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Seismic behavior of RC framed shear wall buildings as per IS 1893 and IBC provisions

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Abstract. Usually the analyses of structures are carried out by assuming the base of structures to be fixed. However, the soil beneath foundation alters the earthquake loading and varies the response of structure. Hence, it is not realistic to analyze structures by considering it to be fixed. The importance of soil-structure interaction was realized from the past failures of massive structures by neglecting the effect of soil in seismic analysis. The analysis of massive structures requires soil flexibility to be considered to avoid failure and ensure safety. Present study, considers the seismic behavior of multi-storey reinforced concrete narrow and wide buildings of various heights with and without shear wall supported on raft foundation incorporating the effect of soil flexibility. Analysis of the three dimensional models of six different shear wall positions founded on four different soils has been carried out using finite element software LS DYNA. The study investigates the differences in spectral acceleration coefficient (Sa/g), base shear and storey shear obtained following the seismic provisions of Indian standard code IS: 1893 (2002) (IS) and International building code IBC: 2012 (IBC). The base shear values obtained as per IBC provisions are higher than IS values.

Keywords: base shear; design response spectrum; natural period; spectral acceleration coefficient; storey shear; shear wall; soil-structure interaction

1. Introduction

Analysis and design of buildings assuming the base of building as fixed is the usual practice. However in reality, influence of the supporting soil plays a major role on the response of the structure as the soil underneath the foundation permits the movement to some extent by its natural ability to deform. The importance of considering soil-structure interaction in the seismic analysis of structures is evident from the lessons taught from past earthquakes. When the system is acted upon by the external forces like earthquake, the displacements of structures and ground movement are dependent on each other. Response of soil influencing the movement of structure and movement of structure influencing the response of the soil is termed as soil-structure interaction (SSI). Employing the SSI consequences enables the designer to judge the real displacements of the soil-structure system precisely under seismic motion. The seismic response of structure due to SSI depends on both the soil and structure properties.

The consequences of soil flexibility are generally ignored in seismic design of buildings. Mylonakis *et al*. (1997) and Roy and Dutta (2001a, b) in their studies showed the possible

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severities of neglecting the effects of the SSI. The lengthening in lateral natural period of buildings due to reduction of lateral stiffness by soil flexibility was reported by Bielak (1975) and Stewart *et al*. (1999a, b). These studies showed that seismic responses of the buildings are altered by lengthening of lateral natural period, making it a significant issue in design considerations. Bhattacharya and Dutta (2004) carried out similar studies on low-rise buildings showing the significance of lengthening of natural period in seismic behavior of structure bearing fundamental lateral period in short period region of the design response spectrum. Investigations on massive concrete structures supported over raft foundation based on seismic soil-structure interaction using ANSYS and LS DYNA software were presented by Rajasankar *et al*. (2007).

Different regions adopt different seismic codes to deal with the differing levels of seismic risk. These seismic codes are revised and updated often to decide performance of the buildings precisely based on additional seismic data collected. The seismic provisions of Indian standard code were also revised in 2001 and have been in effect from 2002. Improvements were done after the destructive earthquake occurred in Bhuj on 26th January, 2001 (Gujarat State, India). From the observations and lessons of 2001 Bhuj earthquake and past earthquakes several studies have been carried out to improve the seismic provisions of Indian standard code.

A Comparative study on seismic provisions of base shear and story drift of different International building codes was done by Pong *et al*. (2006) and Dogangun (2006). A Comparative design using seismic design provisions of IBC 2000 and UBC 1997 codes was reported by Gosh and Khuntia (1999) stating the variations in base shear and quantity of steel in shear wall. Singh *et al*. (2012) carried out a comparative study on various ductility classes and corresponding response reduction factors of 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). Kaushik *et al*. (2006) stated the governing method of analysis to be used for seismic design of buildings as per IS: 1893-2002 provisions. Major differences existing in the basic seismic provisions of ASCE 7, Eurocode 8, NZS 1170.5, and IS 1893 were studied by Khose *et al*. (2012) expressing the minimum design base shear, ductility classification and response reduction factor (R). Chandak (2012) carried out the response spectrum analysis of reinforced concrete buildings to investigate the differences caused by the use of different international codes (IS, UBC and EC 8) in the dynamic analysis of multistoried RC building. Recently, a comparative evaluation of international, European and American seismic design standards for analysis of conventional buildings was carried out by Santos *et al*. (2013).

Present study considers the influence of local ground conditions on the seismic action based on ground types described in the various codes. The emphasis on differences caused by the use of IS spectra and well known IBC spectra are presented for multi-storey reinforced concrete narrow and wide framed buildings of various heights with and without shear wall supported on raft foundation. Advantages of various locations of shear walls and effect of soil flexibility are investigated.

2. Soil-structure interaction analysis

Soil-structure interaction analysis of multi-storey reinforced concrete narrow and wide framed buildings of 4, 6 and 16 storey with and without shear wall on raft foundation was carried out to determine the effect of soil on structural response of the building. Ordinary moment resisting frames by neglecting the effect of infill were considered. To realize the effect of varying positions of shear wall, shear walls having same shear area in either directions of building were placed at six different locations. Narrow buildings consisted of three bays and wide buildings consisted of nine bays of equal width on each direction of the buildings. The effect of soil flexibility was analyzed by incorporating, four soil types classified based on shear wave velocity. Free vibration analysis, being the basic study of any dynamic analysis was carried out on three dimensional building models founded on varying soil types to find the effect of soil flexibility and significance of varying shear wall positions in narrow and wide buildings.

2.1 Structural Idealization

Multi-storey reinforced concrete narrow and wide framed buildings of 4, 6, and 16 storeys with and without shear wall on raft foundation were considered in the analysis. Ordinary moment resisting frames of 3 bay × 3 bay, equal in length in each direction were considered in case of narrow building and 9 bay × 9 bay of equal length in the case of wide building. The effects of infill were neglected. Shear walls of equal size were symmetrically placed in either 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 were generated.

3D space frames with standard two node beam element with three translational and three rotational degrees of freedom at each node were used to idealize the building frames. Four node plate elements with consideration of adequate thickness were used in modeling the slabs at roof and floors of various storeys along with shear wall and raft foundation. Presuming the building to be used for domestic or small office purpose, the storey heights were chosen as 3 m and length of each bay of building frames as 4 m. The thickness of shear wall considered varied from 150-250 mm depending on the building height.

