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Seismic force evaluation of RC shear wall buildings as per international codes

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Abstract. Seismic codes are the best available guidance on how structures should be designed and constructed to ensure adequate resistance to seismic forces during earthquakes. Seismic provisions of Indian standard code, International building code and European code are applied for buildings with ordinary moment resisting frames and reinforced shear walls at various locations considering the effect of site soil conditions. The study investigates the differences in spectral acceleration coefficient (S_a/g), base shear and storey shear obtained following the seismic provisions in different codes in the analysis of these buildings. Study shows that the provision of shear walls at core in low rise buildings and at all the four corners in high rise buildings gives the least value of base shear.

Keywords: base shear; spectral acceleration coefficient; storey shear; shear wall; natural period; design response spectrum

1. Introduction

Structures were designed without the consideration of seismic load in earlier days. Later, lateral loads were considered in design from the lessons learnt from past earthquakes. Thereafter, it was noticed that structures designed for lateral loads performed significantly better than those designed for gravity load alone. Hence, the importance of considering earthquake forces in the design process was realized and seismic resistant design became a practice. Earthquake codes of various countries are being revised and updated often to decide performance of the buildings precisely based on additional seismic data collected.

Comparison studies on seismic provisions for base shear and storey drift of various international building codes were carried out by Pong *et al*. (2006) and Dogangun (2006). Comparative design using the seismic design provisions of IBC 2000 and UBC 1997 codes and study of variations in base shear and quantity of steel in shear wall were reported by S.K Gosh *et al*. (1999). A comparative study on various ductility classes and corresponding response reduction factors, reinforcement detailing provisions of seismic performance of a ductile RC frame building designed using four major codes, viz. ASCE7 (United States), EN1998-1 (Europe), NZS 1170.5 (New Zealand) and IS 1893 (India) was reported by Singh *et al*. (2012). The significant differences

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existing in basic provisions of four major national seismic building codes ASCE 7, Eurocode 8, NZS 1170.5, and IS 1893 was studied by Khose *et al*. (2012) showing the minimum design base shear, ductility classification and response reduction factor. Comparative study of the seismic provisions of Iranian seismic code and International building code 2003 was carried out by Imashi and Massumi (2011) to determine the seismic forces by static analysis method stated in codes. Codal provisions were compared to prove the need of review of Iranian seismic code and to develop more appropriate relations in achieving economic and functional objectives. Santos *et al*. (2013) have carried out a comparative evaluation of international, European and American, seismic design standards for analysis of conventional buildings. Comparison study between the Chinese Code GB50011-2001 and the International Standard ISO3010:2001 (E), stressing the similarities and differences concerned in design requirements, seismic actions and analytical approaches was carried out by Yayong (2004). Similarities considered in the study were earthquake return period, conceptual design, site classification, structural strength and ductility requirements, deformation limits, response spectra, seismic analysis procedures, isolation and energy dissipation, and nonstructural elements. Comparison of provisions of two building codes, the 1997 Uniform Building Code (UBC) and the 2000-2009 International Building Code (IBC) to evaluate the seismic forces generated from a modal response spectrum analysis for ordinary residential buildings of standard occupancy by considering IBC as the benchmark code was carried out by Nahhas (2011). Pong *et al*. (2007) carried out a study focusing on the differences and similarities between the seismic provisions of the International building code 2003 (IBC 2003) and Mexico's manual of civil works for seismic design (MOC-93) to explore how the static force procedures of both codes differed. Malekpour *et al*. (2011) evaluated performances of the structures designed as per Iranian (Standard No. 2800), European (EC8) and Japanese (BCJ) seismic codes with FEMA-356 and ATC-40 provisions and advantages and disadvantages of the codal provisions were discussed.

Present study attempts a parametric study on determination of differences in spectral acceleration coefficient (Sa/g), base shear and storey shear obtained by the use of different seismic codes in the analysis of RC frame buildings with shear wall over raft foundation assumed to be constructed over different soil sites. Effect of location of shear wall on seismic response is also assessed by considering different positions of shearwall in the building. This comparative study is carried out as per Indian seismic code IS 1893(part1):2002 (IS), Eurocode 8 BS EN 1998-1: 2004 (EC8) and International building code 2012 (IBC).

2. Idealization of structure

Present analysis considers multi-storey reinforced concrete framed buildings of 4, 6, and 16 storeys with and without shear wall on raft foundation. Buildings comprise of ordinary moment resisting frames i.e., of 9 bays of equal length in each direction and the effect of infill is not considered. Shear walls of same size are symmetrically placed in both directions of the building in plan at different locations to study the effect of position of shear wall. Based on various locations of shear walls six different building configurations are generated.

The building frames with and without shear wall was idealised by 3D space frames using standard two node beam element with three translational and three rotational degrees of freedom at each node. Shear wall, roof slab, floor slabs and slab of raft foundation were modelled using four-node plate elements with consideration of adequate thickness. The storey height was chosen as 3 m and length of each bay of all the building frames was chosen as 4 m which is reasonable for domestic or small office buildings. Six different positions of shear walls with thickness varying from 150-250 mm were considered depending on the building height. The dimensions of the building components were arrived on the basis of structural design following the respective Indian standard codes for design of reinforced concrete structures, IS 456:2000 and IS13920:1993. These dimensions are as given in Table 1. Thickness of the raft foundation was taken as 0.3 m. The thickness of floor and roof slab were taken as 0.15 m and beam dimensions as 0.23×0.23 m.The materials considered for design of structural elements were M20 concrete and Fe 415 steel.

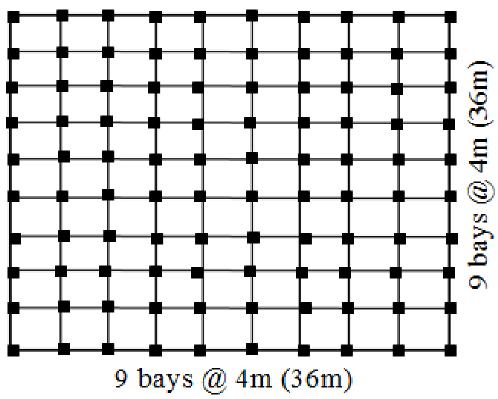
The idealized forms of a typical 9 bay×9 bay frame having plan dimensions of 36 m×36 m with different shear wall locations in the building are represented schematically in Fig.1. Buildings with moment resisting frames alone without shear wall is denoted as 'bare frame' (BF) and 'SW1' to 'SW6' represent the building configurations based on six different locations of shear wall. Shear walls were placed in the core and exterior frames such that the area of shear wall in both principal directions remain the same. Openings in shear walls were not considered assuming additional strengthening and stiffening provided around the openings. These shear walls add 0.81%, 0.78% and 1.3% mass of the bare frames in 4 storey, 6 storey and 16 storey buildings respectively.

