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Comparative study on effect of soil-structure interaction in buildings with different shape shear walls as per international seismic codes

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ABSTRACT: *Building codes are the most apt guidance available in design and construction of structures to ascertain the adequate resistance to seismic forces. Analyses of structures are mostly carried out by presuming the base of structures to be fixed. Nevertheless, the soil below foundation varies the earthquake loading and lateral forces acting on a structure.Present study investigates the effect of soil flexibility on variation of spectral acceleration coefficient and base shear obtained by following the seismic provisions of Indian seismic code (IS 1893), Euro code (EC8) and international building code (IBC) in RC buildings with various shapes of shear walls .Study shows that the value of base shear obtained as per IBC code in C shape shear wall building is highest compared to other codes.*
Keywords –*Base shear, Design response spectrum, Seismic codes, Shear wall, Soil flexibility, Soil-structure interaction.*

1. INTRODUCTION

During earthquakes, neither the structural displacements nor the ground displacements are independent of each other. However it's a usual practice to analyze and design a buildingbyassumingits base as fixed.Lessons learnt from previous earthquakes of neglecting the effect of soil demonstrate the significance of considering soil-structure interaction (SSI) in the seismic analysis of structures.Seismic response of structure due to SSI depends on both the soil and structure properties.

In seismic design of buildings consequences of soil flexibility are generally ignored. The possible severities of neglecting the effects of the SSI are presented in studies [1], [2] and [3]. Soil flexibility leads tolengthening of lateral natural period of buildings due to reduction in lateral stiffness which in turn alters the seismic response of the building. The study on lengthening of lateral natural period due to soil flexibility is reported in literature [4], [5] and [6].

Different regions follow different seismic codes to handle the differing levels of seismic risk. Seismic codes are reviewed and modified often to find performance of the buildings precisely based on additional seismic data collected.A comparative study on seismic provisions such as base shear and story drift for different international building codes is done by [7] and [8].Seismic design provisions of IBC 2000 and UBC 1997 codes were compared by [9] stating the variations in base shear and quantity of steel in shear wall. Similar comparative studies on various ductility classes and corresponding response reduction factors of ductile RC frame building designed using ASCE7 (United States), EN1998-1 (Europe), NZS 1170.5 (New Zealand) and IS 1893 (India) was carried out by [10].

Present study attempts a parametric study in determiningthe variation in lateral natural period, spectral acceleration coefficient (Sa/g)and base shear using IS 1893, EC8 and IBC design spectrum for buildings with different shapes of shear walls assumed to be constructed over different soil sites and founded over different soil types.

2. SOIL-STRUCTURE INTERACTION ANALYSIS

Present analysis considers multi storey reinforced concrete framed buildings resting on raft foundation with and without shear wall. Ordinary moment resisting frame building neglecting the effect of infill were considered. To study the effect of various shapes of shear wall, shear walls of rectangular, I and C Shapes were selected. Four types of soil classes based on shear wave velocity were considered to incorporate the effect of soil flexibility in the study

2.1 Structural Idealization

Modelling ofbuilding frames with and without shear wall as 3D space frames were made using standard two node beam element with three translational and three rotational degrees of freedom at each node and slabs at different storey level, shear wall and foundation were modelled using four-node plate elements with consideration of adequate thickness. The storey height of building frames were chosen as 3 m and length of each bay as 4 m which is rational for domestic or small office buildings. Reckoning on the building height, thickness of shear walls of varying shape were varied from 150- 250 mm.The dimensions of building components were arrived from Indian standard codes [11] and [12]. The dimensions of buildings components are as noted in Table 1.

TABLE 1: Dimensions of components of building

Storeys	Columns (m)		Shear wall thickness (m)
	Up to 3 story	Above 3 story	
4	0.32 X 0.32	0.32 X 0.32	0.15
6	0.35 X 0.35	0.35 X 0.35	0.15
8	0.40 X 0.40	0.35 X 0.35	0.20
12	0.50 X 0.50	0.40 X 0.40	0.20
16	0.60 X 0.60	0.50 X 0.50	0.25

Floor and roof slab thickness were taken as 0.15m and thickness of raft slab as 0.3m. The dimension of T-beam web was taken as 0.23X0.23m. Materials considered in design of structural elements were M20 concrete and Fe 415 steel. Idealized typical 3 bay x 3 bay frame building with varying shear wall shapes are symbolized schematically in Fig.1.

