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A comparative study of seismic provisions between International Building Code 2003 and Uniform Building Code 1997

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Abstract: This study focuses on the comparison of the Uniform Building Code (UBC) 1997 and International Building Code (IBC) 2003 in relation to the seismic design and analysis of special steel moment resisting frame buildings (SMRF). This paper formulates a numerical study of a steel SMRF building, studied in four different situations, namely: as an office building in San Francisco; as an office building in Sacramento; as an essential facility in San Francisco, and as an essential facility in Sacramento. The analytical results of the model buildings are then compared and analyzed taking note of any significant differences. This case study explores variations in the results obtained using the two codes, particularly the design base shear and drift ratios as they relate to different locations and occupancy use. This study also proves that IBC 2003 is more stringent for the redundancy factor under design category E for the SMRF building, and drift limits for essential facilities.

Keywords: Uniform Building Code 1997; International Building Code 2003; building periods; special moment resisting frame; redundancy factor

1 Introduction

Prior to the year 2000, cities and counties across the United States adopted building codes on a regional basis. Breyer *et al*. (2003) notes that local governments used one of the three regional model codes, namely: Uniform Building Code (UBC), which was used in the western portion of the United States; the Building Officials and Code Administrators (BOCA) National Building Code in the north; and the Standard Building Code in the south, respectively. In 1994, the International Code Council (ICC) was created to develop a single comprehensive code without regional limitations. The ICC unified the three model codes and produced the International Building Code (IBC) with IBC 2000 as its first publication (Breyer *et al.*, 2003). IBC 2003 is its latest version and is being considered for adoption by the State of California to replace UBC 1997. There are significant differences between UBC 1997 and IBC 2003 seismic provisions.

UBC 1997 was based on Structural Engineer's Association of California's (SEAOC) recommended guidelines for Lateral Force Requirements, or more popularly known as the "Blue Book" (Dowty *et al.*, 2000). On the other hand, IBC 2003 is based on the Federal Emergency Management Agency's (FEMA) National Earthquake Hazards Reduction Program (NEHRP) Recommended Provisions for the Development of Seismic Regulations for New Buildings. IBC frequently references the American Society of Civil Engineers (ASCE) publication ASCE 7 for technical provisions (Dowty *et al.*, 2000). NEHRP 97 Appendix B explains in detail the rational behind determining the Maximum Considered Earthquake (MCE) and Design Basis Earthquake (DBE) ground Motion Acceleration and Response Spectrum of IBC Section 9.3 (ASCE, 2003).

The intent of this case study is to provide a comparison between UBC 1997 and IBC 2003 with regards to seismic analysis and design. A typical building frame, which is the focus of the case study, is shown in Figure 1. Soil site conditions are assumed to be unknown for all the situations mentioned. The building was studied in four different situations, namely:

- As an office building located at 1600 Holloway Avenue, San Francisco, California with a zip code of 94132.
- As an essential facility building (hospital) located at 1600 Holloway Avenue, San Francisco, California with a zip code of 94132.
- As an office building located at 1209 L St,

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Sacramento, California with a zip code of 95814.

- As an essential facility building (hospital) located at 1209 L St, Sacramento, California with a zip code of 95814.

2 Case study using UBC 1997

This section derives the numerical values used in the seismic design and analysis of the buildings for this case study by following UBC 1997. The calculations are discussed in detail in the following order: design base shear, vertical distribution of the base shear, story drift and drift limits, and redundancy factor.

