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### **INFLUENCE OF SEISMIC ZONE FACTOR AND THE INTERNATIONAL CODAL PROVISIONS FOR VARIOUS LATERAL LOAD RESISTING SYSTEMS IN MULTI STOREY BUILDINGS**

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#### **ABSTRACT**

Earthquake on 26th January 2001 in Gujarat clearly demonstrated the earthquake vulnerability of India. Almost more than 60% of our land is vulnerable to earthquake of magnitude more than 7. This leads to the professionals to carry out the research on seismic forces that influence on the structures. This paper presents a study on influence of zone factors and the various international codal provisions for various lateral load resisting systems. Special moment resisting frames, shear wall systems and dual systems are taken in the present study. Ductile systems are taken in the study, where inelastic analysis procedures effectively account for several sources of force reduction. In the present study, the main factors which contribute for the seismic load have been studied and dynamic analysis results for various structural systems with various zone factors are compared using various international standards. To illustrate the various seismic parameters governing the seismic forces on the building, analytical study is carried out using ETABS for the various structural systems and the similarities and differences are presented for various international standards. The dynamic analysis results such as modal participating mass ratios, response spectrum base reaction, storey shears, storey displacements and storey drifts are discussed in detail. The influence of zone factor and the codal provisions are discussed when the same building is to be located in different regions and remedial measures if any for their strengthening.

Keywords - seismic analysis, zone factors, international standards, structural systems, time period and mode shapes

## NOMENCLATURE:

$A_h$	-	Design horizontal spectrum value using natural period for a structure
$C_a$	-	Seismic coefficient as per Table 16 Q of UBC 1997
$C_t$	-	Factor used to calculate time period as per UBC 1997 depends on structural scheme
$C(T_1)$	-	Elastic site hazard spectrum for horizontal loading as per NZS 1170.5 - 2004
$C_d(T_1)$	-	Horizontal design action coefficient as per NZS 1170.5 - 2004
$C_h(T)$	-	Spectral shape factor as per NZS 1170.5 - 2004
$C_v$	-	Seismic coefficient as per Table 16 R of UBC 1997
$F_b$	-	Seismic Base Shear as per BS EN 1998-1-2004
$I$	-	Importance factor
$IS$	-	Indian Standards
$MCE$	-	Maximum considered earthquake
$N(T,D)$	-	near fault factor as per NZS 1170.5 - 2004
$N_v$	-	Near source factor as per Table 16 T of UBC 1997
$R$	-	Ductility Factor
$S$	-	Soil factor as per BS EN 1998-1-2004
$Sa/g$	-	Spectral acceleration coefficient
$S_d(T_1)$	-	Design spectrum as per BS EN 1998-1-2004
$Sp$	-	Structural performance factor as per NZS 1170.5 - 2004
$SMRF$	-	Special Moment Resisting System
$T$	-	Fundamental natural period as per UBC 1997
$T_a$	-	Fundamental natural period as per IS 1893(Part 1):2002
$T_B$	-	Lower limit of the period of the constant spectral acceleration as per BS EN 1998
$T_C$	-	Upper limit of the period of the constant spectral acceleration as per BS EN 1998
$T_D$	-	The value defining the beginning of the constant displacement as per BS EN 1998
$UBC$	-	Uniform Building Code
$\frac{V_B}{V}$	-	Base shear calculated from dynamic analysis in kN
$\frac{V_B}{V}$	-	Base shear calculated using fundamental natural period $T_a$ in kN
$V$	-	Total design base shear in kN as per UBC 1997
$V_{max}$	-	Maximum design base shear in kN as per UBC 1997
$V_{min}$	-	Minimum design base shear in kN as per UBC 1997
$W$	-	Seismic weight of structure in kN
$Z$	-	Zone Factor
$a_g$	-	Design ground acceleration as per BS EN 1998-1-2004
$d$	-	Base dimension of building in m
$g$	-	Acceleration due to gravity
$h$	-	Height of the building in m
$k_\mu$	-	Inelastic spectrum scaling factor as per NZS 1170.5 - 2004
$m$	-	Total mass of the building
$q$	-	Behavior factor as per BS EN 1998-1-2004
$\beta$	-	Lower bound factor for horizontal design spectrum as per BS EN 1998-1-2004
$\lambda$	-	Correction factor as per BS EN 1998-1-2004
$\phi$	-	Mode shape coefficient
$\Delta_L$	-	Maximum elastic displacement in mm as per IS 1893(Part 1):2002
$\Delta_s$	-	Maximum elastic displacement in mm as per UBC 1997
$\Delta_m$	-	Maximum inelastic response displacement in mm as per UBC 1997
$\mu$	-	Ductility factor as per NZS 1170.5 - 2004