Based on the structural design following the respective Indian standard codes IS: 456 (2000) and IS: 13920 (1993) for design of reinforced concrete structures, the dimensions of building components were arrived. The dimensions of building components are as listed in Table 1. Thicknesses of the raft foundation and floor slab at various storeys were taken as 0.3 m and 0.15 m respectively. Beam dimensions were chosen to be 0.23 × 0.23 m and materials considered for design of structural elements were M20 concrete and Fe 415 steel.

The idealized form of a typical 9 bay × 9 bay frame and 3 bay × 3 bay frame 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 building configurations with six different locations of shear wall are represented by ‘SW1’ to ‘SW6’. Position of shear walls were made such that the area of shear wall in both principal directions remains the same. They were provided in the exterior frames and core in both narrow and wide buildings. Openings in shear walls were not considered assuming additional strengthening and stiffening provided around the openings.

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

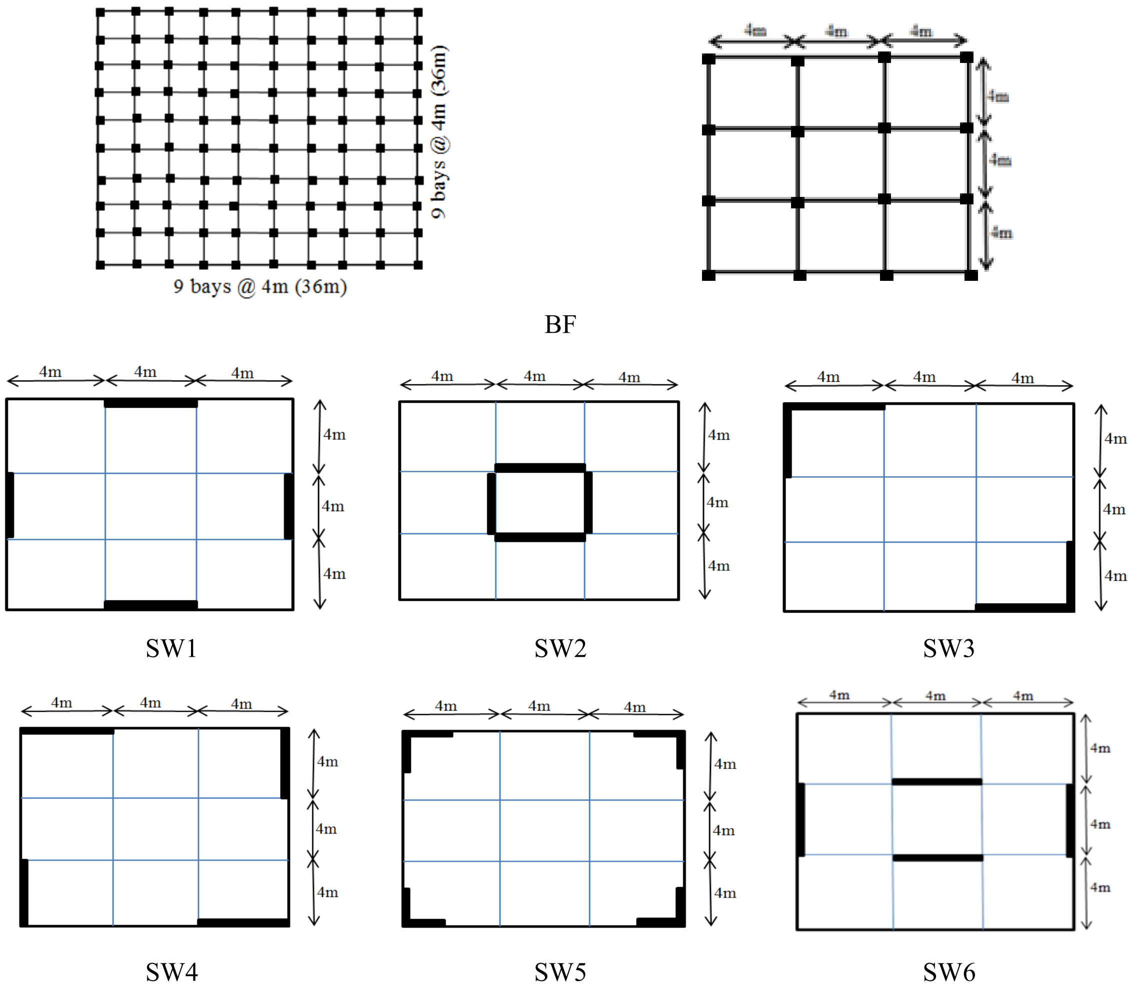

Fig. 1 Plan of bare frame wide and narrow and frame with various locations of shear wall

2.2 Idealization of soil

Present study treats the soil to be homogenous, isotropic and elastic half space medium in examining the soil-foundation and structure interaction. Young’s modulus (Es), Poisson’s ratio (μ) and density of soil were the input considered in linear elastic analysis. The modelling of soil medium underneath the raft was done using eight-node solid brick element with three translation degrees of freedom in the x, y and z directions. Width and thickness of the soil medium were chosen to be 1.5 times and 2 times the least width of the raft foundation as it shows a negligible influence of settlement and contact pressure as reported by Maharaj *et al*. (2004) and Thangaraj and Ilamparuthi (2010). The boundaries at the bottom were restricted from translations while the lateral vertical soil boundaries were modelled as non-reflecting boundaries. Finite element meshes close near the raft were generated with aspect ratio of 1.0 while the mesh away from the raft area was made coarser gradually. Determination of effect of soil-structure interaction on the buildings

Table 2 Details of soil parameters considered [FEMA 273(1997)]

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)
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

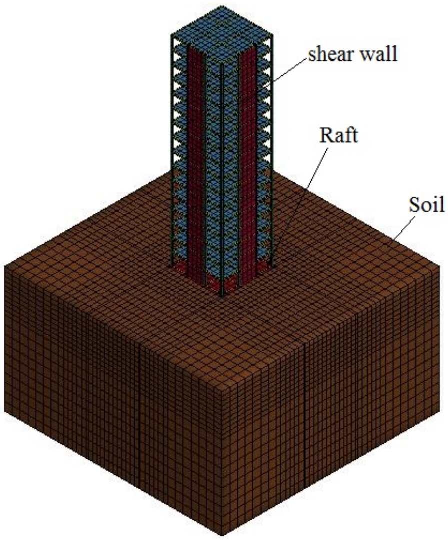

Fig. 2 Idealized soil-foundation-structure model

resting on different non-cohesive soil types, viz., soft, stiff, dense and rock is the primary aim of present study. The classification of these soil types were done according to FEMA 273 from hardest to softest as S_b, S_c, S_d and S_e. The details of different soil parameters are as tabulated in Table 2.