2.1 Design base shear

The design base shear is calculated using the following formulas from UBC 1997 Section 1630.2.1:

$$V = \frac{C_{\mathrm{v}} I}{RT} W \qquad (1)$$

where the maximum value is $V_{\max} = 2.5C_{\mathrm{a}}(I/R)\ W$ and the minimum value is $V_{\min} = 0.11C_{\mathrm{a}}IW$. In addition, for Seismic Zone 4, there is $V_{\min}=0.8ZN_{\mathrm{v}}(I/R)W$. Note that the notation for the equations above is defined as follows: V = the total design base shear; C_{a} = the seismic coefficient, as per UBC 1997 Table 16-Q; C_{v} = the seismic coefficient, as per UBC 1997 Table 16-R; I = the importance factor given in UBC 1997 Table 16-K; R = numerical coefficient representative of the inhere overstrength and global ductility, UBC 1997 Table 16-N for building structures, and W = the total weight of the building.

Table 1 outlines the resulting seismic coefficient values for the different situation of the case study buildings.

2.2 Vertical distribution of base shear

Once the base shear is determined, the lateral seismic force induced at any story level can then be obtained

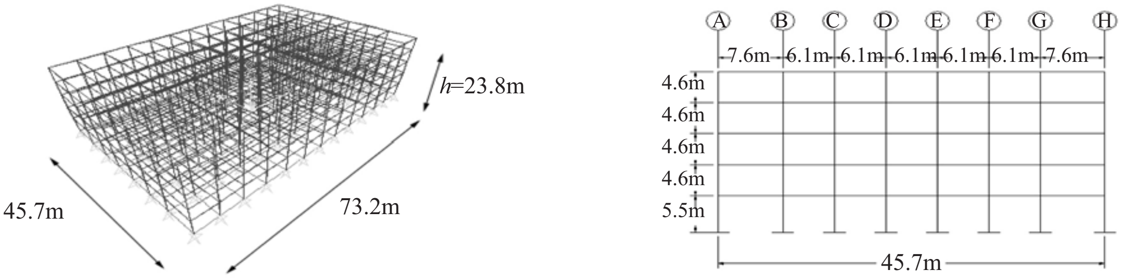


Fig. 1 3-D and 2-D views of the building

Table 1 Design base shear – UBC 1997

Occupancy	Office		Hospital	
Location	San Francisco	Sacramento	San Francisco	Sacramento
Importance factor	1		1.25	
Z	0.4	0.3	0.4	0.3
N_{a}	1.35	N/A	1.35	N/A
N_{v}	1.80	N/A	1.80	N/A
C_{a}	0.594	0.360	0.594	0.360
C_{v}	1.152	0.540	1.152	0.540
T_{s} (s)	0.776	0.600	0.776	0.600
T_{a} (s)	0.919	0.919	0.919	0.919
C_{s}	0.148	0.069	0.185	0.086
max C_{s}	0.175	0.106	0.219	0.132
min C_{s}	0.065	0.040	0.081	0.050
min C_{s} Zone4	0.068	N/A	0.085	N/A
Controlling C_{s}	$\mathrm{C_s}$	$\mathrm{C_s}$	$\mathrm{C_s}$	$\mathrm{C_s}$
V (kN)	11090	5170	13862	6444

Note: For all buildings considered the soil type is D, R=8.5, W=74932 kN using the following equations given in UBC 1997.

$$F_x = \frac{(V - F_t)w_x h_x}{\sum w_i h_i} \tag{2}$$

and

$$V = F_t + \sum F_i \tag{3}$$

where F_i and F_x = the lateral seismic force at story level i or x; w_i and w_x = the portion of the total building weight at story level i or x; h_i and h_x = the height from the ground floor to story level i or x; V = the total base shear mentioned above, and F_t = the concentrated force on the roof. $F_t = 0.07TV$ in general and the maximum value is capped at 25% of V and it may be taken as 0 if the structural period T is ≤ 0.7 seconds.

Table 2 shows the resulting numerical values for the vertical distribution of base shear for the case study buildings. The distributed force at each level was added a 5% factor for accidental eccentricity and then was divided in proportion to the number of frames in the direction being considered.

2.3 Story drift and drift limits

The story drift at each level is then compared to the drift limits of UBC 1997. This procedure of assuming frame member sizes, obtaining the displacements, computing the story drift and comparing the story drift with the drift limit was iterative. It was repeated until a suitable combination of frame member sizes passes the drift limits of UBC 1997.