## **INTRODUCTION**

Earthquakes all over the world have affected the seismic resistant design in different countries and made a revision necessary in many areas. In the present study, the main factors constitute the seismic load have been studied and dynamic analysis results for various structural systems are compared using IS 1893 (Part 1):2002, UBC 1997, NZS 1170.5 – 2004 and BS EN 1998-1-2004. Even though the codes differ in detail, they have essential common features and are comparable.

At first, the codes and their backgrounds are introduced and the design procedures in various codes of practice are described. For calculating the seismic load in each code, the base shear coefficient, seismic zoning, spectral content, fundamental period, structural behavior coefficient, importance factor, effect of soil profile and foundation, and effect of the weight of buildings are precisely discussed and the differences have been mentioned.

This paper deals with a study of influence of various zone factors and the codal provisions provided in IS 1893 (Part 1): 2002, UBC 1997, NZS 1170.5-2004 and BS EN 1998-1-2004. Their similarities and differences are presented with dynamic analysis results carried out using modernized structural engineering software package ETABS for various lateral load resisting structural systems with varying zone factors. Response spectrum analysis is carried out for all four codes of practices for all structural systems considered in this study.

## **LITERATURE REVIEW**

In order to access and to critically evaluate the research work done on the influence of zone factor effect the seismic forces on the structure and the codal provisions for various lateral load resisting structural systems, a detailed review of literature has been undertaken and few of them are listed below.

Hidalgo. P.A et al (1992) studied the comparison of analysis provisions in seismic codes for multi storey buildings subjected to earthquakes and discussed about effects due structural configuration and the model spectral analysis results. Comparison of codal provisions suggested by various countries is studied by Bose et al (1992) and discussed the base shear distribution pattern obtained by dynamic analysis. Thomas Paulay (1983) has given brief review of a deterministic design philosophy with respect to earthquake resisting ductile structures for reinforced concrete buildings and highlighted the capacity design procedures relevant to beams, columns and shear walls. Marjan Faizian et al (2004), studied the international seismic codal provisions and highlighted the factors influence the seismic force. Proper selection of the load carrying system for better performance during earthquake was studied by Moehle et al (1991) and highlighted the redistribution of internal forces in the event of disproportionate collapse. Behavior of reinforced concrete structures with shear wall and infill for seismic forces was studied by Shahabodin.Zaregarizi (2008) and suggested as combination of concrete and brick infill is very effective in resisting the earthquake forces. Noor M.A et al (1997) made critical evaluation and comparison of few sections of the various seismic codes and highlighted the limitations in each code.