Finite element model of idealized soil-foundation-structure system of 3 bay × 3 bay, 16 storey frame-shear wall building on raft foundation is shown in Fig. 2.

3. Methodology

Fundamental natural period being the primary parameter in calculation of earthquake forces acting on a structure, correct assessment of it is very significant. Fundamental natural period is essential parameter in estimation of lateral forces and design base shear based on the matching design response spectrum of code of practice. Design response spectrum demonstrates 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 and IBC for varying soil sites are shown in Figs. 3 and 4.

The expressions for spectral acceleration coefficient of structures founded on various soil types suggested in IS and IBC 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 consistent approach, the equivalent site classes matching the soil profiles considered are mapped as shown in Table 3 according to FEMA 273 classification.

The expressions for spectral acceleration coefficient for structures founded on various soil types, base shear and storey shear suggested in IS and IBC are as described in Table 4.

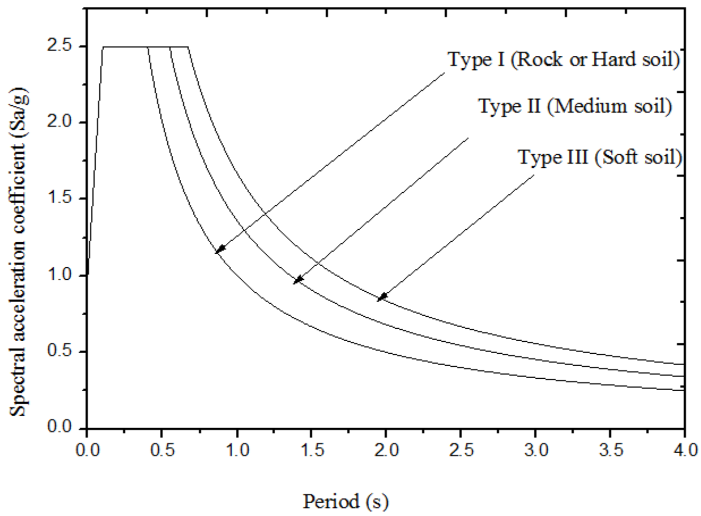

Fig. 3 Design response spectra of IS: 1893 (2002) for 5% damping on various site classes

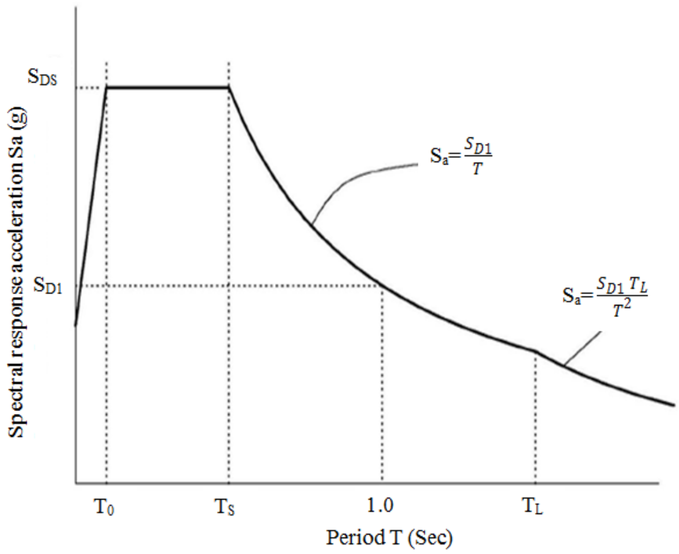

Fig. 4 Design response spectra of IBC 2012 for 5% damping on various site classes

Table 3 Mapping of soil sites in 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

Table 4 Ordinates of elastic spectra, base shear and storey shear defined in IS and IBC

Codes item	IS: 1893 (part1) 2002	IBC: 2012
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 $\frac{S_a}{g}=\begin{cases}1+15T; & 0.00\le T\le 0.10\\ 2.50; & 0.10\le T\le 0.67\\ 1.67/T; & 0.67\le T\le 4.00\end{cases}$	$0\le T\le T_0$ $S_a=0.6\frac{S_{DS}}{T_0}T+0.4S_{DS}$ $T_0\le T\le T_s$ $S_a=S_{DS}$ $T_s\le T\le T_L$ $S_a=\frac{S_{D1}}{T}$ $T_L\le T$ $S_a=\frac{S_{DS}T_L}{T^2}$
Base shear	$V_B=A_hW$, Where $A_h=\frac{ZIS_a}{2Rg}$	$V=C_SW$, Where $C_S=\frac{S_{DS}}{\left(\frac{R}{1}\right)}$ need not exceed $C_S=\frac{S_{D1}}{T\left(\frac{R}{1}\right)}$ for $T\le T_L$, $C_S=\frac{S_{D1}T_L}{T^2\left(\frac{R}{1}\right)}$ for $T>T_L$ and shall not be less than 0.01
Storey shear	$Q_i=V_B\frac{W_ih_i^2}{\sum_{j=1}^{n}W_jh_j^2}$	$F_x=C_{vx}V$, Where $C_{vx}=\frac{w_xh_x^k}{\sum_{i=1}^{n}w_ih_i^k}$

Present study considers multi-storey reinforced concrete framed buildings of 4, 6 and 16 storeys with and without shear wall on raft foundation. The plan dimensions of narrow and wide building considered were 12 m × 12 m and 36 m × 36 m respectively. The structures were assumed to be constructed at New Delhi, India located under seismic zone IV. An importance factor of 1 was considered. The response reduction factor R of 3 was considered for moment resistant frames and 4.5 for ductile shear wall buildings as per IS and equivalent parameters were considered from

IBC. The earthquake forces on the structure were determined using spectral acceleration based on fundamental natural period *T*. The effect of soil-structure interaction and the position of shear walls in buildings constructed over different soil types were evaluated and compared as per seismic provisions of IS and IBC.