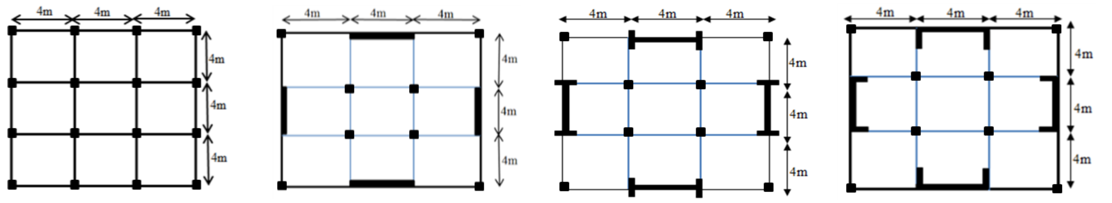

Fig. 1 Plan of bare frame and frame with various shape of shear wall.

2.2 Idealization of soil

Present study treats the soil as a homogenous, isotropic and elastic half space medium. The modelling of which is carried out using eight-node solid brick element having three degrees of freedom of translation at each node. The width and thickness of the soil medium were taken as 1.5 times and 2 times the least width of the raft foundation. The translations at the bottom boundary were restricted while the lateral vertical soil boundaries were modelled as non-reflecting boundaries. Four different types of non-cohesive soils, viz., soft, stiff, dense and rock were considered in the study to determine the effect of soil–structure interaction.Classification of the soil types from hardest to softest as Sb, Sc, Sd and Se were done according to [13] and [14].The details of soil parameters are as tabulated in Table 2.

TABLE 2: Details of soil parameters considered

Soil profile type	Description	Shear wave velocity (Vs) (m/sec)	Poission's ratio μ	Unit weight (ρ) (kN/m^3)	Young's modulus (Es) (kN/m^2)
Sb	Rock	1200	0.3	22	8.40E+6
Sc	Dense soil	600	0.3	20	1.91E+6
Sd	Stiff soil	300	0.35	18	4.46E+5
Se	Soft soil	150	0.4	16	1.03E+5

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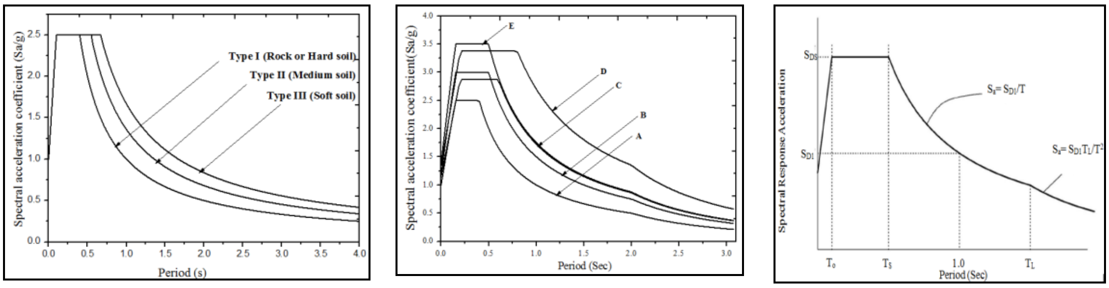
3. METHODOLOGY

In computing earthquake forces acting on a structure, its fundamental natural period plays a major role. Fundamental natural period is required in the estimation of lateral forces and design base shear based on the matching design response spectrum of various codes of practice.The design response spectrum of [15],[16] and [17] building codes are shown in Fig. 2 and corresponding expressions are explained in Table 3.



Design response spectra for 5% damping (IS 1893(part1):2002). Spectral shapes for main site classes (Eurocode8:2004). Design Response Spectrum (IBC: 2006).

Fig. 2Design response spectra for 5% damping.