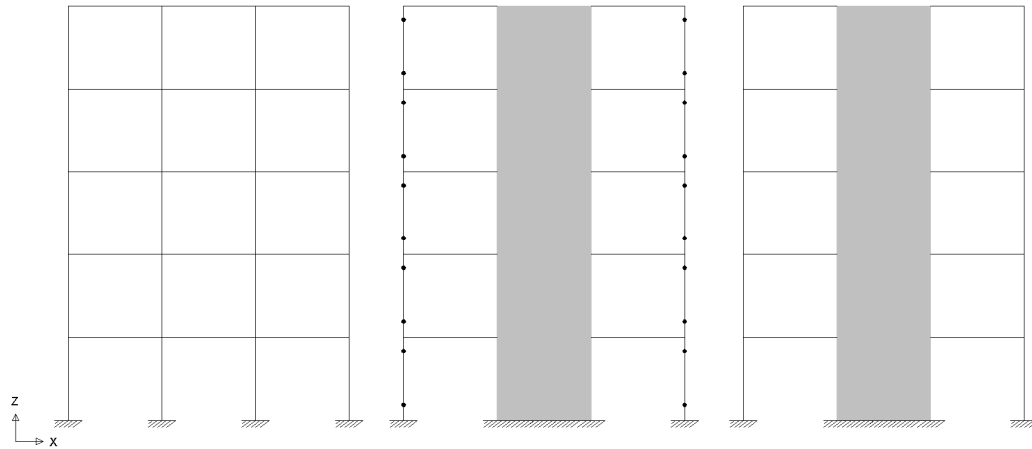
## **PROBLEM REPORTED**

The study is taken on three different lateral load resisting systems namely moment resisting frames, shear wall systems and dual systems. Five storey building is taken in the current study with base dimensions of the building are 10.2x10.2m and the total height of building is 15m. Response spectrum analysis is carried out in all three structural systems for all zones specified in IS 1893 (Part1):2002, UBC 1997, NZS 1170.5 – 2004 and BS EN 1998-1-2004. The structural systems

considered for the current study are shown in Fig. 1 and the dimensions of the structural members are given in Table 1.

Table 1 Member dimensions of the structural systems.

Structural Members	Sizes
Columns	400x600 mm
Walls	100 mm Thick
Beams	400x400mm
Slab Thickness	115 mm Thick



(a) Moment Resisting Frames (b) Shear Wall Systems (c) Dual Systems

Fig. 1 Various Lateral Load Resisting Systems

## METHODOLOGY

Buildings with regular, or nominally irregular plan configuration may be modeled as a system of masses lumped at floor levels with each mass having one degree of freedom, that of lateral displacement in the direction under consideration. Undamped free vibration analysis of entire building modeled as spring - mass model shall be performed using appropriate masses and elastic stiffness of the structural system to obtain natural periods ( $T$ ) and mode shapes  $\{\phi\}$  of those of its modes of vibration that needs to be considered. The number of modes to be used should be such that the sum of total of modal masses of all modes considered is at least 90% of total seismic mass.

Various codes of practices include the effect of seismic risk, spectral content, structural behavior and soil/foundation for seismic load. The seismic storey forces are determined on the basis of a base shear. It is the total design lateral force acting at the bottom of a structure. The base shear is assumed to be depending on all or some of the following factors:

- a. Time period
- b. Seismic activity of the region
- c. Importance of the structure
- d. Type of structural system employed
- e. Soil profile
- f. Weight of the structure

## Time Period

Most seismic codes necessitate that structures be designed to resist specified static lateral forces related to the structure and the seismicity of the region. Based on an estimate of the fundamental natural period of the structure, formulas are specified for the base shear. Empirical formulae used to calculate the time period of the structure recommended by all codes of practices. It is based on the height of the structure and the structural systems in all codes of practices. IS code of practice also gives separate empirical equation to calculate the time period of structure with brick infill which considers the base dimensions of the building.

### Zone Factor

Zone factors are given on the basis of expected intensity of the earthquake in different zones. In IS Code, it is given based on the Maximum Considered Earthquake (MCE) and service life of the structure in a zone. IS Code considers 4 zones ranging from low to very severe seismic intensity, where the factor varying from 0.10 to 0.36 respectively. UBC considers 5 zones, factor varying from 0.075 to 0.40. NZS 1170.5 – 2004 considers hazard factor not less than 0.13 and up to 0.60 depends upon locality. Similarly BS EN 1998-1-2004 considers peak ground acceleration from 0.02 to 0.18. Table 2 shows the zone factors as per IS, UBC, NZS and Eurocode code of practices. This research study considers all zones in various codes of practices.