LS DYNA explicit dynamic analysis finite element software was used in the analysis of 3D finite element model of soil-foundation-structure to determine the fundamental natural period '*T*' of buildings by Eigen value analysis. The fundamental lateral periods of the building frames and shear wall buildings with and without considering the effect of soil flexibility thus determined were used to determine the change in spectral acceleration coefficients (Sa/g) calculated from design response spectrums of IS and IBC. The design base shear and lateral forces of the building were further obtained from the corresponding equations specified in building codes according to simplified modal response spectrum method. Results obtained are expressed in terms of relative stiffness of raft (K_{rs}) based on the recommendation of Hemsley (1998).

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

$$\eta = \log\left(\frac{1}{K_{rs}}\right) \quad (2)$$

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;
η = Relative stiffness factor for raft.

Analyses were carried out for buildings with values of η ranging from 3.0 to 6.4. Lower and higher limit of η corresponds to foundation resting over soft and hard soil respectively.

The structural response values corresponding to the fixed base structure to be built on different site classes were designated as 'Fixed'. Similarly, the response of integrated soil-foundation-structure system where buildings were found on different soil types was designated as 'SSI'. In SSI system, values of Sa/g were computed from the base line for rocky strata of design response spectrum given in codes. The results thus obtained were analysed and compared to assess the effect of location of shear wall, effect soil flexibility and the seismic provisions in the codes.

4. Results and discussions

To compute the natural period of buildings accounting for the effect of soil–structure interaction three dimensional finite element models of integrated soil-raft foundation-RC shear wall buildings were considered for free vibration analysis. From the lateral natural periods obtained, matching values of Sa/g were computed as per the seismic provisions in IS and IBC. Further the design base shear and lateral force distribution in buildings were computed from the representing equations specified in building codes. The variations in base shear and storey shear due to the effect of soil flexibility and location of shear walls were analysed.

4.1 Lateral natural period

Fundamental natural period has important role in the seismic response of a structure. The modification in fundamental lateral natural period due to the effect of soil-structure interaction was studied for buildings with varying height over raft foundation resting on various soil types viz. S_b, S_c, S_d and S_e. The values of natural period found for bare frame and frame shear wall buildings from the free vibration analysis of 3D finite element models are as shown in Fig. 5. The response of narrow and wide buildings is represented in figures by solid and dash lines respectively.

From Fig. 5 it is observed that the value of natural period increases with increase in height of the building due to increase in flexibility of building. However, the natural period decreases by addition of shear wall to the building due to the gain in stiffness of building by addition of shear wall. The inclusion of soil flexibility in buildings results in lengthening of lateral natural periods due to decrease in lateral stiffness. This lengthening of natural period considerably alters the seismic response of the buildings.

No significant variation is observed in values of natural period in narrow and wide bare frame buildings, since the natural period of buildings are influenced predominantly by the height of the building rather than its width. In narrow bare frame buildings, the natural period is increased by 15 to 21% due to the effect of supporting soil flexibility. In wide bare frame buildings, this increase ranges from 13% to 16.6%. Even in S_b (rock) this increase is more than 13%. However in narrow shear wall buildings, the natural period is increased by 1.7% to 127.8% due to the effect of supporting soil flexibility. In wide shear wall buildings; this increase ranges from 3% to 51.73%. Among narrow shear wall buildings, the minimum value of natural period 'T' is observed in SW2 shear wall configuration and maximum in SW5 shear wall configuration for all the soil types except for Se where SW3 shear wall configuration shows the maximum value of natural period. In wide shear wall buildings, the minimum value of natural period is observed in SW6 shear wall configuration for all the soil types except for S_e in 6 and 16 storey, where SW2 shear wall configuration shows the minimum. However, the maximum value of natural period was observed in SW5 shear wall configuration in 16 storey building and SW2 shear wall configuration in 4 and 6 storeys for all the soil type except for S_e.

Inclusion of shear wall at various locations have brought down the natural period of 4 and 6 storey buildings below 1 sec and most of the 4 storey shear wall buildings have the natural period below 0.4 sec.

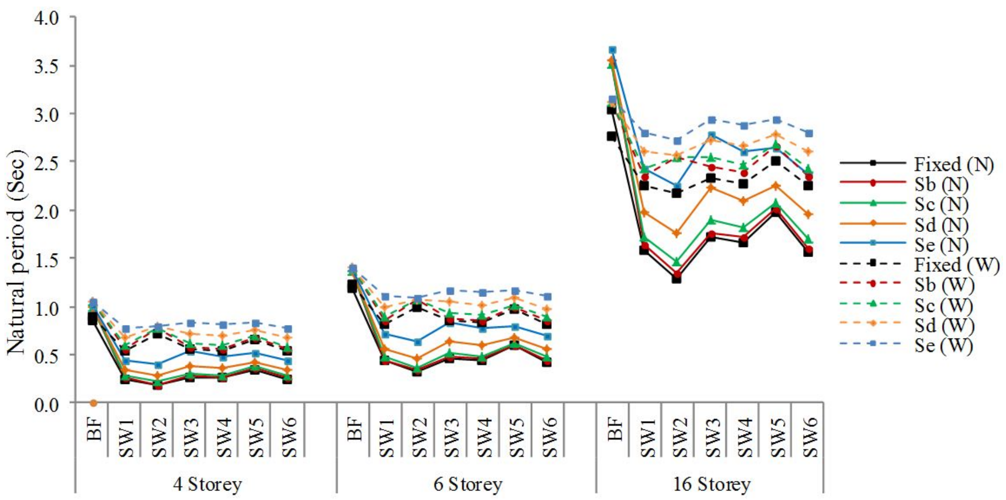

Fig. 5 Lateral natural period of buildings with and without shear wall over various soil types

It is observed from Table 5 that the maximum reduction in natural period due to inclusion of shear wall was observed in SW2 shear wall configuration for narrow building (up to 80.68%) and SW6 shear wall configuration for wide building (up to 47.04%) of all heights over soil type S_b.

