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SSI Analysis of RC Buildings of various Shear Wall Shapes – A comparative study of various international seismic code provisions

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Abstract: Conventional structural design practice assumes the base of structures to be fixed by neglecting the effect of soil-structure interaction (SSI). During earthquakes, structural displacements and ground displacements are interdependent of each other. This mutual dependency of the structure and soil behaviour is termed as SSI. It is unrealistic to analyse structure by considering it to be fixed. Hence present study looks into the effect of soil flexibility on variation in natural period, spectral acceleration coefficient, and base shear obtained by adopting the seismic provisions of Indian seismic code (IS 1893) and International building code (IBC) in multi-storey reinforced concrete framed buildings with different aspect ratio having rectangular, channel and cylindrical shapes of shear walls over raft foundation. Analysis of 3D models with these three different shear wall shapes founded on four different soil types categorized based on shear wave velocity are been carried out using finite element software LS DYNA. The results show that the SSI effects are substantial in altering the seismic response. The base shear in cylindrical shape shear wall buildings is lowest for buildings with aspect ratio below 3 when compared with other shapes of shear walls.

Keywords: *Base shear, Shear Wall, Soil-structure interaction, Spectral acceleration coefficient*

Introduction:

When the structure is acted upon by the external forces like earthquake, the displacements of structures and ground movement are dependent on each other. However, in practice the effects of soil are generally being neglected by assuming the base of structure to be fixed resulting in variation of responses obtained. Employing the effect of soil in analysis enables the designer to judge the real displacements precisely under seismic motion. The consequences of neglecting the effects of soil in analysis were stated by Mylonakis et al,(1997), Roy and Dutta(2001), Bielak (1975), Stewart et al. (1999) and Bhattacharya and Dutta (2004).

Seismic codes are revised and modified regularly depending on the advancements in researches carried out. Seismic provisions of Indian standard code were revised in 2002 after the destructive Bhuj earthquake which occurred in 2001. Different regions adopt different seismic codes to deal with the varying levels of seismic risk. Hence present study emphasis on studying the differences caused by the use of IS code with internationally adopted IBC code in seismic analysis of building.

A comparative study on evaluation of international seismic design standards for conventional buildings was carried out by Santos et al. (2013). Chandak (2012) performed the response spectrum analysis on reinforced concrete buildings to investigate the differences caused by the use of Indian Standard Code, Uniform Building Code and Euro Code 8.The major differences in basic seismic provisions of ASCE 7, Eurocode 8, NZS 1170.5, and IS 1893 was studied by Khose et al.(2012).A comparative study on various ductility classes and corresponding response reduction factors of ductile RC frame building designed using four major codes was carried out by Singh et.al, (2012).Pong (2006) and Dogangun (2006) performed a comparative study on seismic provisions base shear and story drift for different international building codes.

Present work carry out a parametric study on reinforced concrete building with varied shapes of shear wall by considering the effect of soil flexibility. The variation in lateral natural period, spectral acceleration coefficient (Sa/g) and base shear for buildings viewed to be constructed over different soil sites and founded over different soil types are attempted for IS 1893 and IBC design spectrums. Results of the study are conveyed in terms of dimensionless parameter aspect ratio which is the height-to-base ratio of building (h/r) and relative stiffness of raft (K_{rs}), which is the ratio of absolute stiffness of raft K_r and soil K_s.

Soil–Structure Interaction:

During earthquake, response of the structure is influenced by the motion of supporting soil; simultaneously the response of soil is influenced by the motion of structure. This mutuality of response between the structure and the soil is referred to as SSI. In present study, SSI analysis is carried out on multi-storey reinforced concrete framed buildings of aspect ratio 1, 1.5, 2, 3 and 4 with varied shear wall shapes resting on raft foundation. The effects of soil flexibility are incorporated in analysis using four types of soil based on shear wave velocity.

2.1 Structural Characteristics:

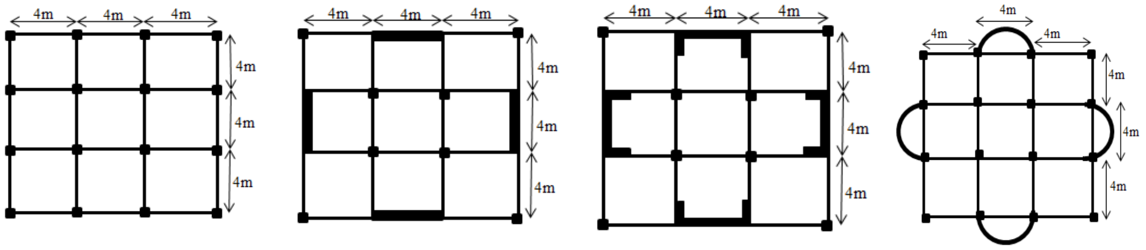
Building considered for the study are ordinary moment resisting frames with 3 bays of equal length in each direction. Plan of the building is symmetric and the effects of infill's are neglected. Varied shapes of shear walls are placed symmetrically in either directions of exterior frame to study the effect of shapes. Storey height and length of each bay of frame were taken as 3m and 4m respectively, regarding the building as domestic or small office building. Dimension of building elements were arrived following the respective Indian standard codes IS 456:2000and IS13920:1993. The details of different geometric parameters of building components are shown in Table 1