The effect of site soil conditions on buildings which are assumed to be constructed over different soil sites was assessed by considering four different soil sites corresponding to soft, stiff, dense and rock. FEMA 273 and FEMA 356 classify such soil profile types from hardest to softest as Sb, Sc, Sd and Se. The details of different soil parameters considered are as tabulated in Table 2.

A typical 16 storied frame-shear wall building on raft foundation and the finite element model of the corresponding idealized structure are as shown in Figs. 2(a)-(b) respectively.

Table 1 Dimensions of components of building

Storeys	Columns (m)		Shear wall thickness (m)
	Up to 3 storey	Above 3 storey	
4	0.32×0.32	0.32×0.32	0.15
6	0.35×0.35	0.35×0.35	0.15
16	0.60×0.60	0.50×0.50	0.25



Bare frame

Fig. 1 Plan of bare frame and frame with various locations of shear wall

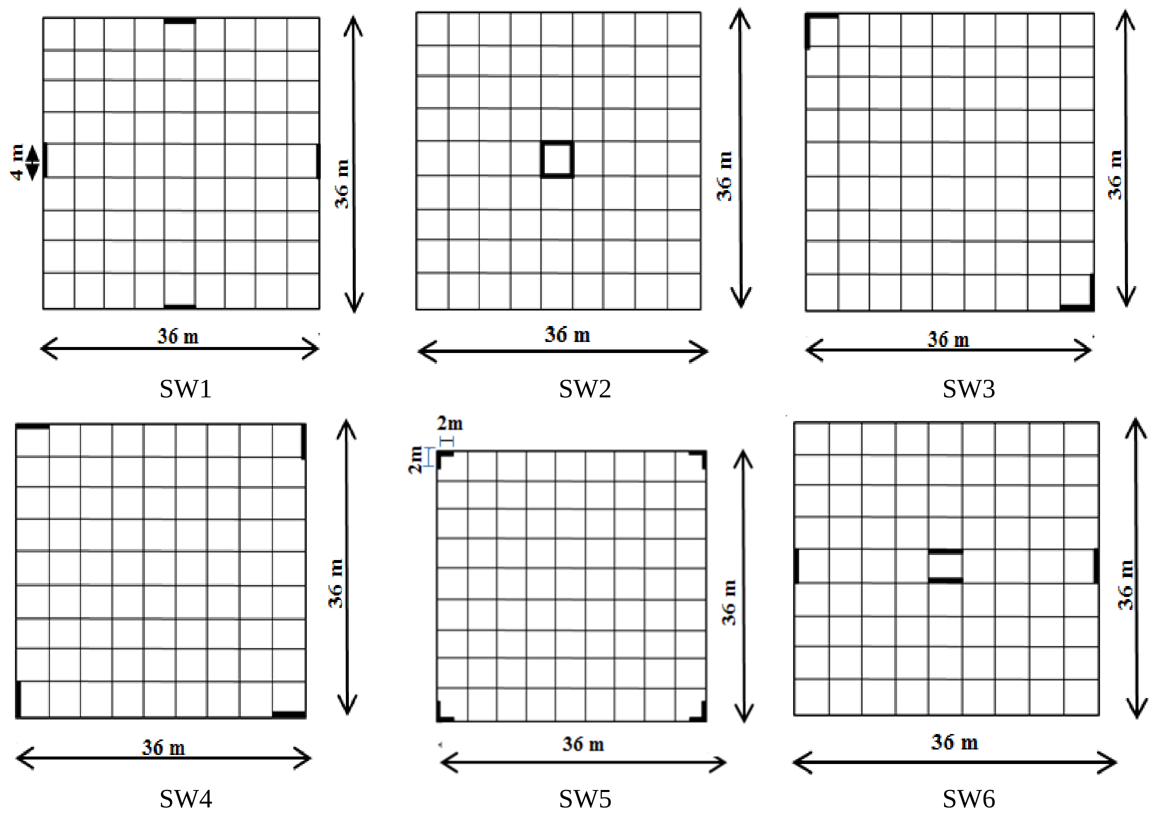
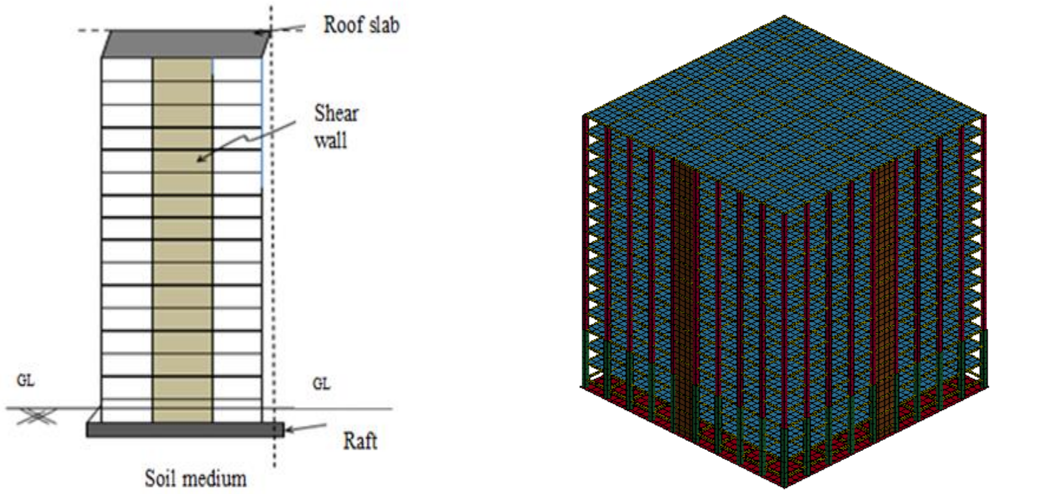