UBC 1997 Section 1630.10 gives the guidelines for calculating the maximum inelastic response drift, Δ_M, and the deflection is then determined by elastic analysis using UBC 1997 shear force, Δ_S, limits as follows:

- $\Delta_M = 0.7R\Delta_S \leq 2.5\%$ of story height for $T < 0.7$second;
- $\Delta_M = 0.7R\Delta_S \leq 2\%$ of story height for $T \geq 0.7$second.

The numerical values for the story drift and drift limits calculations are outlined in Tables 3A to 3D.

2.4 Redundancy factor

In addition to passing the drift limit requirement, the case study buildings also have to pass the requirement for redundancy factor. UBC 1997 Section 1630.1.1 indicates guidelines for determining the reliability/redundancy factor, ρ, and its limiting values using following formula:

$$\rho = 2 - \frac{20}{r_{\max}\sqrt{A_B}} \tag{4}$$

Where $r_{\max}$ = the maximum element story shear ratio; r_i = element story shear ratio for any given story level I, and A_B = Ground floor area of the building.

Note that the limiting values of ρ for the SMRF buildings are given by $1 \leq \rho \leq 1.25$.

3 Case study using IBC 2003

This section derives the numerical values used in the seismic design and analysis of the case study buildings using IBC 2003. IBC 2003 incorporates ASCE 7 provisions by reference, instead of including them in its text. Again, the calculations used for this case study are discussed in detail in the order of Design Base Shear, Vertical Distribution of the Base Shear, Story Drift and Drift Limits, and Redundancy Factor.

The Design Ground Motion Parameters of IBC 2003 are different from those of UBC 1997. These parameters can be derived from the tables and contour maps of IBC 2003. The use of the design spectrum has been included in the calculation of the seismic coefficient for the equivalent lateral force procedure in IBC 2003. The mapped maximum considered earthquake spectral response acceleration for the short period, S_s, (0.2 seconds) and the 1-second period, S_1, are first obtained from the IBC 2003 seismic maps. The contours represent the spectral response acceleration as a percent of gravity assuming 5% critical damping and soil conditions classified under site class B. The United States Geological Survey (USGS) researched and developed the new seismic hazard maps, which contain these isoseismic contours whose numbers equate to percentage of acceleration of gravity “g”. Site coefficients, F_a and F_v, were multiplied by S_s and S_1 respectively for each site class other than site class B, whose F_a and F_v values are equal to 1.

Table 2 Vertical distribution of design base shear – UBC 1997

kN

Occupancy	Office		Hospital	
Location	San Francisco	Sacramento	San Francisco	Sacramento
Roof	3094	1442	3867	1798
5th	3108	1449	3886	1806
4th	2368	1104	2960	1376
3rd	1628	759	2035	946
2nd	891	415	1114	518

Table 3A Drift and drift limits-office at San Francisco – UBC 1997

Floor	Δ_S (cm)	Δ_M (cm)	0.02× story height (cm)	O.K.	Drift ratio
Roof	6.95	41.35	47.55	Yes	0.87
5th	6.06	36.06	38.40	Yes	0.94
4th	4.55	27.05	29.26	Yes	0.92
3rd	3.23	19.20	20.12	Yes	0.94
2nd	1.74	10.36	10.97	Yes	0.94

Table 3B Drift and drift limits-office at Sacramento – UBC 1997

Floor	Δ_S (cm)	Δ_M (cm)	0.02× story height (cm)	O.K.	Drift ratio
Roof	6.82	40.56	47.55	Yes	0.85
5th	6.08	36.20	38.40	Yes	0.94
4th	4.68	27.85	29.26	Yes	0.95
3rd	3.34	19.86	20.12	Yes	0.99
2nd	1.81	10.78	10.97	Yes	0.98