***Table 1**: Dimensions of components of building*

h/r	Columns (m)		Shear wall thickness (m)		
	Up to 3 story	Above 3 story	Rectangular	Channel	Cylindrical
1.0	0.32 X 0.32	0.32 X 0.32	0.15	0.09	0.11
1.5	0.35 X 0.35	0.35 X 0.35	0.15	0.09	0.11
2.0	0.40 X 0.40	0.35 X 0.35	0.20	0.12	0.15
3.0	0.50 X 0.50	0.40 X 0.40	0.20	0.12	0.15
4.0	0.60 X 0.60	0.50 X 0.50	0.25	0.15	0.19

Raft foundation slab: 0.3m
Roof and floor slab: 0.15m
Beams : 0.23X0.23m

Thicknesses of shear wall were varied depending on shapes, such that the total mass of structure remains same. M20 grade concrete and Fe 415 grade steel were selected as the materials for design of structural elements. Idealized 3 bay x 3 bay frame having plan dimensions of 12m X 12m with various shapes of shear walls are as presented in Fig. 1.



Bare frame Rectangle Channel Cylindrical

***Figure 1**: Plan of bare frame and frame with various shape of shear wall.*

2.2 Geotechnical Characteristics:

Present study considers four types of non-cohesive soils based on shear wave velocity for the analysis, the details of which are as tabulated in Table 2. Different codes adopt different approach to classify the soil sites. Hence, present study classifies the soil types according to FEMA 273 and FEMA 356for a uniform approach. Mapping of the soil sites according to codes are shown in Table3. The continuum soil medium of study is treated as a homogenous, isotropic and elastic half space medium. Lateral boundaries of soil were placed at a distance of 1.5 times the width of raft foundation and bedrock was assumed to be at a depth of 30 m. Non-reflecting boundaries were modelled along the lateral vertical soil while the bottom boundaries were restricted from translations.

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

Soil profile type	Description	Shear wave velocity (Vs) (m/sec)	Poission's ratio μ	Unit weight (ρ) (kN/m3)	Young's modulus (Es) (kN/m2)
S_b	Rock	1200	0.3	22	8.40E+6
S_c	Dense soil	600	0.3	20	1.91E+6
S_d	Stiff soil	300	0.35	18	4.46E+5
S_e	Soft soil	150	0.4	16	1.03E+5

***Table 3**: Mapping of soil sites of IS and IBC.*

Soil profile type	Description	Equivalent site class	
		IS	IBC
S_b	Rock	Type I	B
S_c	Dense soil	Type I	C
S_d	Stiff soil	Type II	D
S_e	Soft soil	Type III	E

2.3 Finite element modelling:

Finite element modeling and analyses in the present study were carried out using the commercial finite element software LS DYNA. Modelling of building frames were done using standard two node beam element with three translational and three rotational degrees of freedom at each node. Four node shell element having both bending and membrane capabilities with six degrees of freedom at each node were used in modelling of slabs at various storey levels, raft foundation and shear wall. The soil stratum below the raft was modelled using eight-node solid brick element with three translation degrees of freedom. Idealized finite element model of soil–foundation–structure system of 6 storey frame-shear wall building on raft foundation is shown in Fig. 2

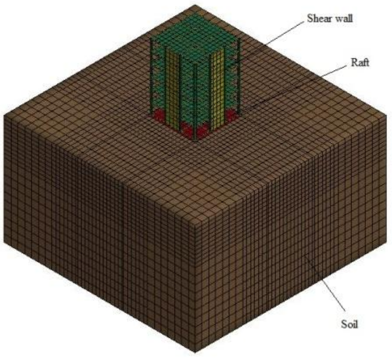
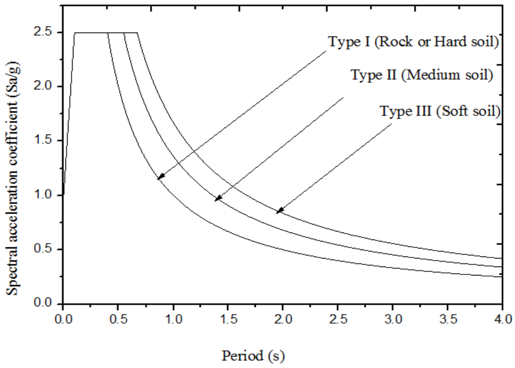