Fig. 1 Continued

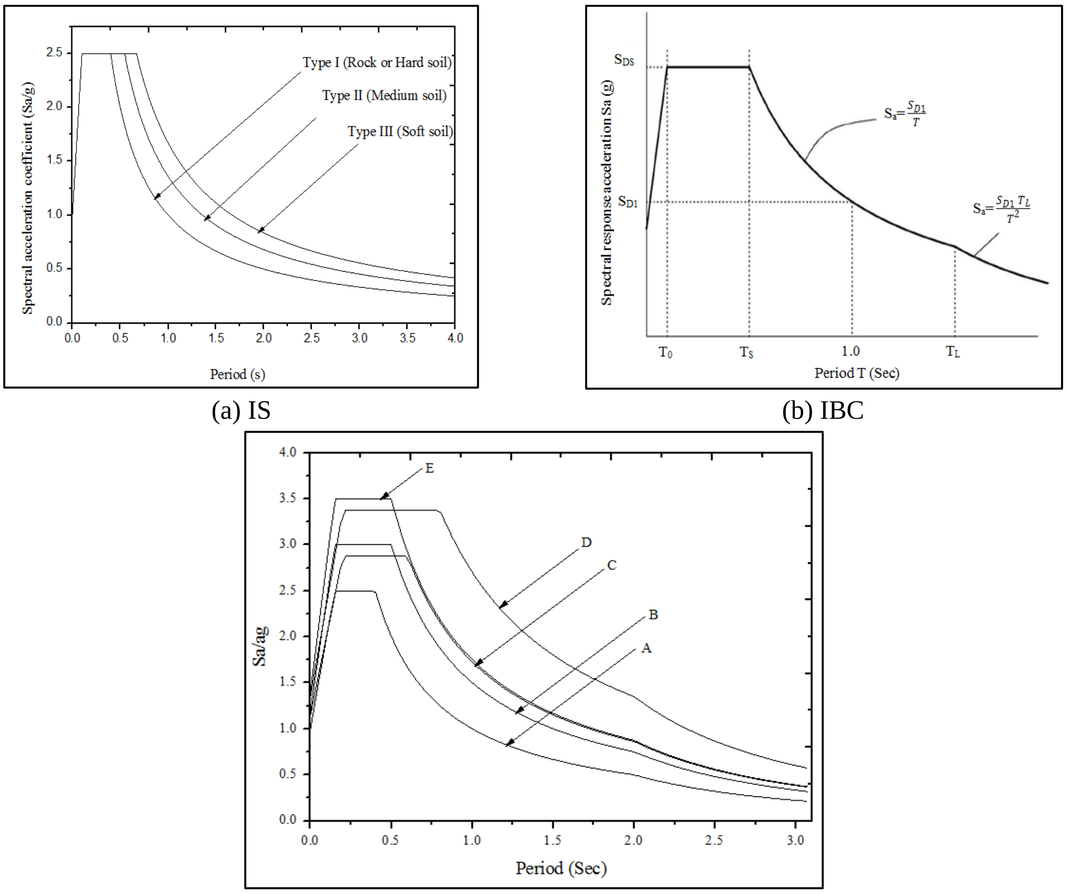


(a) Isometric view (b) Idealized 16 storey frame-shear wall building

Fig. 2 16 storied frame-shear wall building on raft foundation

Table 2 Details of soil parameters [FEMA 273(1997) and FEMA 356 (2000)]

Soil profile type	Description	Shear wave velocity (Vs) (m/sec)	Poission's ratio	Unit weight
Sb	Rock	1200	0.3	22
Sc	Dense soil	600	0.3	20
Sd	Stiff soil	300	0.35	18
Se	Soft soil	150	0.4	16



(a) IS

(b) IBC

(c) EC8

Fig. 3 Design response spectra for 5% damping on various site classes

3. Methodology

The primary parameter in calculation of earthquake forces acting on a structure is its fundamental natural period. Natural period of the structure is essential in estimating the lateral forces and design base shear based on the matching design response spectrum of various codes of practice. Hence, correct assessment of fundamental periods of buildings is very important.

Design response spectrum presents the average smoothened plot of maximum acceleration as a function of time period of vibration for a specified damping ratio for earthquake excitations at the base of a single degree of freedom system equivalent to the structure. Design spectrum represented in IS, EC8 and IBC building codes for varying soil sites are shown in Fig. 3.

The expressions for spectral acceleration coefficient for structures founded on various soil types suggested in different codes are described in the following sections. Different seismic codes classify the soil sites based on shear wave velocity or standard penetration test (SPT) values. Hence for a uniform approach, the equivalent site classes corresponding to the soil profiles considered are mapped as shown in Table 3 according to FEMA 356 (2000) classification.

3.1 Design response spectra and design base shear as per IS1893 (part1):2002

The average spectral acceleration coefficients (S_a/g) corresponding to natural period T (sec) of structures represented as design response spectra in IS 1893 (Fig. 3(a)) for various soil sites are expressed as,

For rocky, or hard soil site

$$\frac{S_a}{g} = \begin{cases} 1+15T; 0.00 \le T \le 0.10 \\ 2.50; 0.10 \le T \le 0.40 \\ 1.00/T; 0.40 \le T \le 4.00 \end{cases}$$

For medium soil site

$$\frac{S_a}{g} = \begin{cases} 1+15T; 0.00 \le T \le 0.10 \\ 2.50; 0.10 \le T \le 0.55 \\ 1.36/T; 0.55 \le T \le 4.00 \end{cases}$$

For soft soil site

$$\frac{S_a}{g} = \begin{cases} 1+15T; 0.00 \le T \le 0.10 \\ 2.50; 0.10 \le T \le 0.67 \\ 1.67/T; 0.67 \le T \le 4.00 \end{cases} \quad (1)$$

The maximum value of S_a/g is 2.5 as per IS 1893.The effect of site soil conditions are significant for structures with natural period more than 0.4 second.

The design base shear which is the total horizontal force on the structure is calculated on the basis of structure mass and fundamental period of vibration and corresponding mode shape. The base shear of structure is calculated in accordance to the formula given below.

$$V_B = A_h W \quad (2)$$

Where,

A_h=Design horizontal seismic coefficient based on the fundamental natural period T in the considered direction of vibration, and

W=Seismic weight of the building.