Table 2 Seismic Zone Factor

IS 1893 (Part 1): 2002		UBC 1997		NZS 1170.5 – 2004	BS EN 1998-1-2004
SEISMIC ZONE	Z	SEISMIC ZONE	Z	Hazard Factor Z	Design Ground Acceleration ( $a_g$ )
III	0.16	1	0.075	Considers hazard factor not less than 0.13 and up to 0.60 depends upon locality.	BS EN 1998-1-2004 considers peak ground acceleration from 0.02 to 0.18
IV	0.24	2A	0.15		
V	0.36	2B	0.20		
-	-	3	0.30		
-	-	4	0.40		

### Importance Factor

Importance factor are introduced to account for the varying degrees of importance for various structures. It is a factor used to obtain the design seismic force depending on the functional use of the structure, characterized by hazardous consequences of its failure, its post earthquake functional need, historic value or economic importance.

For residential apartments, importance factor of 1 is considered in IS, UBC and Euro code of practices. NZS code considers the return period factor ( $R=1$ ) which describes the importance level 2 for the residential building. It is found that, all codes of practices consider the same factor for residential building.

### Structural Behavior Coefficient

The concept of ductility estimates the capacity of the structural system and its components to deform prior to collapse, without a substantial loss of strength, but with an important energy amount dissipated. This coefficient considers the ductile performance of the buildings and the values for most ductile structure and usual structure are listed in their respective codes depends upon the structural system selected. The ratio of this coefficient for most ductile building to usual building is varying from 0.2 to 0.67 in various codes of practices. The ratio is maximum in Euro code and minimum in NZS.

### Spectral Content

Design acceleration spectrum refers to a graph of maximum acceleration as a function of natural frequency or natural period of vibration in single degree of freedom system for a specified damping ratio, to be used in design of structure. Also it depends upon the soil profile. The value of damping for the structure is taken as 2% and 5% of the critical for the dynamic analysis of steel and reinforced concrete buildings respectively. The standard spectrum is developed for 5% damping in all code of practices. BS EN 1998-1-2004 provides type 1 and type 2 spectra in which type 1 is used for the surface wave magnitude greater than 5.5 and latter is used for magnitude less than 5.5. Comparison of Elastic response spectrum curve of IS 1893 (Part 1): 2002 and UBC 1997 for various zone factors specified in their respective codes are shown in Fig.2.

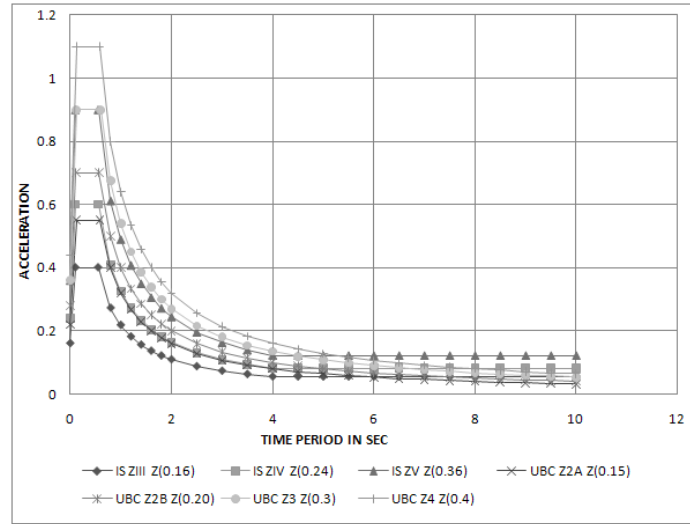


Fig. 2 Elastic Response Spectra for IS-Type II (Medium Soil) & UBC-Stiff Soil (Type SD) for 5% Damping

### Seismic Weight

The Seismic weight of each floor is its full dead load plus appropriate portion of live load is considered during the seismic mass participation in IS code, whereas UBC neglects the live load except in storage and warehouse occupancies where the portion of live load is accounted. NZS considers full dead load plus 30% of imposed load and Euro code considers full dead load plus 24% of imposed load during seismic mass participation.

### Base Shear Calculation

Method of calculation of base shear of the structure is explained below for IS 1893 (Part 1): 2002, UBC 1997, NZS 1170.5 – 2004 and BS EN 1998 -1: 2004.