TABLE 3: Expressions for design spectrum and base shear as per various codes

Code / Item	IS 1893(part1):2002	Eurocode8:2004	IBC: 2006
Spectral acceleration (Sa/g)	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 $\frac{S_a}{g}=\begin{cases}1+15T; 0.00\le T\le 0.10\\ 2.50; 0.10\le T\le 0.67\\ 1.67/T; 0.67\le T\le 4.00\end{cases}$	$0\le T\le T_B : S_d(T)=a_g S\left[\frac{2}{3}+\frac{T}{T_B}\left(\frac{2.5}{q}-\frac{2}{3}\right)\right]$ $T_B\le T\le T_C : S_d(T)=a_g S\frac{2.5}{q}$ $T_C\le T\le T_D : S_d(T)\begin{cases}=a_g S\frac{2.5}{q}\left[\frac{T_C}{T}\right]\\ \ge \beta a_g\end{cases}$ $T_D\le T : S_d(T)\begin{cases}=a_g S\frac{2.5}{q}\left[\frac{T_C T_D}{T^2}\right]\\ \ge \beta a_g\end{cases}$	$0\le T\le T_0\ S_a=0.6\frac{S_{DS}}{T_0}T+0.4S_{DS}$ $T_0\le T\le T_S\ S_a=S_{DS}$ $T_S\le T\le T_L\ S_a=\frac{S_{D1}}{T}$ $T_L\le T\ S_a=\frac{S_{D1}T_L}{T^2}$
Base shear	$V_B=A_h W$ Where, A_h= Design horizontal acceleration spectrum value, W= Seismic weight of the building. $A_h=\frac{ZIS_a}{2Rg}$ Where, Z= Zone factor I= Importance factor R=Response reduction	$F_b=S_d(T_1)m\lambda$ 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 m is the total mass of the building, above the foundation λ is the correction factor, the value of which is equal to 0.85 if $T_1\le 2T_c$ and the building has more than two stories or λ=1.0 otherwise	$V=C_S W$ Where, C_s is the seismic response coefficient, W is the effective seismic weight. $C_S=\frac{S_{DS}}{\left(\frac{R}{I}\right)}$ I is the occupancy importance factor, and R is the response modification factor

	factor S_a/g=Average response acceleration coefficient for rock and soil sites		S_{DS} = the design spectral response acceleration parameter at short periods Value of C_s computed should need not exceed $T<T_L$, $C_s = \frac{S_{D1}}{T\left(\frac{R}{I}\right)}$ S_{D1} = the design spectral response acceleration parameter at 1 second period T = the fundamental period of the structure T_L= Long-period transition period

Different types of soil considered viz., Sb, Sc, Sd and Se corresponds to the various site classes mentioned in IS, EC8 and IBC and are as shown in Table 4.

TABLE 4:Mapping of soil sites.

Soil profile type	Description	Equivalent site class		
		IS	EC8	IBC
Sb	Rock	Type I	A	B
Sc	Dense soil	Type I	B	C
Sd	Stiff soil	Type II	C	D
Se	Soft soil	Type III	D	E

Analysis of 3D finite element model of soil-foundation-structure was carried out using LS DYNA explicit dynamic analysis finite element software to determine the fundamental natural period 'T' of buildings. The fundamental lateral periods thus determined are used to determine the spectral acceleration coefficients (Sa/g) from design response spectrums. The design base shear and lateral forces of the building are further found from the representing equations specified in building codes. The response quantities of fixed base structure to be built on different site classes are designated as 'Fixed' and structure built on different soil typesare designated as 'SSI'.

4. RESULTS AND DISCUSSIONS

Variations in the values ofnatural period, spectral acceleration coefficientand base shear obtained due to effect of soil flexibilityand shear walls shapes were analyzed.

4.1 Lateral natural period

Fundamental natural period of a building is an essential component in lateral load calculation procedure ofseismic analysis of all seismic building codes. The values of natural period obtained from the free vibration analysis of 3D finite element modelsof bare frame and frame shear wall buildings are as shown in Fig.3.

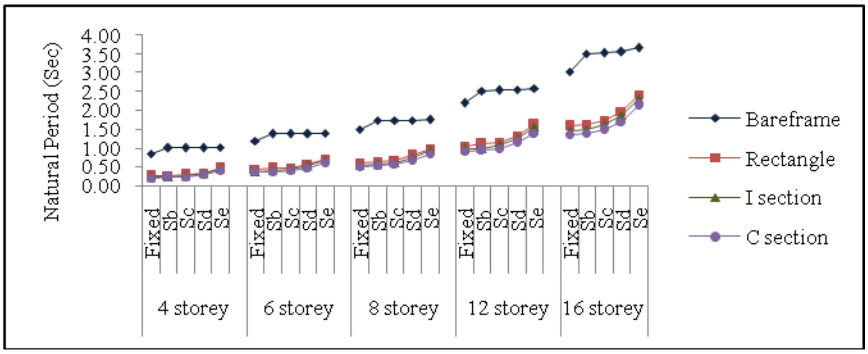


Fig. 3 Lateral natural period of buildings with and without shear wall over various soil types

From Fig.3, it is observed that with increase in height of the buildingthe value of natural period increases. Natural period is lower for shear wall building when compared to bare frame building due to increase instiffness of the building by addition of shear wall. Soil flexibility increases the value of natural period of the building i.e.,it is more forbuildings on soft soil (Se) and less for buildings on hard soil (Sb).