The design horizontal seismic coefficient Ah for a structure shall be determined by

$$A_h = \frac{ZIS_a}{2Rg} \tag{3}$$

Where,
Z=Zone factor (Table 2 of IS 1893)
I=Importance factor, (Table 6 of 1893)
R=Response reduction factor, (Table 7 of 1893)
S_a/g=Average response acceleration coefficient for rock and soil site

The seismic base shear is distributed throughout the structure in accordance with its mass and stiffness and are expressed as

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{j=1}^{n} W_j h_j^2} \tag{4}$$

Where,
Q_i=Design lateral force at floor i,
W_i=Seismic weight of floor i,
h_i=Height of floor i measured from base and
n=Number of storeys in the building (number of levels at which the masses are located).

3.2 Design response spectra and design base shear as per IBC: 2012

The design response spectrum represented in IBC (Fig. 3(b)) is expressed as

$$\begin{aligned} 0 \le T \le T_0 &: S_a = 0.6\frac{S_{DS}}{T_0}T + 0.4S_{DS} \\ T_0 \le T \le T_s &: S_a = S_{DS} \\ T_S \le T \le T_L &: S_a = \frac{S_{D1}}{T} \\ T_L \le T &: S_a = \frac{S_{D1}T_L}{T^2} \end{aligned} \tag{5}$$

Where,
S_{DS}=Design spectral response acceleration parameter at short periods
S_{D1}=Design spectral response acceleration parameter at 1 second period
T=Fundamental period of the structure (sec)
T_0=$0.2S_{D1}/S_{DS}$
T_S=S_{D1}/S_{DS}
T_L=Long-period transition period

Design acceleration parameters S_{DS} and S_{D1} are determined by the following equation

$$S_{DS} = \frac{2}{3} S_{MS};\ \ S_{D1} = \frac{2}{3} S_{M1} \tag{6}$$

The maximum considered earthquake spectral response accelerations for short period (S_{MS}) and 1-second period (S_{M1}) are as follows

$$S_{MS} = F_a S_S;\ \ S_{M1} = F_v S_1 \tag{7}$$

Where,

F_a and F_v are site coefficients as defined in table 4 and table 5.

S_S=Mapped spectral accelerations for short periods

S_1=Mapped spectral accelerations for a 1-second period

The parameters S_S and S_1 shall be determined from the respective 0.2 sec and 1.0 sec spectral response accelerations specified on the basis of geotechnical site. Maximum values of S_S and S_1 are 1.24 and 0.56 for India.

The seismic base shear, V, as per IBC: 2012 in a given direction is determined in accordance with the following equation

$$V = C_S W \tag{8}$$

Where,

C_s is the seismic response coefficient, and

W is the effective seismic weight.

The seismic response coefficient, C_s, is defined by

$$C_S = \frac{S_{DS}}{\left(\frac{R}{I}\right)} \tag{9}$$

I is the occupancy importance factor, and

R is the response modification factor

The value of C_s computed in accordance with Eq. (9) need not exceed the following

For $T \leq T_L$
$$C_S = \frac{S_{D1}}{T\left(\frac{R}{I}\right)} \tag{10}$$

Table 4 Value of site coefficient F_a

Site Class	Mapped MCE Spectral response acceleration parameter at 0.2 second period				
	$SS \leq 0.25$	SS=0.50	SS=0.75	SS=1.00	$SS \geq 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9

Table 5 Value of site coefficient F_v

Site Class	Mapped MCE Spectral response acceleration parameter at 0.2 second period				
	$S1 \leq 0.1$	$S1=0.2$	$S1=0.3$	$S1=0.4$	$S1 \geq 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4

For $T>T_L$

$$C_S = \frac{S_{D1} T_L}{T^2 \left(\frac{R}{I} \right)} \tag{11}$$

In the above, T_L is long-period transition period

C_s shall not be less than 0.01. In addition, for structures located where $S_1$is equal to or greater than 0.6 g, C_s shall not be less than

$$C_S = \frac{0.5 S_1}{\left(\frac{R}{I} \right)} \tag{12}$$

The lateral seismic force (F_x) induced at any level shall be determined, in accordance with ASCE/SEI 7-05 Section 12.8.3, from the following equations

$$F_x = C_{vx} V \tag{13}$$

$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k} \tag{14}$$

Where,

C_{vx}=Vertical distribution factor,

w_i and w_x=Portion of the total effective seismic weight of the structure (W) located or assigned to level i or x,

h_i and h_x=Height (ft or m) from the base to level i or x,

n=Total number of storeys,

k=An exponent related to the structure period as follows:

for structures having a period of 0.5 s or less, k=1,

for structures having a period of 2.5 s or more, k=2,

for structures having a period between 0.5 and 2.5 s, k shall be 2 or shall be determined by linear interpolation between 1 and 2.

3.3 Design response spectra and seismic base shear as per Eurocode8:2004

Spectral shapes as per EC8 for main site classes are as shown in Fig. 3(c).The ordinates and shapes of response spectrum depend on the seismic hazard level and site class respectively.

The spectral shape represented in Fig. 3(c) are expressed as, (Iervolino 2008)

$$\begin{aligned} 0 \le T \le T_B &: S_e(T) = a_g S\left[1+\frac{T}{T_B}(\eta 2.5-1)\right] \\ T_B \le T \le T_C &: S_e(T) = a_g S\eta 2.5 \\ T_C \le T \le T_D &: S_e(T) = a_g S\eta 2.5\left[\frac{T_C}{T}\right] \\ T_D \le T \le 4s &: S_e(T) = a_g S\eta 2.5\left[\frac{T_C T_D}{T^2}\right] \end{aligned} \tag{15}$$

Where,

T is the vibration period of a linear SDOF;

a_g is the design ground acceleration;

S is the soil factor;

T_B, T_C are the limiting periods of the spectrum's plateau;

T_D is the lowest period of the constant displacement spectral portion;

η is the damping correction factor, and it is equal to one for 5% viscous damping.