#### IS 1893 (part 1): 2002

- a.  $\overline{V}_B = A_h * W$  As per Clause 7.5.3 of IS 1893 (Part 1):2002
- b.  $A_h = (Z/2 * I/R * S_a/g)$  As per Clause 6.4.2 of IS 1893 (Part 1):2002
- c. For medium soil,  $(S_a/g) = 1.36/ T_a$  As per Clause 6.4.5 of IS 1893 (Part 1):2002
- d. Fundamental natural period:
  1. With infill:  $T_a = 0.09 * h / \text{sqrt}(d)$  As per Clause 7.6.2 of IS 1893 (Part 1):2002
  2. Without infill:  $T_a = 0.075 * h^{0.75}$  for RC frame building As per Clause 7.6.1 of IS 1893 (Part 1):2002

- e. The design base shear  $V_B$  from the dynamic analysis shall be compared with base shear  $\overline{V}_B$  calculated using a fundamental period  $T_a$ , as given by empirical formula of clause 7.6 of IS 1893 (Part 1):2002. Where  $V_B$  is less than  $\overline{V}_B$ , all the response quantities shall be multiplied by  $\overline{V}_B / V_B$ .

#### UBC 1997

- a.  $V = C_v * I * W / (R * T)$  As per Clause (30-4) of UBC 1997  
 b.  $V_{\max} = 2.5 * C_a * I * W / R$  As per Clause (30-5) of UBC 1997  
 c.  $V_{\min} = 0.11 * C_a * I * W$  As per Clause (30-6) of UBC 1997  
 d.  $V_{\min} = 0.80 * Z * N_v * I * W / R$  In addition for seismic zone 4 as per Clause (30-7)  
 e. Fundamental natural period:  
 $T = C_t * h^{0.75}$   
 Where  $C_t = 0.0853$  for steel moment resisting frames  
 Where  $C_t = 0.0731$  for reinforced concrete moment resisting frames and eccentrically braced frames  
 Where  $C_t = 0.0488$  for all other buildings

#### NZS 1170 -5: 2004

- a.  $V = C_d(T_1) W$  As per Clause 6.2.1.2 of NZS 1170.5 - 2004  
 b.  $C_d(T_1) = C(T_1) S_p / k\mu$  As per Clause 5.2.1.1 of NZS 1170.5 - 2004  
 c.  $C(T_1) = Ch(T) Z R N(T,D)$  As per Clause 3.1.1 of NZS 1170.5 - 2004  
 d. Fundamental natural period:  
 e.  $T_1 = 1.25 K_t h^{0.75}$  As per Clause 4.1.2.2 of NZS 1170.5 – 2004 (Commentary)  
 Where  $K_t = 0.075$  - for moment resisting concrete frame  
 Where  $K_t = 0.050$  - for all other frames

#### BS EN 1998 -1: 2004

- a.  $F_b = S_d(T_1) \cdot m \cdot \lambda$  As per Clause 4.3.3.2.2 (1) of BS EN 1998  
 Where Design Spectrum  $S_d(T_1)$  shall be defined from the following expression.  
 $0 \leq T \leq T_B : S_d(T_1) = a_g \cdot S \cdot \left[ \frac{2}{3} + \frac{T}{T_B} \cdot \left( \frac{2.5}{q} - \frac{2}{3} \right) \right]$  As per Clause 3.2.2.5 of BS EN 1998  
 $T_B \leq T \leq T_C : S_d(T_1) = a_g \cdot S \cdot \frac{2.5}{q}$  As per Clause 3.2.2.5 of BS EN 1998  
 $T_C \leq T \leq T_D : S_d(T_1) = a_g \cdot S \cdot \frac{2.5}{q} \left[ \frac{T_C}{T} \right] \geq \beta \cdot a_g$  As per Clause 3.2.2.5 of BS EN 1998  
 $T_D \leq T : S_d(T_1) = a_g \cdot S \cdot \frac{2.5}{q} \left[ \frac{T_C \cdot T_D}{T} \right] \geq \beta \cdot a_g$  As per Clause 3.2.2.5 of BS EN 1998  
 b. Fundamental natural period:  
 $T_1 = 0.075 h^{0.75}$  - for RC frame As per Clause 4.3.3.2.2 (3) of BS EN 1998  
 $T_1 = 0.085 h^{0.75}$  - for steel frame  
 $T_1 = 0.050 h^{0.75}$  - for all other structure