Table 5 Variation in natural period

Building type	% variation due to soil						% variation due to shear wall					
	S_b						S_b					
	Narrow			Wide			Narrow			Wide		
	4	6	16	4	6	16	4	6	16	4	6	16
BF	17.65	15.13	15.84	15.84	14.03	12.94	-	-	-	-	-	-
SW1	4.00	2.27	3.80	3.83	2.98	4.56	-74.00	-67.15	-53.28	-46.89	-39.20	-24.34
SW2	7.31	6.25	4.69	8.41	7.85	17.58	-80.68	-75.18	-61.82	-25.12	-23.09	-18.08
SW3	3.70	2.13	2.91	4.52	3.50	5.26	-72.00	-64.96	-49.57	-44.45	-36.70	-21.40
SW4	3.85	2.22	3.61	4.00	3.12	4.68	-73.00	-66.42	-51.00	-45.91	-38.20	-23.28
SW5	2.86	1.69	2.02	3.51	3.01	5.97	-64.00	-56.20	-42.45	-35.24	-28.57	-14.66
SW6	4.00	4.65	3.21	3.82	2.98	4.75	-74.00	-67.15	-54.13	-47.04	-39.38	-24.54
	S_c						S_c					
BF	17.65	15.13	16.17	15.88	14.07	13.04	-	-	-	-	-	-
SW1	12.00	9.09	9.49	10.40	7.92	8.21	-72.00	-64.96	-50.85	-43.55	-36.31	-21.76
SW2	22.22	15.63	14.06	8.79	8.14	17.77	-78.00	-72.99	-58.52	-24.89	-22.91	-18.01
SW3	14.81	10.64	10.47	12.42	9.37	9.31	-69.00	-62.04	-46.02	-40.28	-33.14	-18.44
SW4	11.54	8.89	9.04	10.66	8.16	8.39	-71.00	-64.23	-48.58	-42.47	-35.21	-20.63
SW5	8.57	5.08	5.05	6.72	5.42	7.49	-62.00	-54.74	-40.91	-33.25	-26.94	-13.51
SW6	12.00	11.63	8.97	10.38	7.90	8.40	-72.00	-64.96	-51.70	-43.71	-36.51	-21.98
	S_d						S_d					
BF	17.65	15.13	17.49	16.04	14.25	13.36	-	-	-	-	-	-
SW1	36.00	27.27	25.32	25.90	19.48	15.97	-66.00	-59.12	-44.38	-35.72	-29.60	-16.39
SW2	61.11	46.88	37.50	9.18	8.46	18.02	-71.00	-65.69	-50.56	-24.72	-22.81	-18.08
SW3	44.44	34.04	29.65	30.03	22.36	17.41	-61.00	-54.01	-37.36	-31.02	-25.31	-12.65
SW4	38.46	31.11	26.51	26.82	20.25	16.49	-64.00	-56.93	-41.01	-34.16	-28.07	-14.93
SW5	20.00	15.25	13.64	15.02	11.68	11.24	-58.00	-50.36	-36.80	-28.16	-22.71	-10.74
SW6	36.00	30.23	25.00	25.81	19.41	16.13	-66.00	-59.12	-45.22	-35.93	-29.85	-16.65
	S_e						S_e					
BF	18.82	16.81	20.79	16.62	14.85	14.36	-	-	-	-	-	-
SW1	80.00	61.36	53.16	46.78	34.65	24.87	-55.45	-48.92	-33.88	-25.43	-21.08	-10.77
SW2	127.8	100.0	76.56	9.90	9.08	25.80	-59.41	-53.96	-38.25	-24.60	-22.77	-13.45
SW3	100.0	78.72	62.21	51.73	37.99	26.09	-46.53	-39.57	-23.77	-19.91	-16.21	-7.01
SW4	88.46	71.11	57.23	49.35	36.62	26.06	-51.49	-44.60	-28.69	-22.85	-18.71	-8.76
SW5	48.57	35.59	33.84	28.20	21.77	17.14	-48.51	-42.45	-27.60	-20.33	-16.17	-6.84
SW6	80.00	62.79	52.56	46.51	34.45	24.91	-55.45	-49.64	-34.97	-25.77	-21.43	-11.14

4.2 Spectral acceleration coefficient

The maximum acceleration of an equivalent single degree of freedom structure with same natural period subjected to design basis earthquake excitations for the region is defined as spectral acceleration coefficient. It is the vital component in estimation of design base shear based on design response spectrum and is dependent on the primary parameter, the fundamental period T of the building. As the period alters due to the effect of structure interaction with supporting soil, the value of spectral acceleration coefficient is apt to shift to high or low values which successively affect the value of design base shear calculated.

The design response spectrum as suggested in IS and IBC were utilized to obtain the spectral acceleration coefficient of structures founded on various soil types. The value of spectral acceleration coefficient obtained by considering the three dimensional soil-structure interaction effect (SSI) in buildings are lesser than those obtained by the standard conventional design practice (Fixed).

Among all the building configurations considered here, spectral acceleration is found to be least for multi-storey moment resisting bare frames and highest for buildings with shear wall, with or without SSI effect. This is due to the reduction in fundamental natural period of buildings by the addition of shear walls which shifts the spectral acceleration to higher value as the natural period of these bare frame buildings lies in the descending curve of the spectra.

For the building configurations considered in the present study, Sa/g value decreases with increase in height of the building. The values of Sa/g are higher for narrow buildings as compared to wider buildings except for the 16 storey bare frame building.

The values of spectral acceleration coefficient obtained for buildings considered as per IS and IBC for buildings with fixed base assumed to be constructed over different soil sites and with actual three dimensional soil-structure interaction are as shown in Figs. 6 and 7. In Figs. 6 and 7, IS values are represented by solid line and IBC values are represented by dash lines.

From Figs. 6 and 7 it is observed that the value of design spectral acceleration obtained is higher as per IS than IBC. The variation in the value of Sa/g between fixed base condition and SSI increases with increase in value of η. Viewing into the height aspect of buildings, variation in value of Sa/g between fixed base condition and SSI increases with increase in height for narrow buildings and decreases with increase in height for wider buildings.

In general, irrespective of the code considered, the value of Sa/g in case of narrow building is found to be maximum in SW2 shear wall configuration for all the values of η. It is minimum in SW5 shear wall configuration for η ranging from 4.0 to 5.0 and in SW3 for $\eta = 3.0$. However in wider buildings, Sa/g values are found to be maximum in SW6 shear wall configuration for all the values of η. Sa/g values are minimum in SW2 shear wall configuration of 4 and 6 storey for η ranging from 5.4 to 6.4 and in SW5 for $\eta = 4.4$.

4.3 Design base shear

Seismic base shear reflects the seismic lateral vulnerability of the structure and is considered as one of the principal input in seismic design of structures. The base shear was computed from the expressions given in codes as given in Table 4.