4.2 Spectral acceleration

Spectral acceleration coefficient describes the maximum acceleration of an equivalent single degree of freedom structure in an earthquake.It is determined fromdesign response spectrumsuggested in different codes. Itforms the vital component in design base shear estimation.

Spectral acceleration coefficient value obtained for buildings with fixed base and incorporating soil-structure interaction effect (SSI) are as shown in Fig4 for various site classes

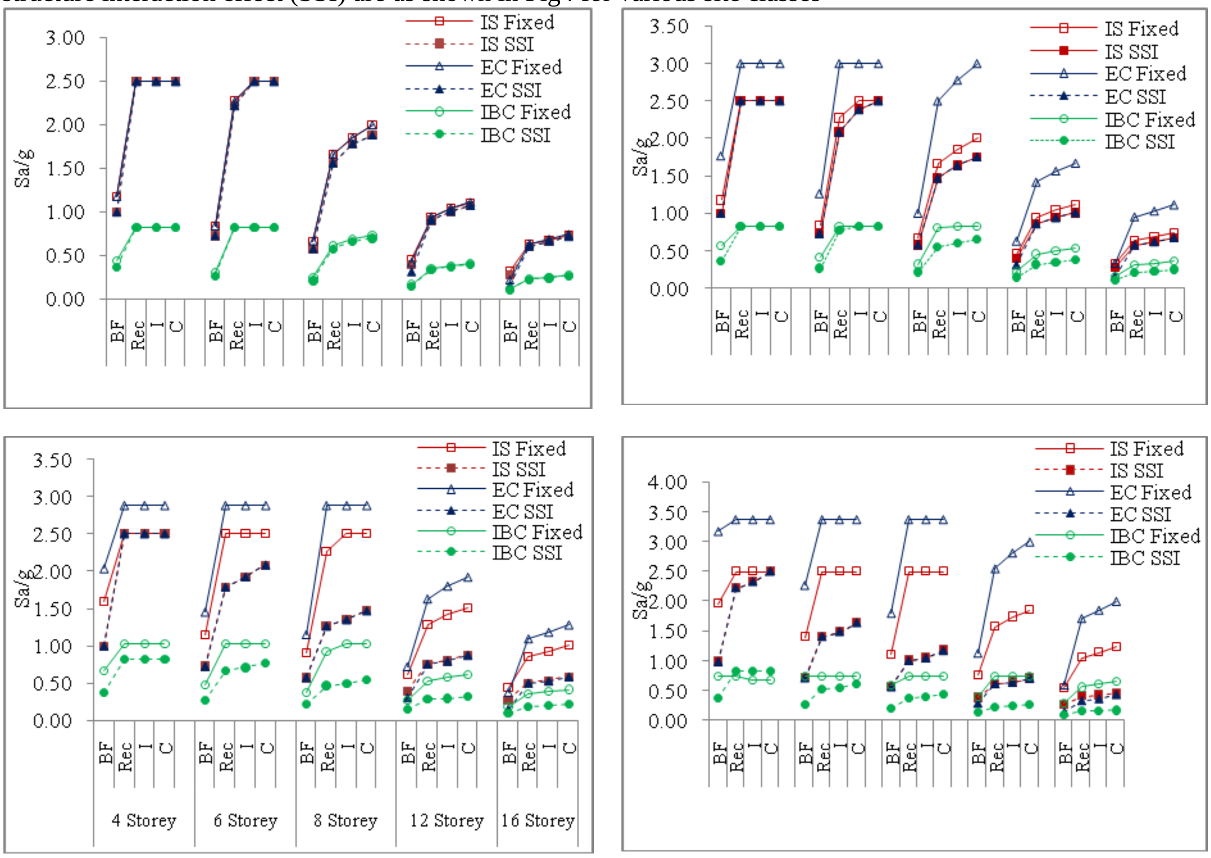


Fig 4: Value of spectral acceleration coefficient as per IS 1893, EC8 and IBC for various site classes

From Fig 4 it is observedthatvalue of design spectral acceleration obtained is highest as per EC8 code and lowest as per IBC code. The values of spectral acceleration coefficient obtained from fixed base condition are mostly higher than SSI making the conventional design procedure conservative. As per the building codes considered buildings with C shape shear wallpossess the highestvalue of spectral acceleration coefficient than rectangular and I shape shear wall and rectangular shape shear wallpossess the least value.