### ANALYSIS RESULTS

Seismic analysis is performed using response spectrum analysis of IS 1893(Part 1):2002, UBC 1997, NZS 1170.5 – 2004 and BS EN 1998-1-2004 for the typical five storey building to be located in different regions with various lateral load resisting systems. Initial modes are found to be in translation for all structural system and excite more than 90% of the total mass. Fig. 3 shows the Comparison of Base Shear for all zone factors in various international standards for Special Moment Resisting Frames. Fig. 4 shows the Comparison of Base Shear for all zone factors in various international standards for Ductile Shear Wall system. Fig. 5 shows the Comparison of Base Shear for all zone factors in various international standards for building with dual system.

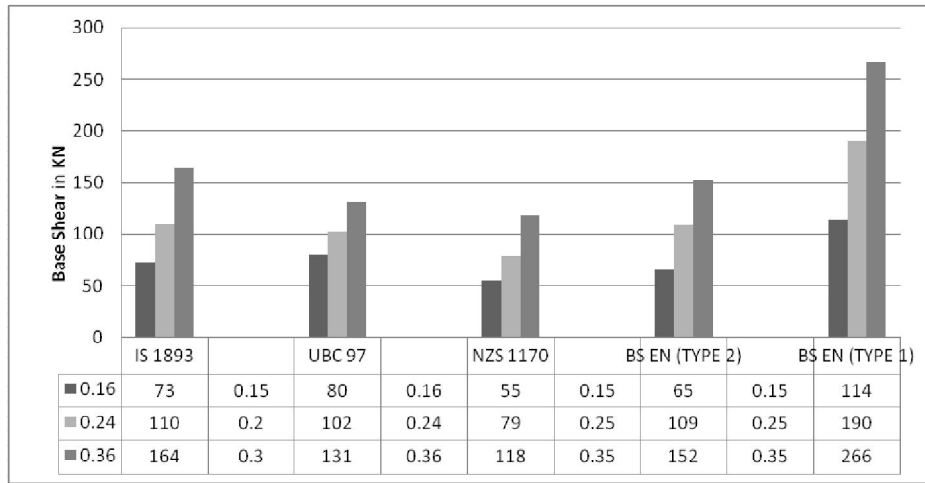


Fig. 3 Comparison of Base Shear in Special Moment Resisting Frame

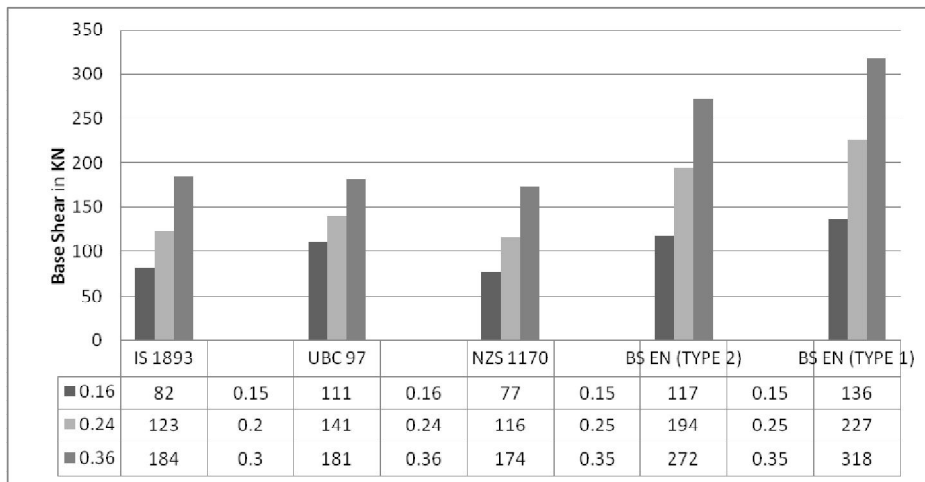


Fig. 4 Comparison of Base Shear in Ductile Shear Wall

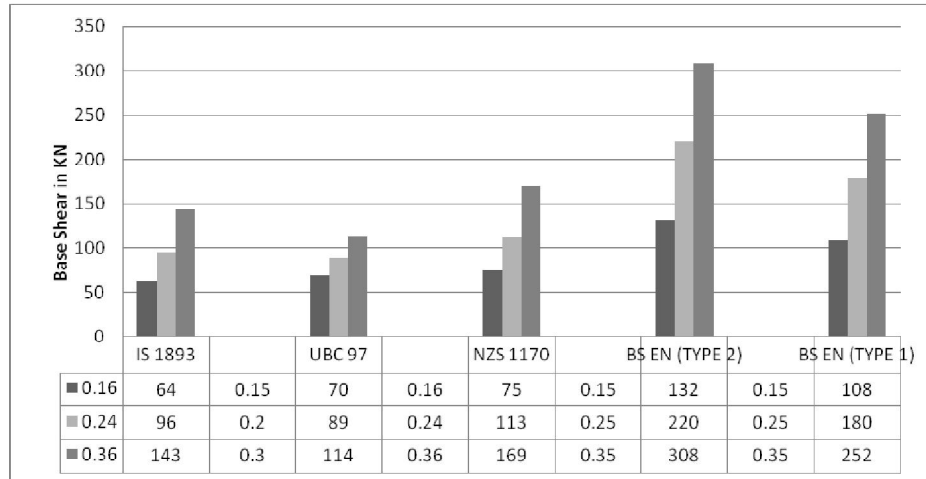


Fig.5 Comparison of Base Shear in Dual System

Type II soil as per IS 1893(Part 1):2002, Type SD category as per UBC 1997, Class C Shallow soil site as per NZS 1170.5 - 2004 and Ground type C as per BS EN 1998 -1 : 2004 are considered for the comparison study of all the structural systems.

As per clause 7.8.2 of IS 1893 the design base shear  $V_B$  shall be compared with base shear  $\overline{V}_B$  calculated using a fundamental period  $T_a$ . It is found from ETABS dynamic analysis, the design base shear  $V_B$  is less than  $\overline{V}_B$  calculated using a fundamental period  $T_a$ , so that all the response quantities such as member forces, displacements, storey forces, storey shear and base reactions shall be multiplied by  $\overline{V}_B / V_B$ . Table 3 shows the Seismic Storey force, Displacement and Storey drift for SMRF system for all zone factor as per IS 1893 (Part 1): 2002.