The value of base shear as per IS and IBC for multi-storey reinforced concrete framed buildings of different heights with and without shear wall supported on raft foundation with varying values of η are as shown in Figs. 8 and 9.

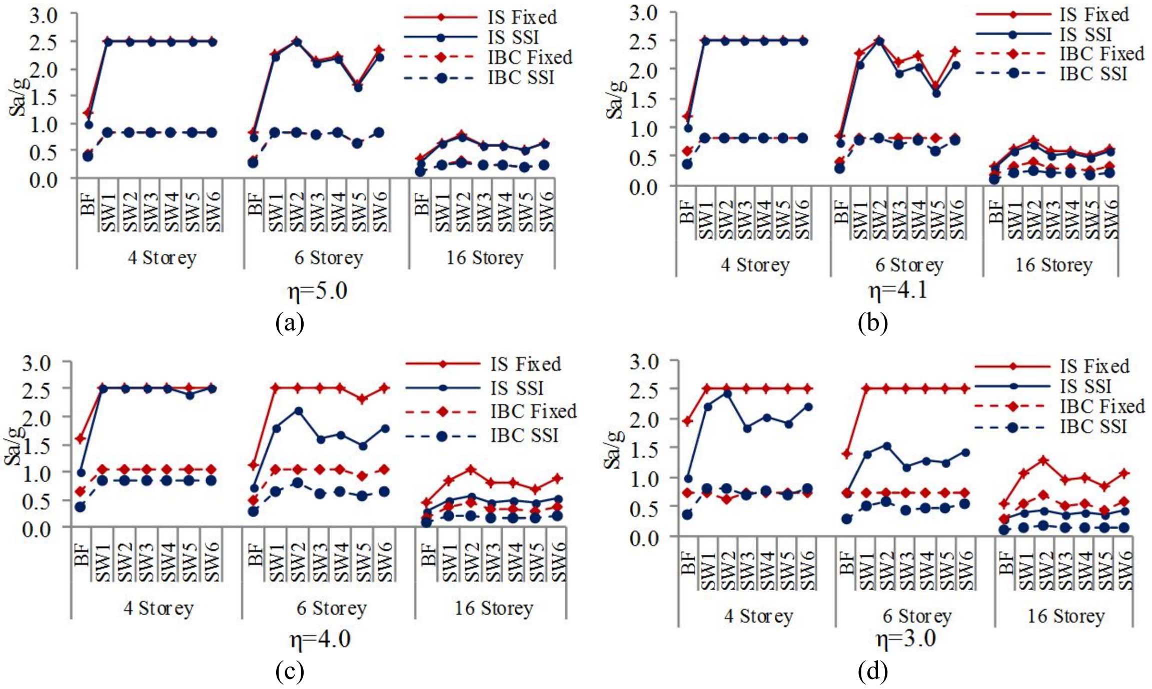

Fig. 6 Value of spectral acceleration coefficient of narrow buildings as per IS and IBC for various site classes

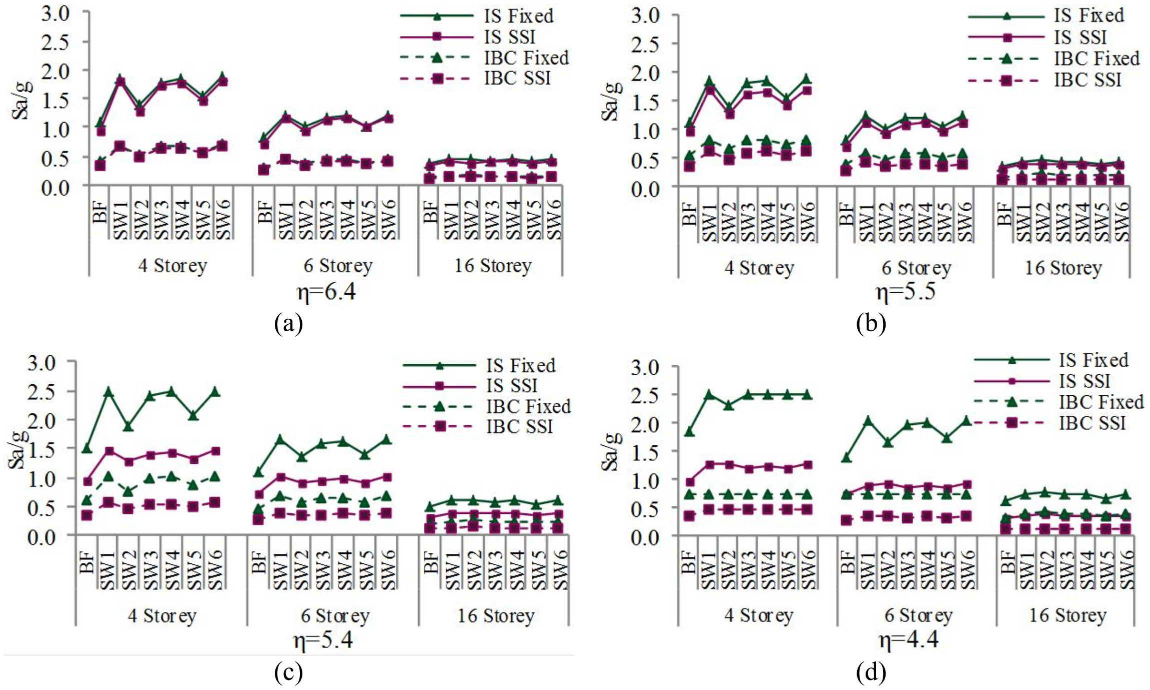

Fig. 7 Value of spectral acceleration coefficient of wider buildings as per IS and IBC for various site classes