To avoid explicit inelastic structural analysis in design, the capacity of the structure to dissipate energy, through mainly ductile behaviour of its elements and/or other mechanisms, is taken into account by performing an elastic analysis based on a response spectrum reduced with respect to the elastic one, called "design spectrum". This reduction is accomplished by introducing the behaviour factor. The behaviour factor is an approximation of the ratio of the seismic forces that the structure would experience if its response was completely elastic with 5% viscous damping, to the seismic forces that may be used in the design, with a conventional elastic analysis model, still ensuring a satisfactory response of the structure.

The upper limit value of the behaviour factor, to be used in conjunction with Eq. (15) to account for energy dissipation capacity, should be greater than or equal to 1.5. In the present study value of behaviour factor is taken as 1.5.

The seismic base shear force F_b, for each horizontal direction in which building is analysed as per EC8: 2004 is given as

Table 6 Spectral shape controlling parameters according to EC8:2004

Site class	S-factor	TB(s)	TC(s)	TD(s)
A	1.00	0.15	0.40	2.00
B	1.20	0.15	0.50	2.00
C	1.15	0.20	0.60	2.00
D	1.35	0.20	0.80	2.00
E	1.40	0.15	0.50	2.00

$$F_b = S_d(T_1) m \lambda \tag{16}$$

Where,

$S_d(T_1)$ is the ordinate of the design spectrum at period T_1.

T_1 is the fundamental period of vibration of the building for lateral motion in the direction considered.

m is the total mass of the building, above the foundation or above the top of a rigid basement.

λ is the correction factor, which is equal to 0.85 if $T_1 \leq 2Tc$ and the building has more than two stories or λ=1.0 otherwise.

When the fundamental mode shape is approximated by horizontal displacements increasing linearly along the height, the horizontal forces F_i should be taken as

$$F_i = F_b \frac{z_i m_i}{\sum_{j=1}^{n} z_j m_j} \tag{17}$$

Where,

F_i is the horizontal force acting on storey *i*;

F_b is the seismic base shear in accordance with Eq. (16)

m_i, m_j are the storey masses computed

z_i, z_j are the heights of the masses m_i and m_j above the level of application of the seismic action (foundation or top of a rigid basement).

The spectral acceleration determined utilizing fundamental natural period *T* of the structure decides the earthquake force on the structure. In the present study, the effect of site class and position of shear walls in buildings assumed to be constructed over different soil sites are assessed as variation in the estimated spectral acceleration and these are compared as per seismic provisions given in different international seismic codes. For this, 4, 6, 16 storey buildings with 36 m×36 m plan dimensions were considered. Moment resistant frames with and without shear walls were considered. The different locations of shear walls form six building configurations. These structures were assumed to be in zone IV with an importance factor of 1. For moment resistant frames the response reduction factor R of 3 and for ductile shear wall buildings R of 4.5 were taken as per IS and equivalent parameters were considered as per IBC and EC8.

Eigen value analysis of 3D finite element models were carried out for buildings with and without shear wall to determine the fundamental natural period 'T' of the structure. Explicit dynamic analysis finite element software LS DYNA was used for this analysis. Realising the fundamental lateral periods of the building frames and shear wall buildings spectral acceleration coefficients (S_a/g) corresponding to the natural period of fixed base structure to be built on different site classes were computed from design response spectrums of IS, EC8 and IBC. The design base shear and lateral forces of the building were further obtained from the corresponding equations specified in building codes. These results were analysed and compared to assess the effect of site class, effect of location of shear wall and the seismic provisions in the codes.

4. Results and discussions

Free vibration analysis was carried out on three dimensional finite element models of RC shear

Table 7 Fundamental lateral natural period of various building configurations

Storeys	Lateral natural period (Sec)						
	Bare frame	SW1	SW2	SW3	SW4	SW5	SW6
4	0.90	0.54	0.72	0.56	0.54	0.65	0.53
6	1.22	0.82	1.00	0.85	0.84	0.97	0.82
16	2.76	2.25	2.17	2.32	2.28	2.51	2.24

wall buildings for computing natural period of buildings. From the lateral natural periods obtained, the corresponding values of S_a/g were computed as per the seismic provisions in various codes. Further the design base shear and lateral force distribution in the building were computed from the corresponding equations specified in building codes. The variations in base shear and storey shear due to the effect of location of shear walls according to various international codes were analysed.

4.1 Lateral natural period

Fundamental natural period has significant role in the seismic response of a structure. The values of natural period obtained for bare frame and frame shear wall buildings from the free vibration analysis of 3D finite element models are as tabulated in the Table 7

It is observed from Table 7 that, the value of natural period increases with increase in height of the building. The values of natural period decreases for shear wall building when compared with bare frame building due to the increase in stiffness of the building by the addition of shear wall. The value of natural period is highest for shear wall type building SW2 and least for shear wall type building SW6 for buildings upto 6 storeys.

In low rise buildings, the shear wall placed at the core is more flexible than other shear wall configurations considered even with the area of shear wall being same for all the building configurations. Hence position of shear wall plays a major role in the value of earthquake forces obtained. But in case of a 16 storey building shear walls of 250 mm thickness are stiffer than in 4 and 6 storeys. Here the configuration SW5 has highest and SW2 the least value of natural period.

4.2 Spectral acceleration coefficient

Spectral acceleration coefficient is the maximum acceleration in an equivalent single degree of freedom structure with same natural period subjected to design basis earthquake excitations for the region. The value of spectral acceleration coefficient for structures founded on various soil types were found from the design response spectrum, suggested in different codes. The natural period of 4, 6 and 16 storey bare frame buildings correspond to the descending curve of design response spectrum. Natural period of 4 storey buildings correspond to the top end and 16 storey buildings to the tail end of the descending curve.

The values of spectral acceleration coefficient obtained for buildings considered as per Indian code, International building code and European code for buildings with fixed base assumed to be constructed over different soil sites are as shown in Fig. 4.