Table 3C Drift and drift limits-hospital at San Francisco – UBC 1997

Floor	Δ_S (cm)	Δ_M (cm)	0.02× story height (cm)	O.K.	Drift ratio
Roof	7.05	41.95	47.55	Yes	0.88
5th	6.18	36.80	38.40	Yes	0.96
4th	4.65	27.67	29.26	Yes	0.95
3rd	3.32	19.75	20.12	Yes	0.98
2nd	1.80	10.68	10.97	Yes	0.97

Table 3D Drift and drift limits-hospital at Sacramento – UBC 1997

Floor	Δ_S (cm)	Δ_M (cm)	0.02× story height (cm)	O.K.	Drift ratio
Roof	6.86	40.82	47.55	Yes	0.86
5th	6.10	36.30	38.40	Yes	0.95
4th	4.65	27.69	29.26	Yes	0.95
3rd	3.27	19.47	20.12	Yes	0.97
2nd	1.73	10.32	10.97	Yes	0.94

$$S_{DS} = \frac{2}{3} S_{MS} = \frac{2}{3} F_a S_s \tag{5}$$

$$S_{D1} = \frac{2}{3} S_{M1} = \frac{2}{3} F_v S_1 \tag{6}$$

where S_{DS} = the design spectral response acceleration at short periods; S_{D1} = the design spectral response acceleration at 1 second; S_{MS} = the maximum considered earthquake spectral response acceleration at short periods, and S_{M1} = the maximum considered earthquake spectral response acceleration at 1 second.

Where a design response spectrum is required by these provisions and site-specific procedures are not used, the design response spectrum curve shall be developed as indicated in Fig. 2, in which T = the fundamental period of the structure, $T_0 = 0.2S_{D1} / S_{DS}$ and $T_S = S_{D1} / S_{DS}$.

3.1 Seismic use group and seismic design category

As indicated in Section 1616.2 of IBC 2003, each building was assigned to a particular seismic use group and given a corresponding occupancy importance factor I_E. A typical office building would fall under category II, which includes buildings and structures not listed in categories III, IV, and I. The seismic importance factor, I_E, was equal to 1.0.

3.2 Calculation of base shears and story forces

The approximate fundamental period of this building is about 0.914 seconds using the following equation,

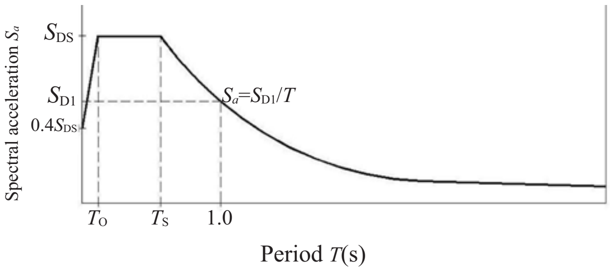


Fig. 2 IBC 2003 design response spectrum

$$T_a = C_t h_n^{\ x} \tag{7}$$

where C_t is 0.028 for a steel moment resisting frame system, h_n = 78 ft (23.77 m) and x = 0.8.

The seismic base shear V was determined using the following equation:

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

where C_s is the seismic response coefficient and W is the total weight of the building. C_s can be obtained by multiplying *1/R* by the spectral response acceleration S_{DS} from the design response spectrum curve according to the respective structural period. However, C_s can not be greater than $S_{D1}I_E/R/T_a$. The response modification coefficient, R, may be described as a numerical value representing the inherent overstrength and global ductility capacity of the lateral force resisting system (Tena-Colunga, 1999). For a "Special Reinforced Concrete Moment Frame" defined in IBC 2003, the value of R is equal to 8, which means that the lateral force resisting system would be quite ductile, so quite a bit of reduction is expected in the base shear forces. In addition, C_s must not be taken less than $0.044S_{DS}I_E$ or $0.5S_1I_E/R$, for structures in Seismic Design Categories E and F. Finally, the coefficients C_s and V, are summarized in Table 4 for San Francisco and Sacramento.