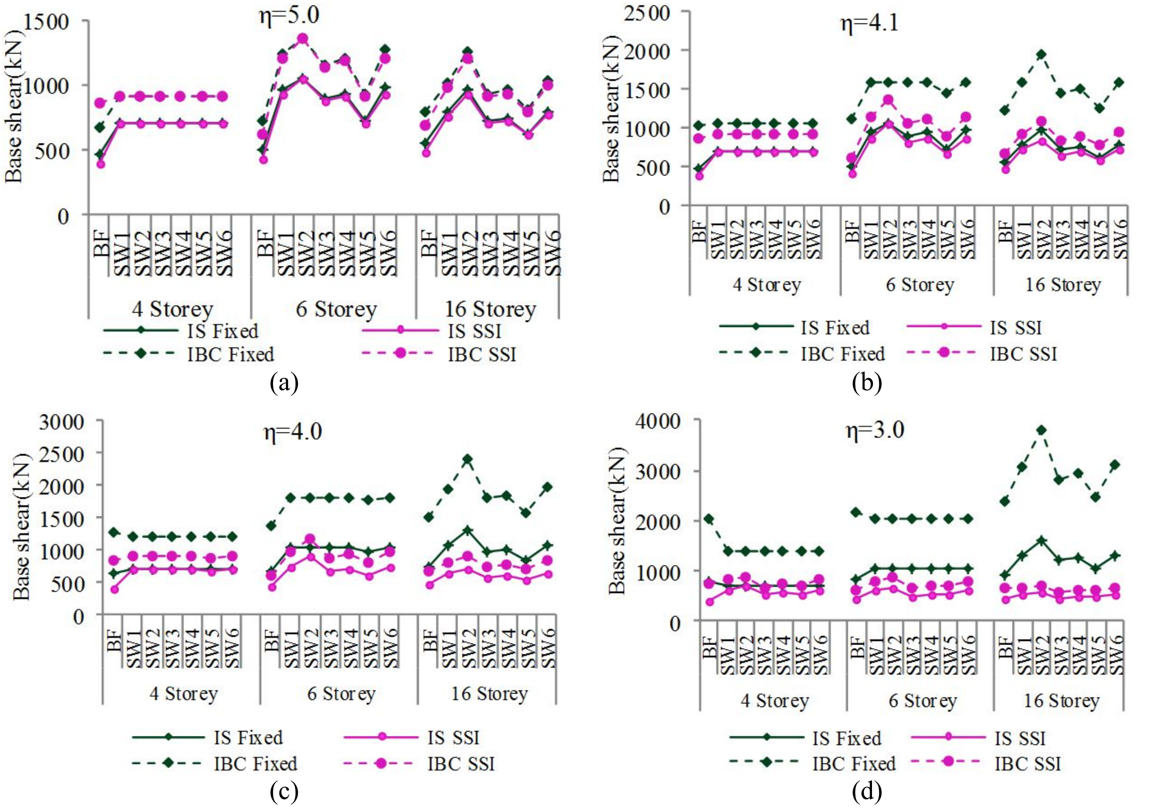

Fig. 8 Value of base shear of narrow buildings as per IS and IBC for various site classes

From Figs. 8 and 9 it is observed that the value of base shear obtained by considering the three dimensional soil-structure interaction effect (SSI) in buildings are lesser than those obtained by the standard conventional design practice (Fixed). Values of base shear increases with increase in η values. Variation in base shear values between SSI and fixed case increases with increase in η value and are found to be more in narrow bare frame building when compared with wider bare frames. However in shear wall buildings, variation is more in wider buildings.

In narrow shear wall buildings of all heights, minimum value of base shear is observed in SW5 shear wall configuration for the values of η ranging from 4 to 5 and SW3 shear wall configuration for $\eta = 3$. However, in wide shear wall buildings minimum value of base shear is observed in SW2 shear wall configuration for 4 and 6 storeys with η ranging from 5.4 to 6.4. For 16 storey wide shear wall building minimum value of base shear is observed in SW5 shear wall configuration for all values of η.

Values of base shear in buildings of all heights with or without SSI effect are highest in accordance to IBC seismic code provisions. Base shear of 6 and 16 storey wide shear wall buildings are lesser than the base shear in bare frame building. This reduction in the value of base shear is due to response reduction factor/response modification factor ‘R’ 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.

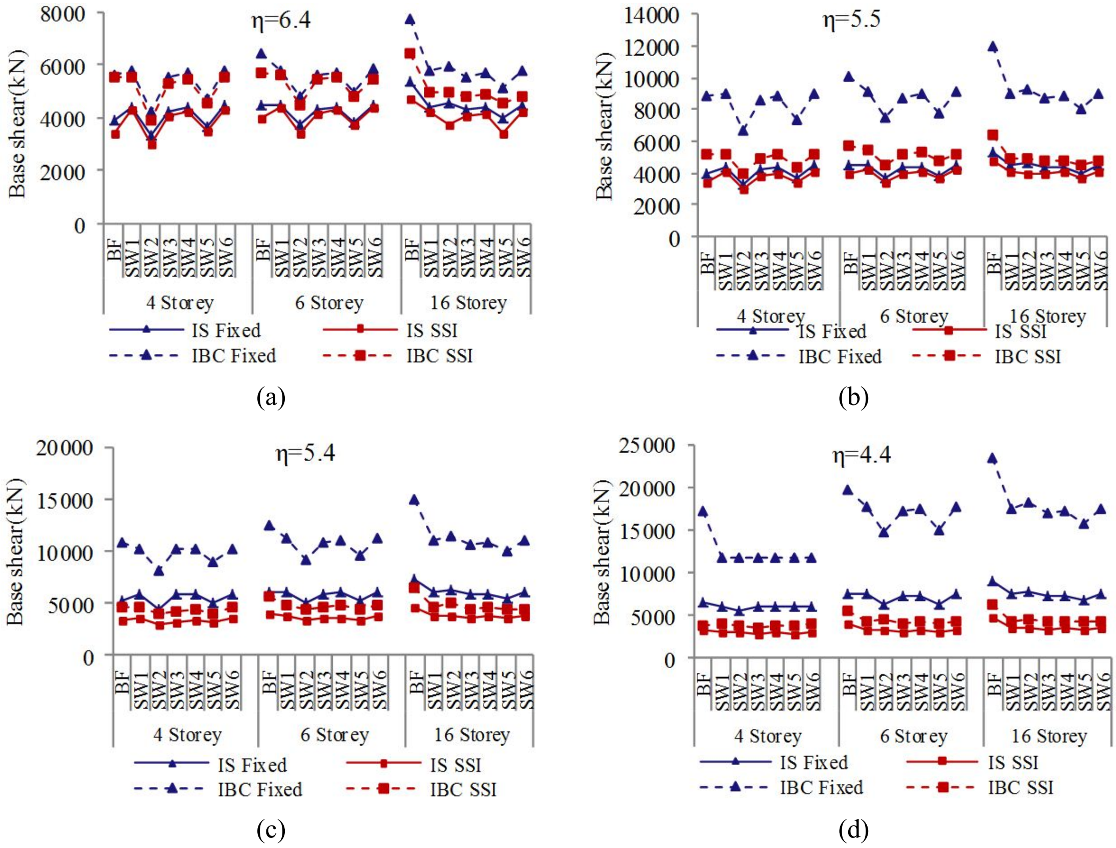

Fig. 9 Value of base shear of wider buildings as per IS and IBC for various site classes