It is observed from Fig. 4 that the value of spectral acceleration increases with decrease in stiffness of the soil in all the building types since the seismic provisions for various site classes are formulated for considering this aspect. The value of spectral acceleration coefficient of bare frames

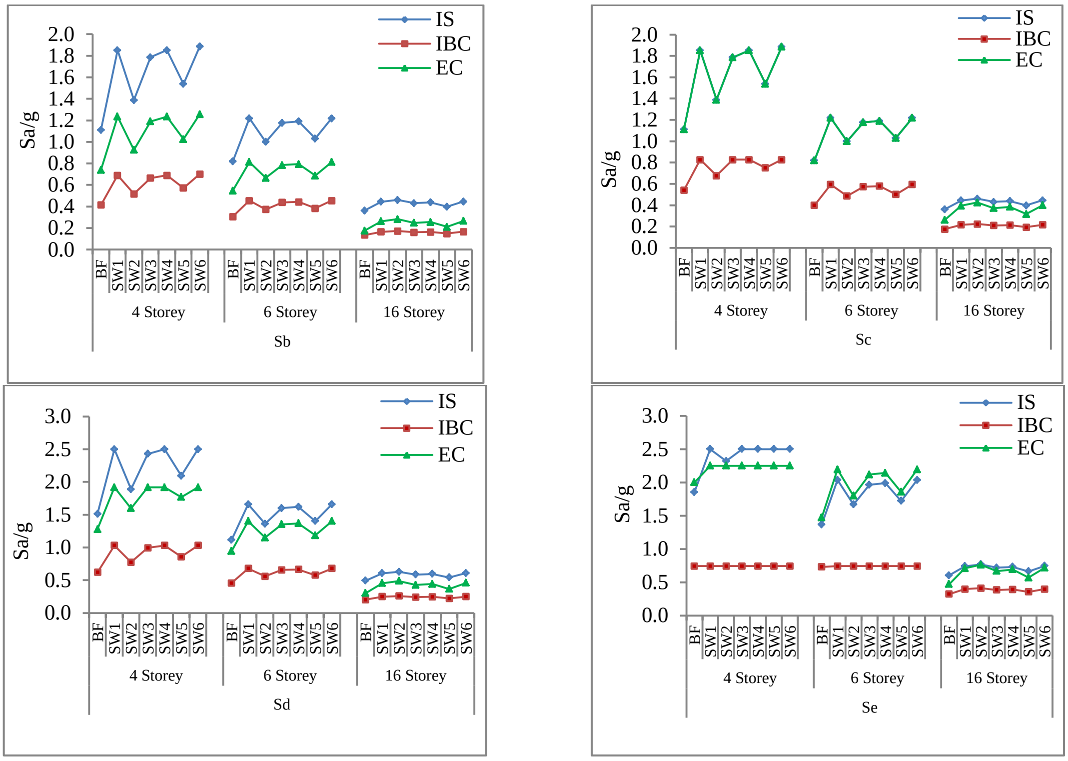


Fig. 4 Value of spectral acceleration coefficient as per IS 1893, IBC and EC8 for various site classes

are pushed to higher value by the addition of shear wall, irrespective of the location considered, due to the reduced natural period of shear wall frame buildings. Among the various shear wall types considered the least variation of spectral acceleration is observed in SW2 for 4 and 6 storey building (lower storeys) and SW5 for 16 storey building when compared with bare frame building.

As per IS code, the values of spectral acceleration corresponding to natural period of four storey SW1,SW4 and SW6 shear wall buildings resting over S_d and S_e soil type lies in the maximum spectral acceleration plateau of design response spectrum leading to higher values of earthquake forces. Whereas, as per IBC code the value of spectral acceleration coefficient obtained for S_d site class is higher than the value obtained for S_e (softest) site class in a 4 storey building for all shear wall positions.

The vital component in estimation of design base shear is spectral acceleration coefficient which is dependent on the primary parameter, the fundamental period T of the building. As the period varies due to the addition of shear walls and considering the interaction with supporting soil the value of spectral acceleration coefficient is apt to shift to high or low values which in turn affect the value of design base shear calculated.

4.3 Design base shear

Seismic base shear reflects the seismic lateral vulnerability and is regarded as one of the primary input in seismic design. Base shear of the buildings with fixed base are acquired from the expressions given in codes for design spectra of 5% critical damping.

Table 8, Table 9 and Table 10 show the values of base shear for bare frame building and corresponding percentage variation in base shear for buildings with shear wall placed at various positions.

It is observed from Tables 8 and 9 that the value of base shear in shear wall building of 6 and 16 storey as per IS and IBC provisions are less than the value of base shear obtained from bare frame building for all positions of shear wall considered. This reduction in the value of base shear even with the increase in mass of the building and spectral acceleration coefficient are due to the factor '*R*' (response reduction factor/response modification factor) used in the calculation of base shear in shear wall buildings. The response modification coefficient '*R*' is the numerical value representing the inherent over strength and global ductility capacity of shear walls as a lateral force resisting system.

The seismic base shear in buildings increase with increase in flexibility of soil. As per IS code provisions, the base shear of buildings in Sd and Se soil sites are 1.36 and 1.67 times of that in hard soil sites Sb. According to IBC seismic provisions, the base shear of buildings in Sc and Sd soil sites are 1.3 and 1.5 times that in hard soil. But in soft soil site Se it is 2.4 times that in Sb site for 6 and 16 storey buildings where as it is only 1.8 times that in Sb site for 4 storey buildings.

As per EC8 seismic provisions, the seismic base shear in buildings increases 1.3 times (4 storey, Sc soil) to 2.7 times (16 storey, Se soil) as compared to buildings in hard soil due to soil flexibility. Since the percentage variation in base shear due to different locations of shear wall as compared to a bare frame is directly proportional to the ratio of natural period of bare frame to natural period of shear wall, the percentage variation in base shear remains the same for each shear wall configuration irrespective of soil site. For buildings with same or maximum spectral acceleration coefficient the percentage variation in base shear across shear wall models remains the same corresponding to each soil site.