***Figure 2** Elastic 3D Continuum Model of soil and 6 storey shear wall building*

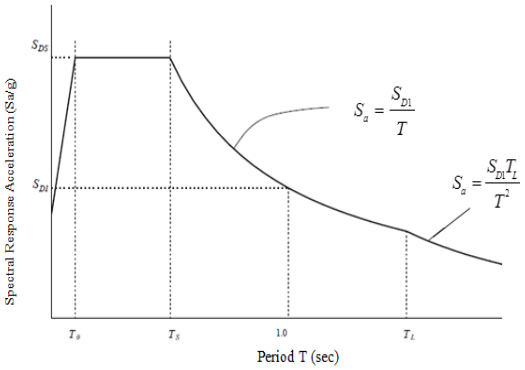
Methodology:

Finite element software LS DYNA was used to determine the fundamental natural period ‘T’ of buildings by Eigen value analysis. Fundamental natural period determined forms the prime parameter in determining the seismic forces of structures. From the design response spectra of IS and IBC codes the spectral acceleration coefficients (Sa/g) corresponding to the natural period of structure were determined. The values of spectral acceleration coefficients thus obtained were utilized to determine the design base shear of buildings using the equations specified in building codes. Results obtained were further analysed and compared to evaluate the effect of varied shear wall shapes, effect of soil flexibility and seismic code provisions.

The design response spectrum of IS and IBC building codes for varying soil sites are shown in Fig. 3 and the corresponding expressions for spectral acceleration coefficient and design base shear are shown in Table 4 and Table 5.



IS 1893(part1):2002.



IBC: 2006

***Figure .3** Design response spectrums for 5% damping*

***Table 4**: Ordinates of elastic design spectra of IS and IBC Codes*

Codes	Spectral acceleration coefficient			
IS	For rocky r hard soil site	For medium soil site	For soft soil site	
	$\frac{S_a}{g} = \begin{cases} 1+15T; 0.00 \le T \le 0.10 \\ 2.50; 0.10 \le T \le 0.40 \\ 1.00/T; 0.40 \le T \le 4.00 \end{cases}$	$\frac{S_a}{g} = \begin{cases} 1+15T; 0.00 \le T \le 0.10 \\ 2.50; 0.10 \le T \le 0.55 \\ 1.36/T; 0.55 \le T \le 4.00 \end{cases}$	$\frac{S_a}{g} = \begin{cases} 1+15T; 0.00 \le T \le 0.10 \\ 2.50; 0.10 \le T \le 0.67 \\ 1.67/T; 0.67 \le T \le 4.00 \end{cases}$	
IBC	$0 \le T \le T_0$	$T_0 \le T \le T_S$	$T_S \le T \le T_L$	$T_L \le T$
	$S_a = 0.6\frac{S_{DS}}{T_0}T + 0.4S_{DS}$	$S_a = S_{DS}$	$S_a = \frac{S_{D1}}{T}$	$S_a = \frac{S_{D1}T_L}{T^2}$

Table 5*: Base shear and storey defined in IS and IBC Codes*

Codes	Design base shear
IS	$V_B = A_h W$, Where $A_h = \frac{ZIS_a}{2Rg}$;
IBC	$V = C_S W$, Where $C_S = \frac{S_{DS}}{\left(\frac{R}{I}\right)} < C_S = \frac{S_{D1}}{T\left(\frac{R}{I}\right)}$ for $T \leq T_L$, $C_S = \frac{S_{D1}T_L}{T^2\left(\frac{R}{I}\right)}$ for $T > T_L$ and > 0.01;

Results in the study are expressed in terms relative stiffness of raft (K_{rs}). The relative stiffness$K_{rs}$is determined based on the recommendation of Hemsely(1998) which is as follows.

$$K_{rs} = \frac{E_r(1-\upsilon_s^2)}{E_s(1-\upsilon_r^2)}\left(\frac{t_r}{B}\right)^3$$

Where,

E_s = Elastic modulus of soil; E_r = Elastic modulus of raft; υ_s = Poisson's ratio of soil;

t_r = thickness of raft; B= width of the raft; υ_r = Poisson's ratio of foundation material;

Influence of K_{rs} on natural period, spectral acceleration and base shear were studied. The analyses were carried out for the value of K_{rs} ranging from 0.00001 to 0.001. Where thelower limit of K_{rs} corresponds to foundation over hard soil and higher limit corresponds to foundation over soft soil.