Once the base shear is determined, the lateral seismic force induced at any story level can be then obtained using the following equations given in IBC 2003.

$$F_x = C_{vx} V \tag{9}$$

and

$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k} \tag{10}$$

where F_x = the lateral seismic force at story level x;C_{vx} = vertical distribution factor;w_i (w_x) = the portion of the total building weight at story level i (or x);h_i (h_x) = the height from the ground floor to story level i (or x); k = an exponent related to the structure period; k = 1, if $T_a \leq 0.5$ seconds and k = 2, if $T_a \geq 2.5$ seconds.

The resulting k was calculated to be 1.207 using the interpolation method. These final calculations are summarized in Table 5.

3.3 Determining the story drift

The deflection of story level x at the center of the mass, δ_x, can be determined with the following equation:

$$\delta_x = \frac{C_d \delta_{xe}}{I} \tag{11}$$

where C_d = the deflection amplification factor (a factor of 5.5 was determined for this study) and δ_{ex} = the deflection determined by the elastic analysis using IBC-2003.

The maximum inelastic story drift, Δ_M, is equal to 0.020 times the story height for office buildings, while it is equal to 0.010 times the story height for essential facility. After various trials, each of the four site class buildings were analyzed and designed to meet the requirement of $\delta_x \leq \Delta_M$. Tables 6A to 6D list the δ_x versus the Δ_M. The trials continued until at least several, if not most, of the floors were close enough to the maximum inelastic story drift.

3.4 Redundancy factor

IBC 2003 references ASCE 7 Section 9.5.2.4 for the redundancy factor and its limiting values. ASCE 7 Section 9.5.2.4 also categorizes redundancy factor by seismic design category. In this case study, for buildings that fall under seismic category D, ASCE 7 Section 9.5.2.4.2 gives the following formula:

$$\rho = 2 - \frac{20}{r_{\max}\sqrt{A_X}} \tag{12}$$

where $r_{\max}$ = the ratio of the design story shear resisted by the single element carrying the most shear force in the story to the total design story shear, for a given direction of loading, and A_X = floor area of the diaphragm level immediately above the story.

Limiting values of ρ in general appear as $1 \leq \rho \leq 1.50$. Furthermore, values of ρ for SMRF under seismic category E appear as $1 \leq \rho \leq 1.10$. Numerical values for the redundancy factor of each floor for the case study buildings are presented in Table 7.

4 Comparison results

4.1 Importance factor and design ground motion parameters

Although IBC 2003 revised its table for the importance factors, IBC 2003 gives the same value of I = 1 for the seismic importance factor as UBC 1997 for the office buildings. UBC 1997 gives I = 1.25 for the essential facilities. IBC 2003, however, increased its importance factor for essential facilities, such as the

Table 4 Design base shear – IBC 2003

Location	San Francisco	Sacramento	San Francisco	Sacramento
Occupancy	Office		Hospital	
Importance factor	1		1.5	
S_S	1.828	0.563	1.828	0.563
S_1	1.161	0.218	1.161	0.218
F_a	1.00	1.35	1.00	1.35
F_v	1.50	1.96	1.50	1.96
$S_{MS}=F_a*S_S$	1.828	0.760	1.828	0.760
$S_{M1}=F_v*S_1$	1.742	0.427	1.742	0.427
$S_{DS}=2/3*S_{MS}$	1.219	0.507	1.219	0.507
$S_{D1}=2/3*S_{M1}$	1.161	0.285	1.161	0.285
Seismic design category	E	D	F	D
$T_S=S_{D1}/S_{DS}$	0.953	0.562	0.953	0.562
C_s	0.152	0.063	0.229	0.095
max C_s	0.159	0.039	0.238	0.058
min C_s	0.054	0.022	0.080	0.033
min C_s category E,F	0.073	N/A	0.109	N/A
Controlling C_s	Cs	Max	Cs	Cs
V (kN)	11418	2922	17127	4384