Table 8 Value of base shear as per IS 1893

Storey	Soil condition	Base shear in bare frame (kN)	% variation in base shear					
			SW1	SW2	SW3	SW4	SW5	SW6
4	Sb	3928.93	12.02	-15.99	8.02	12.02	-6.94	14.13
	Sc	3928.93	12.02	-15.99	8.02	12.02	-6.94	14.13
	Sd	5343.35	11.19	-15.99	8.02	11.19	-6.94	11.19
	Se	6561.32	-9.45	-15.99	-9.45	-9.45	-9.45	-9.45
6	Sb	4513.90	-0.03	-18.03	-3.56	-2.42	-15.49	-0.03
	Sc	4513.90	-0.03	-18.03	-3.56	-2.42	-15.49	-0.03
	Sd	6138.90	-0.03	-18.03	-3.56	-2.42	-15.49	-0.03
	Se	7538.21	-0.03	-18.03	-3.56	-2.42	-15.49	-0.03
16	Sb	5353.67	-17.16	-14.11	-19.66	-18.25	-25.74	-16.79
	Sc	5353.67	-17.16	-14.11	-19.66	-18.25	-25.74	-16.79
	Sd	7280.98	-17.16	-14.11	-19.66	-18.25	-25.74	-16.79
	Se	8940.62	-17.16	-14.11	-19.66	-18.25	-25.74	-16.79

Table 9 Value of base shear as per IBC

Storey	Soil condition	Base shear in bare frame (kN)	% variation in base shear					
			SW1	SW2	SW3	SW4	SW5	SW6
4	Sb	12169.4	-14.92	-37.00	-18.12	-16.33	-30.45	-14.70
	Sc	15823.5	-22.46	-37.00	-22.46	-22.46	-30.45	-22.46
	Sd	18270.4	-32.85	-37.00	-32.85	-32.85	-32.85	-32.85
	Se	21923.4	-49.59	-49.59	-49.59	-49.59	-49.59	-49.59
6	Sb	13977.6	-25.14	-38.03	-27.74	-26.26	-36.26	-24.92
	Sc	18174.6	-25.14	-38.03	-27.74	-26.26	-36.26	-24.92
	Sd	20985.1	-25.14	-38.03	-27.74	-26.26	-36.26	-24.92
	Se	33576.2	-48.76	-48.76	-48.76	-48.76	-48.76	-48.76
16	Sb	16663.9	-38.03	-35.63	-39.95	-38.81	-44.31	-37.75
	Sc	21667.6	-38.03	-35.63	-39.95	-38.81	-44.31	-37.75
	Sd	25018.3	-38.03	-35.63	-39.95	-38.81	-44.31	-37.75
	Se	40029.3	-38.03	-35.63	-39.95	-38.81	-44.31	-37.75

Table 10 Value of base shear as per EC8

Storey	Soil condition	Base shear in bare frame (kN)	% variation in base shear					
			SW1	SW2	SW3	SW4	SW5	SW6
4	Sb	6675.0	42.82	7.12	37.72	42.82	18.65	45.52
	Sc	8510.7	68.02	26.02	62.02	68.02	39.59	71.19
	Sd	9787.3	51.22	26.02	51.22	51.22	39.59	51.22
	Se	15319.2	13.42	13.42	13.42	13.42	13.42	13.42
6	Sb	7668.9	49.95	22.96	44.66	46.38	26.76	49.95
	Sc	11503.3	27.46	4.51	22.96	24.42	7.75	27.46
	Sd	13228.8	27.46	4.51	22.96	24.42	7.75	27.46
	Se	17600.1	49.95	22.96	44.66	46.38	26.76	49.95
16	Sb	6591.0	52.43	63.87	43.37	48.44	22.48	53.79
	Sc	9886.5	52.43	63.87	43.37	48.44	22.48	53.79
	Sd	11369.5	52.43	63.87	43.37	48.44	22.48	53.79
	Se	17795.7	52.43	63.87	43.37	48.44	22.48	53.79

The values of base shear in shear wall buildings are the highest for buildings of all heights according to the EC8 seismic code provisions except for Sb soil site. As per IS and IBC, the maximum percentage reduction in the value of base shear is observed in SW2 shear wall configuration for 4 and 6 storey building while for 16 storey building SW5 gives maximum percentage reduction over all soil types. However, according to EC8 the maximum percentage variation in base shear for 4 and 6 storeys is observed in SW6 and for 16 storeys in SW2

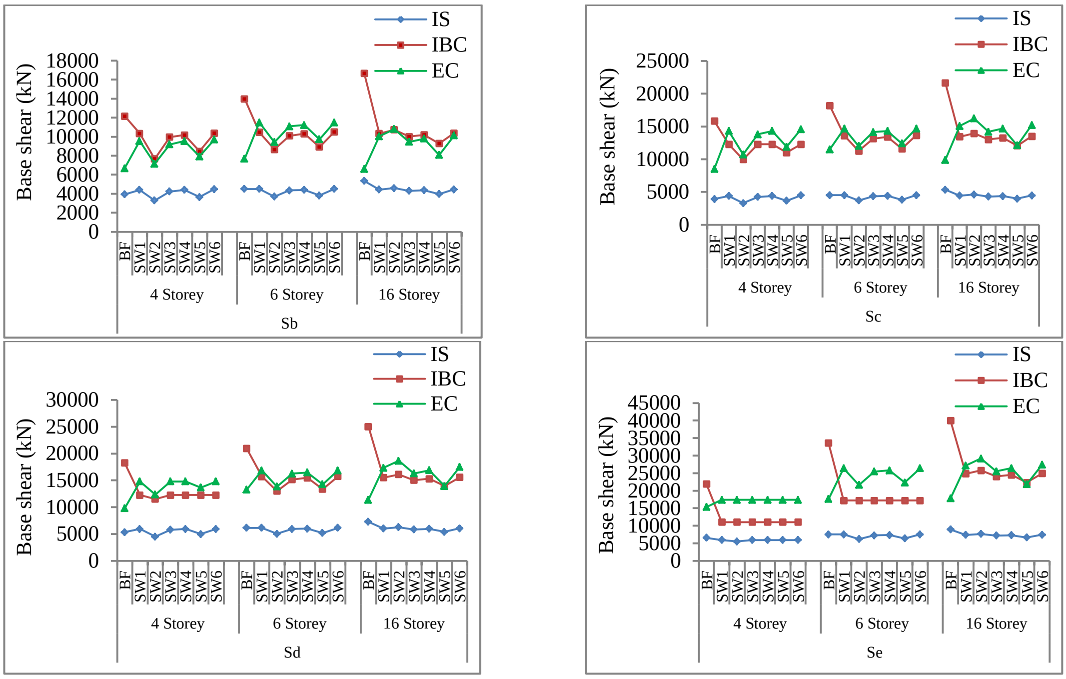


Fig. 5 Variation of base shear in Sb, Sc, Sd and Se soil site as per IS 1893, IBC and EC8

configuration.