4.3Base shear

Seismic base shear is regarded as one of the primary input in seismic design of structures. It reflects the seismic lateral vulnerability.Base shear values as per IS 1893, EC8 and IBC codes for multi-storey reinforced concrete framed buildings of varying heights with and without shear wall supported on raft foundation over soil are as shown in Fig.5.

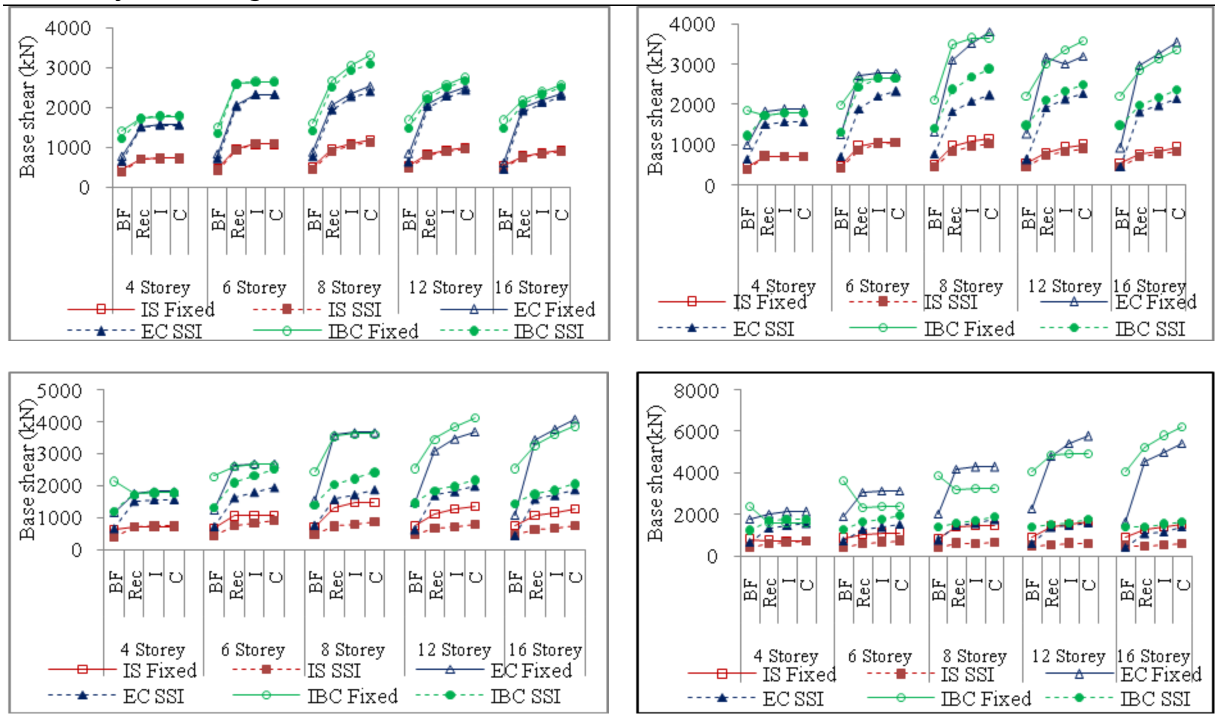


Fig 5: Value of base shear as per IS 1893, EC8 and IBC for various site classes.

From Fig 5 it is observed that the values of base shear obtained by conventional design practice (Fixed) are much higher than the SSI irrespective of the code considered. Base shear values in buildings of all heights with or without SSI effect according to IBC seismic code provisions are higher in all soil types except for Se soil type, where EC8 is highest. Seismic base shear of buildings increase with increase in flexibility of soil. The value of base shear with or without SSI effect is found to be highest in buildings with C shape shear wall.

5. CONCLUSIONS

The results of the study lead to the following conclusions

- The value of fundamental natural periods of buildings with fixed-base is lower than the soil-structure system. Fundamental natural periods increases with increase in flexibility of soil and height of the building and decreases with the addition of shear wall.
- Spectral acceleration coefficient is higher for the buildings with shear wall than that of bare frames.
- Significant differences are observed between the base shear values evaluated using the IS, EC8 and IBC codes. IBC codal provisions give higher value of base shear for buildings than the IS and EC8 codes.
- The value of base shear with or without SSI effect is found to be least in buildings with rectangular shape shear wall.

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