Table 3 Seismic Storey force, Displacement and Storey drift for SMRF as per IS 1893 (Part 1): 2002

IS 1893 (PART 1) : 2002	SPECIAL MOMENT RESISTING FRAME								
	ZONE III (Z=0.16)			ZONE III (Z=0.24)			ZONE III (Z=0.36)		
	STOREY FORCE (kN)	$\Delta_L$ (mm)	STOREY DRIFT	STOREY FORCE (kN)	$\Delta_L$ (mm)	STOREY DRIFT	STOREY FORCE (kN)	$\Delta_L$ (mm)	STOREY DRIFT
STOREY 5	19.04	5.97	0.44	28.56	8.95	0.66	42.84	13.4	1.00
STOREY 4	18.28	5.53	0.73	27.42	8.29	1.09	41.13	12.4	1.63
STOREY 3	15.47	4.80	1.04	23.21	7.20	1.56	34.81	10.8	2.34
STOREY 2	12.28	3.76	1.45	18.42	5.64	2.17	27.63	8.46	3.25
STOREY 1	7.95	2.31	2.31	11.92	3.47	3.47	17.89	5.21	5.21

The Storey drifts shall be computed using the maximum inelastic response displacement  $\Delta_m$  as per UBC 1997.  $\Delta_m = 0.7 * R * \Delta_s$ , where  $\Delta_s$  is the maximum elastic deformation. Calculated storey drift using the  $\Delta_m$  shall not exceed 0.025 times the storey height for structures having a fundamental period of less than 0.7 second. For structures having a fundamental period of 0.7 second or greater, the calculated storey drift shall not exceed 0.020 times the story height. But in the IS 1893(Part 1):2002 code of practice, the storey drift in any storey due to minimum specified design lateral force, with partial load factor of 1.0, shall not exceed 0.004 times the storey height. As per the BS EN 1998 and NZS 1170.5, the drift limitations are 0.005 and 0.025times the storey height respectively.