4. Results and discussions:

SSI studies were conducted on buildings with varied aspect ratio and shear wall shapes. Variations in values of natural period, spectral acceleration coefficient and base shear thus obtained were analysed.

4.1 Lateral natural period:

Lateral natural period being the prime parameter in determination of seismic forces weredeterminedby free vibration analysis of 3D finite element models.Natural period of buildings with fixed base and varying values of $K_{rs}$are as tabulated in Table 6. The variation in natural period of buildings with varying aspect ratio and shear walls shapes are as shown in Fig 4.

From Table 6, it is observed that inclusion of soil flexibility in analysis increases the value of natural period obtained. The valueof natural period increases with increases in the value of Krs and aspect ratio. Highest values of natural period were observed in bare frame buildings and lowest in channel shape shear wall buildings. The highest percentage variation in natural period due to the effect of soil flexibility was observed to be 80% in rectangular shape shear wall building of aspect ratio 1 with K_{rs} value 0.001.

Table 6*: Fundamental lateral natural period*

Aspect ratio (h/r)	Type of building	Natural period				
		Fixed	K_{rs}			
			0.00001	0.00008	0.0001	0.001
1	Bare frame	0.85	1.00	1.00	1.00	1.01
	Rectangular SW	0.25	0.26	0.28	0.34	0.45
	Channel SW	0.23	0.24	0.26	0.30	0.39
	Cylindrical SW	0.26	0.28	0.29	0.35	0.44
1.5	Bare frame	1.19	1.37	1.37	1.37	1.39
	Rectangular SW	0.44	0.45	0.48	0.56	0.71
	Channel SW	0.39	0.40	0.42	0.49	0.60
	Cylindrical SW	0.44	0.46	0.49	0.56	0.69
2	Bare frame	1.50	1.72	1.72	1.73	1.75
	Rectangular SW	0.60	0.64	0.68	0.79	0.99
	Channel SW	0.54	0.56	0.59	0.68	0.83

	Cylindrical SW	0.62	0.65	0.68	0.78	0.96
3	Bare frame	2.19	2.52	2.53	2.54	2.59
	Rectangular SW	1.06	1.10	1.16	1.32	1.61
	Channel SW	0.92	0.94	0.99	1.11	1.34
	Cylindrical SW	1.05	1.09	1.14	1.29	1.54
4	Bare frame	3.03	3.51	3.52	3.56	3.66
	Rectangular SW	1.58	1.64	1.73	1.98	2.42
	Channel SW	1.35	1.38	1.45	1.63	1.96
	Cylindrical SW	1.55	1.60	1.68	1.89	2.26

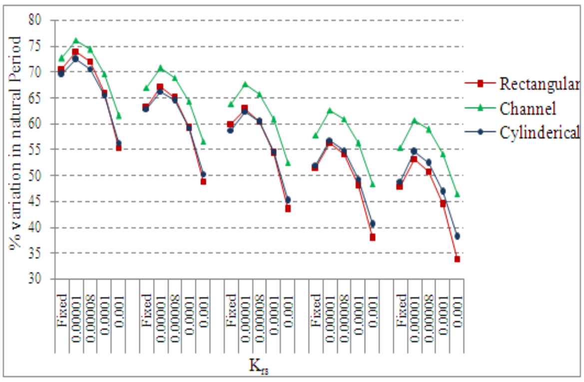


***Figure.4**: Percentage variation in natural period due to effect of shear wall*

It is noted form Fig 4 that percentage variation in natural period due to inclusion of shear wall decreases with increase in value of K_{rs} and aspect ratio. Highest percentage variation in natural period was observed in buildings with channel shape shear wall for all the values of $K_{rs}$and aspect ratio. However, the lowest percentage variationof natural period was observed in rectangular shape shear wall building of aspect ratio 3 and above for all values of K_{rs}.

4.2 Spectral acceleration coefficient:

Spectral acceleration coefficient (Sa/g) refers to maximum acceleration of an equivalent single degree of freedom structure possessing natural period value same as design basis earthquake excitations for the region.It is dependent on the primary parameter natural period T. The spectral acceleration coefficient for buildings with varying aspect ratio and shear walls shapes as per IS and IBC code are shown in Fig 5.