The values of base shear obtained from different international seismic code for buildings of varying height with fixed base assumed to be constructed over different soil sites are shown in Fig. 5. From Fig. 5 it is observed that, among all the codes considered in study the value of base shear obtained as per IS code is lowest and EC8 is highest for all the soil site except Sb soil site for 4 and 16 storey. The values of base shear obtained as per EC8 remain high for all shear wall buildings over all the soil site except Sb soil site for 4 and 16 storey. But for bare frame building the seismic base shear as per IBC is the maximum.

4.3 Storey shear

Storey shear is the sum of design lateral forces at all levels above the storey under consideration. In reinforced concrete shear wall buildings the storey shear forces are generally carried by horizontal shear in the wall and in the interface between the wall and beams. Storey shear value as per various international seismic codes are calculated and plotted for buildings with different heights resting on different soil types.

Representative variation in the pattern of distribution of lateral shear force in buildings corresponding to the seismic provisions in IS, EC and IBC are as shown in the Fig. 6. It is observed that the value of storey shear increase with decrease in stiffness of soil i.e., it is highest for the soft soil type (Se) and lowest in hard soil type (Sb). Storey shear found in bare frame buildings as per IBC is highest when compared to other two codes considered. However, storey shear as per EC is highest for shear wall buildings. The value of storey shear obtained as per IS code remains the lowest for all the building types.

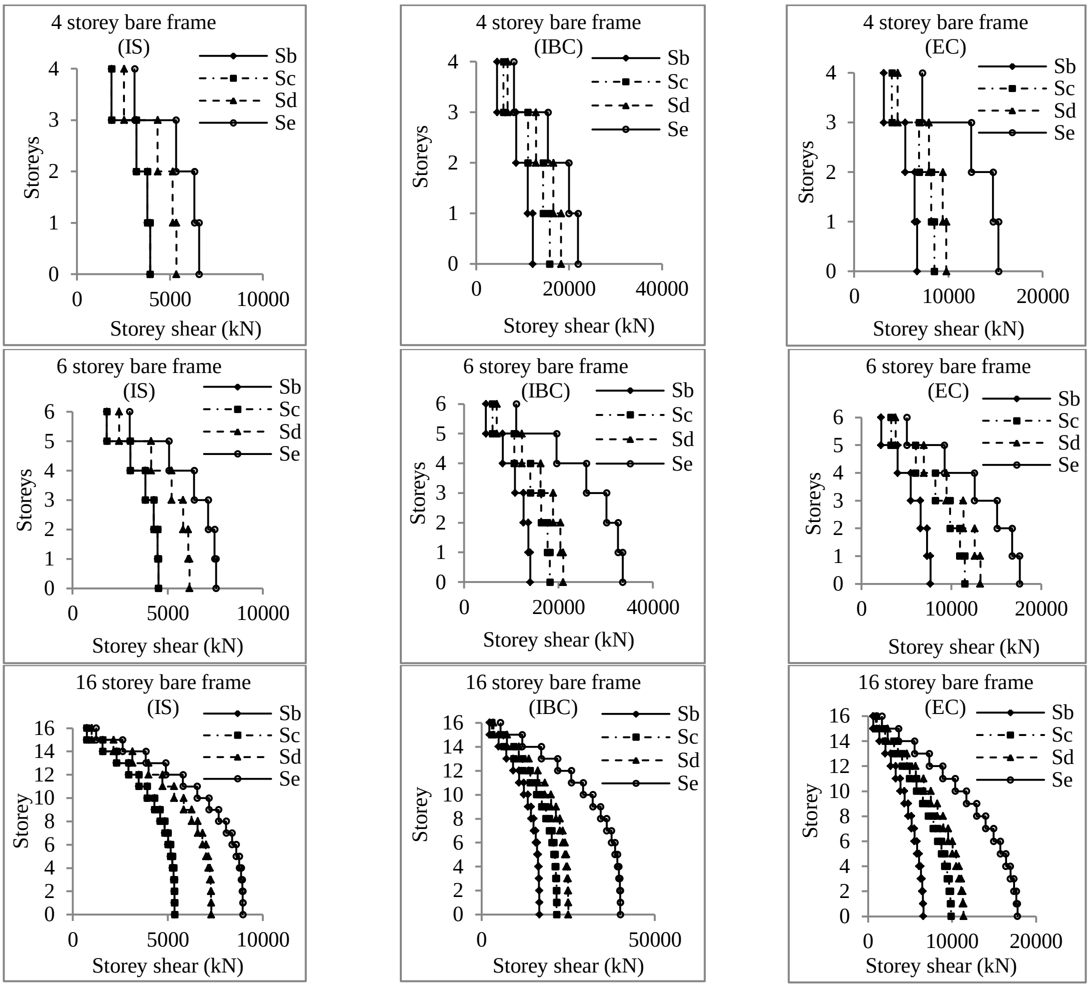


Fig. 6 Variation of storey shear as per Sb, Sc, Sd and Se site classes

5. Conclusions

Analysis of multi-storey reinforced concrete building frames with various positions of shear wall with fixed base assumed to be constructed over different soil sites resulted in the following conclusions.

• IBC and EC8 codal provisions follow the ground type classification based on shear wave velocity of soil whereas it is based on SPT value in IS code.

• Energy dissipation capacity of a structure is accounted by a behavior factor in EC8 and using a response reduction factor (R) in IS code.

• Natural periods of low rise buildings with shear walls placed at core are more than that of buildings with shear walls distributed at exterior frames.

• Positioning of shear walls at core in low rise buildings and positioning of shear walls at the four corners in high rise buildings cause the least increase in spectral acceleration of bare frame buildings.

• In general, spectral acceleration coefficients as per seismic provisions of IS code are higher than the other codes considered.

• The value of base shear increases with increase in flexibility of soil.

• Base shear is the least when shear walls are provided at all the four corners in high rise buildings.

• Base shear is lowest for all buildings as per IS code provisions and highest for bare frame buildings as per IBC.

• Significant differences are observed between the base shear values evaluated using the three international codes (IS, IBC & EC8). EC8 codal provision gives higher value of base shear for shear wall buildings than the IS code and IBC.

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