## DISCUSSION OF RESULTS

1. Time period of the structure recommended by various international code of practices are based on the height of the structure and the structural system. IS code of practice also gives separate

empirical equation to calculate the time period of structure with brick infill which considers the base dimensions of the building.

2. The number of modes to be used should be such that the sum of total of modal masses of all modes considered is at least 90% of total seismic mass in all code of practices. In the present study, the initial modes are found to be in translation for all structural system based on various codes of practices and excite more than 90% of the total mass.

3. The ratio of the coefficient for most ductile building to usual building is varying from 0.2 to 0.67 on various codes of practices. The ratio is maximum in BS EN 1998 and minimum in NZS 1170.5.

4. The Seismic weight of each floor is its full dead load plus appropriate portion of live load is considered in all codes except the UBC 97 neglects the live load except in storage and warehouse occupancies where the portion of live load is accounted.

5. UBC 1997 recommends the minimum and maximum limitations of base shear which is not included in other codes of practices. Near source factors also taken in the base shear calculation for higher zone in UBC code of practice. Near fault factor is also considered in NZS 1170.5 – 2004.

6. The moment resisting frames are designed to independently resist at least 25 percent of the design seismic base shear for dual systems as per IS 1893(Part 1):2002, but there is no such cases specified in other codes of practices.

7. It is to be found from dynamic analysis of SMRF system that, base shear is lesser in NZS 1170.5 and highest in BS EN 1998(Type 1). 25%, 33% and 52% force higher in IS 1893, UBC 97 and in BS EN 1998(Type 1) respectively compared to NZS 1170.5. In SMRF system, the base shear attracted is high in UBC 1997 compared to IS 1893 in the initial zones, but vice-versa for the higher zones.

8. For dual system with SMRF, the base shear attracted is lesser in IS 1893 and highest in BS EN 1998 (Type 2). 9%, 15% and 52% force higher in UBC 97, NZS 1170.5 and in BS EN 1998(Type 2) respectively compared to IS 1893. For dual system with OMRF, the base shear attracted is high in IS 1893(Part 1):2002 compared to UBC 1977.

9. For the ductile shear wall systems, the base shear is lesser in NZS 1170.5 and highest in BS EN 1998(Type 1). 6%, 31% and 45% force higher in IS 1893, UBC 97 and in BS EN 1998(Type 1) respectively compared to NZS 1170.5.

10. A quantitative comparison of the base shear for the three systems is presented. However their seismic performance during the seismic events will vary. Although the three systems have different attributes, they all have acceptable performance and are expected to behave desirably in seismic events.

## CONCLUSIONS

In the present study, the main factors constitute the seismic load have been studied and dynamic analysis results for various structural systems with various zone factors are compared using in IS 1893 (Part 1):2002, UBC 1997, NZS 1170.5 – 2004 and BS EN 1998-1-2004. Even though various codes differ in detail, they have essential common features and are comparable. All codes of practices include the effect of seismic risk, spectral content, importance of building, structural behavior and soil/foundation for seismic load. To illustrate the various seismic parameters governing the seismic forces on the building, analytical study is carried out using the modernized structural engineering software package ETABS for various structural systems and the similarities and differences are presented for all four codes of practices. The presented approach enables engineers to understand the codal provisions given in IS 1893 (Part 1):2002, UBC 1997, NZS 1170.5 – 2004 and BS EN 1998-1-2004 in relative to another and the influence of zone factor on the effect of seismic forces are discussed when the same building to be located in different regions.

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