From Fig.5, it is observed that value of Sa/g obtained from IBC code spectra are lesser than the values obtained by IS codes. In general, for the buildings considered the value of Sa/g decreases with increase in aspect ratio. Sa/g values for buildings with fixed base are higher than buildings found on soil. Highest value of Sa/g in shear wall buildings was observed in channel shape shear wall and lowest in cylindrical shape shear wall for aspect ratio 2 and below. However for higher aspect ratios rectangular shape shear wall building shows the lowest Sa/g value. As the value of K_{rs} increases, the variation between the fixed base and SSI increases. The highest percentage variation of 62% as per IS code and 73.5% as per IBC Code was observed in channel shape shear wall building for value of K_{rs} 0.001.

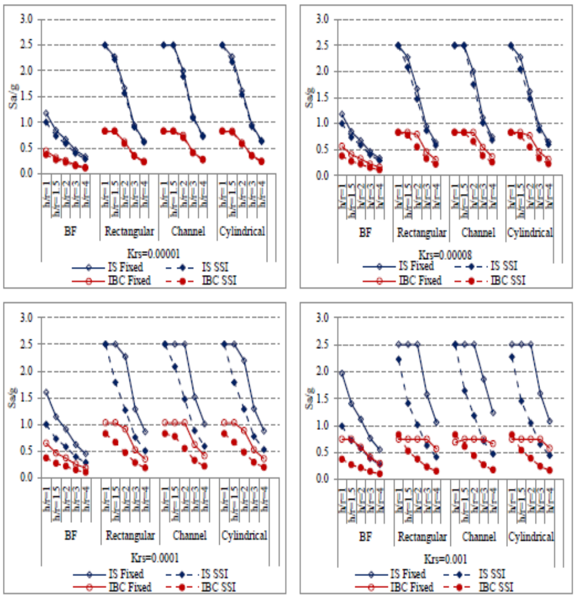


***Figure 5** Value of spectral acceleration coefficient as per IS 1893 and IBC for various site classes.*

Design base shear:

Base shear is stated as; the maximum expected lateral force that is likely to occur at the base of a structure due to seismic ground motion. Value of base shear for buildings with varying shapes of shear walls and K_{rs} values as per IS and IBC codes are as shown in Fig. 6. From Fig. 6 it is observed that the value of base shear obtained as per IBC code are higher than the IS code values. Base shear values and variation in base shear values among fixed base and SSI increases with increase in value of K_{rs}. Lowest value of base shear were observed in cylindrical shape shear wall building of aspect ratio 2 or below. However, for buildings with higher aspect ratios rectangular shape shear wall shows the lowest base shear. Highest value of base shear was observed in channel shape shear wall buildings. The value of base shear increases with increase in aspect ratio for bare frame building. However for shear wall buildings,base shear decreases for buildings of aspect ratio above 2 this is because of the corresponding spectral acceleration coefficient which lies in descending curve of design response spectra.

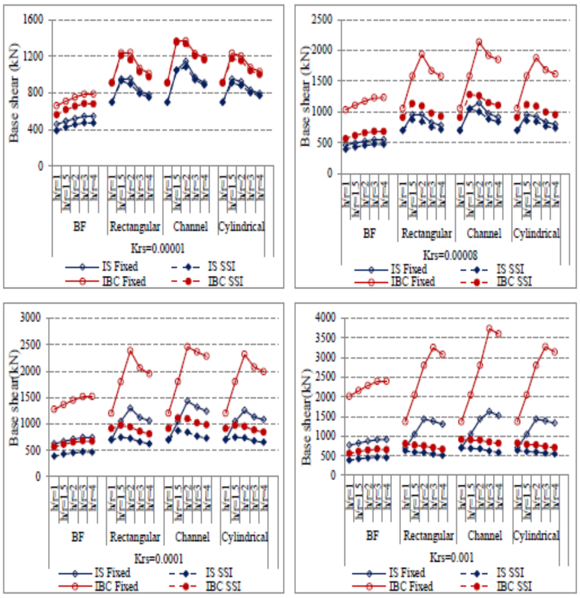


Figure 6 *Base shear values as per IS 1893 and IBC codes.*

Conclusions:

The results of the study led to following conclusions.

- Value of natural periodincreases by considering the effect of soil flexibility in analysis. It increases with increases in the value of Krs and aspect ratio.
- In shear wall buildingsnatural period are lowest in channel shapeshear wall.
- Sa/g values for buildings with fixed base are higher than buildings found on soil. Highest value of Sa/g in shear wall buildings was found in channel shape shear wall.
- Lowest value of base shear is observed in cylindrical shape shear wall buildingsfor aspect ratio 2 or below and in rectangular shape shear wallbuilding for higher aspect ratios.
- Base shear obtained as per IBC code are higher than the IS code values.

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