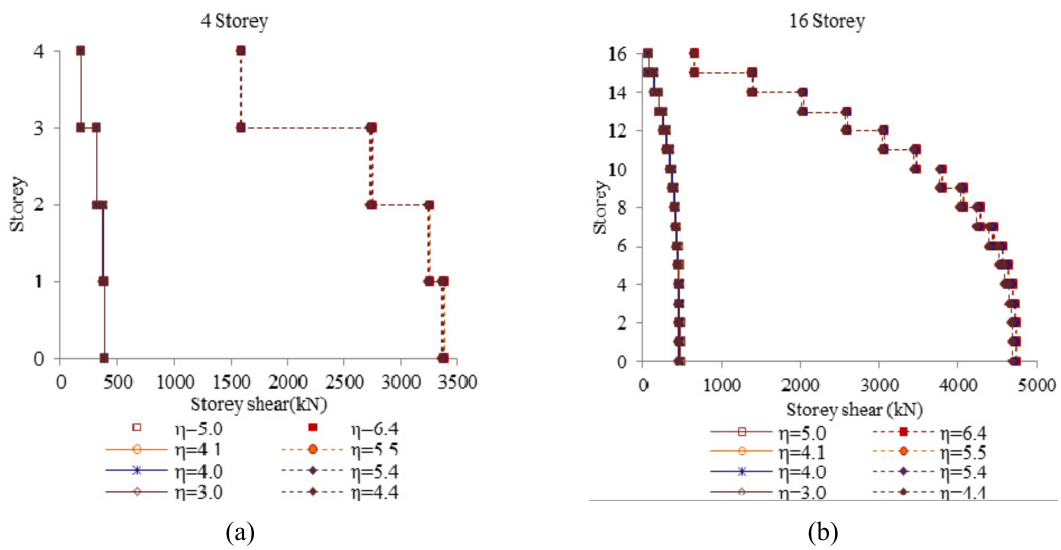

Fig. 10 Variation of storey shear as per IS

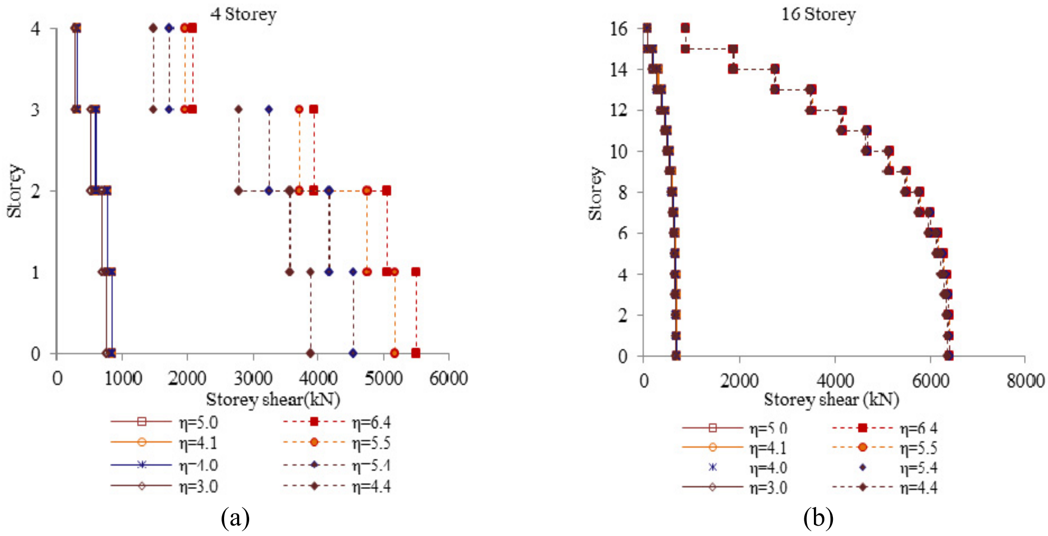

Fig. 11 Variation of storey shear as per IBC

4.4 Storey shear

The sum of design lateral forces at all levels above the storey under consideration is storey shear. In shear wall buildings, storey shear forces are generally carried by horizontal shear in the wall and interface between the wall and beams. Storey shear value as per IS and IBC seismic codes for narrow and wide building were 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 4 and 16 storey bare frame buildings corresponding to the seismic provisions of IS and IBC are as shown in the Figs. 10 and 11. It is observed that value of storey shear increase with decrease in value of η. The variation is more in a 4 storey building as per IBC.

For all the building types considered the value of storey shear obtained is highest as per IBC.

5. Conclusions

An attempt to analyze the multi-story reinforced concrete narrow and wide building frames with shear wall at various positions of building considering the flexibility of supporting soil is carried out in present study. The result of the study leads to following conclusions.

- Fundamental natural period obtained for buildings considering the effect of SSI are more than the standard fixed-base condition. Natural period increases with increase in value of η. It is highest for 16 storey building with higher η values and lowest for 4 storey building with lower η values.
- SSI effect increases the natural period of bare frame buildings more than 13% even in the hardest soil.
- The maximum value of natural period in narrow shear wall buildings corresponds to SW5 configuration. Hence provision of shear wall at exterior corners of narrow buildings is

advantageous.

- In wider shear wall buildings founded on soft soil, SW3 and SW5 configuration results in the maximum natural period. Hence provision of shear walls at the diagonally opposite corners or at four corners of the buildings is advantageous.
- The value of design spectral acceleration is higher as per IS than IBC. The variation in the value of Sa/g between fixed base condition and SSI increases with increase in value of η.
- Base shear values obtained as per IBC are higher than IS values.
- In narrow and wide tall shear wall buildings, minimum value of base shear is observed in buildings with shear wall at exterior corners for all the values of η.

In general, shear walls placed at exterior corners or diagonally opposite corners reduces the seismic force in the building. Base shear in all buildings as per conventional fixed base approach are conservative values according to both IS and IBC.

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