear in the equivalent static method. However, a direct comparison of seismic forces is not possible because there are large differences in the seismic intensity from country to country, leading to differences in the design value of Zone factor Z. The requirements of equivalent static method are primarily intended to provide life safety, not property protection, at the maximum expected earthquake level. Observations of structural systems responding in the inelastic range indicate that as the structure yields, the period, damping, and other dynamic properties change, often substantially. The effect of these changes in dynamic properties is that, while the force levels actually experienced by the structure are greater than those used in the design, they are less than those that would occur in a fully elastic response. The more ductile is the system's performance, the greater is its capacity to accommodate inelastic displacements and forces. The development of earthquake resistant design regulations is considered to be a steady task. It is expected that code provisions are to be revised on regular basis. In future versions of various codes additional factors, such as soil foundation factor, may be incorporated. It is expected that in future seismic conditions will be described in terms of a system of maps with different return periods and that the level of protection will be specified by return periods and construction verification criteria of structures along with the importance of the structures.

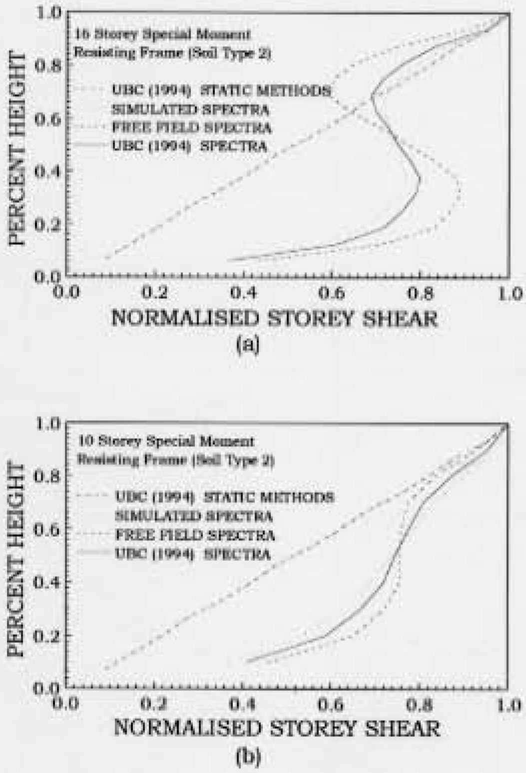

Fig 10. Base shear distribution of 10 and 16 storey moment resisting concrete frame for soil type 2.

From the above discussion it is noted that further refinement in the equation pertaining to the calculation of time period may not be rewarding. Further research may be undertaken in order to improve zone factor, importance factor, site dependent spectral coefficient, and structural system factor.

It has been observed from above discussion that, for directional analysis in three-dimensional analysis any mode shapes transverse to the direction and torsional modes shapes have no participation to the final result of the structure.

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NOTATION

a	Zonal acceleration ratio
C	Numerical coefficient
C_t	Numerical coefficient used in Eqn. 2

D	Depth below ground level
D_s	Maximum base dimension of building in direction parallel to the applied seismic force
H	Total height of building
h_n	Height above base to level "n"
I	Importance factor
K	Structural performance factor
[M]	Mass matrix
N	Total number of storey above ground to level "N"
n	Number of storey to level "n"
R	Force modification factor
R_t	Design spectral coefficient
R_w	Numerical coefficient depend on basic structural system
S	Site coefficient
T	Natural time period
U	Calibration factor used in National Building Code of Canada
v	Zonal velocity ratio
{x}	Eigenvector
Z	Zone factor
Z_a	Acceleration related seismic zone
Z_v	Velocity related seismic zone
α	Ratio of total height of storey of steel construction to height of building
β	Coefficient depend upon soil foundation system
λ	Damping ratio
ν	Zonal velocity ratio
α_0	Basic horizontal seismic coefficient
χ	Eigenvalues

ABBREVIATIONS

BNBC	Bangladesh National Building Code
BSLJ	Building Standard Law of Japan
IAEE	International Association of Earthquake Engineering
IMRF	Intermediate Moment Resisting Frame
IS	Indian Standard Institution
NBC	National Building Code of Canada
OMRF	Ordinary Moment Resisting Frame
SMRF	Special Moment Resisting Frame
UBC	Uniform Building Code