Note: For all buildings considered the soil type is D, T_a=0.914s, R=8, W=74932kN

Table 5 Vertical distribution of design base shear – IBC 2003

kN

Occupancy	Office		Hospital	
Location	San Francisco	Sacramento	San Francisco	Sacramento
Roof	2856	731	4285	1096
5th	3568	913	5353	1370
4th	2570	658	3855	987
3rd	1635	418	2453	628
2nd	789	202	1184	303

hospital in the case study to I_E = 1.5. IBC 2003 uses a subscript *E* to distinguish the importance factor for seismic force.

IBC 2003's significant difference from UBC 1997 is its Design Ground Motion Parameters. It introduced several different parameters that are not in UBC 1997. It is therefore difficult to directly correlate the parameters used in the two codes.

4.2 Design response spectrum

Figure 3 superimpose the design response spectrum for the two codes and show the variations in relation to the different soil types for the case study. The two arrows indicate the structural period for each of the codes. From these figures, they show that the design response spectrum under different soil types does not vary significantly between the two codes for the San Francisco area of the case study. IBC 2003 design response spectrum gives a lower value than UBC 1997. For the case study buildings located in San Francisco, which assumes soil type D, the structural period for IBC 2003 falls within the plateau of the curve and the structural period for UBC 1997 falls just to the right of the plateau into the descending curve. For the Sacramento area, however, the charts generally show that IBC 2003's design response spectrum is lower than

Table 6A Drift and drift limits-office at San Francisco – IBC 2003

Floor level	δ_{ex} (cm)	δ_x (cm)	0.02× story height (cm)	O.K.	Drift ratio
Roof	7.061	38.83	47.55	Yes	0.82
5th	6.325	34.79	38.40	Yes	0.91
4th	4.750	26.13	29.26	Yes	0.89
3rd	3.327	18.30	20.12	Yes	0.91
2nd	1.778	9.78	10.97	Yes	0.89

Table 6B Drift and drift limits-office at Sacramento – IBC 2003

Floor level	δ_{ex} (cm)	δ_x (cm)	0.02× story height (cm)	O.K.	Drift ratio
Roof	3.81	20.96	47.55	Yes	0.44
5th	3.48	19.14	38.40	Yes	0.50
4th	2.67	14.67	29.26	Yes	0.50
3rd	1.91	10.48	20.12	Yes	0.52
2nd	1.02	5.59	10.97	Yes	0.51

Table 6C Drift and drift limits-hospital at San Francisco – IBC 2003

Floor level	δ_{ex} (cm)	δ_x (cm)	0.01× story height (cm)	O.K.	Drift ratio
Roof	8.59	31.48	23.78	No	1.32
5th	7.77	28.50	19.2	No	1.48
4th	5.84	21.42	14.63	No	1.46
3rd	4.11	15.09	10.06	No	1.50
2nd	2.21	8.10	5.49	No	1.48

Table 6D Drift and drift limits-hospital at Sacramento – IBC 2003

Floor level	δ_{ex} (cm)	δ_x (cm)	0.01× story height (cm)	O.K.	Drift ratio
Roof	4.62	16.95	47.55	Yes	0.71
5th	4.22	15.46	38.40	Yes	0.81
4th	3.20	11.73	29.26	Yes	0.80
3rd	2.24	8.20	20.12	Yes	0.81
2nd	1.17	4.28	10.97	Yes	0.78

UBC 1997. For the case study buildings located in Sacramento, which assumes soil type D, the structural period for UBC 1997 and IBC 2003 both fall beyond the plateau into the descending curve.

4.3 Design base shear

For the case study office building in San Francisco, IBC 2003 and UBC 1997 design base shear values show little difference. IBC 2003 is slightly higher by 3%. However, for the case study office building in Sacramento, the IBC 2003 design base shear is 43% lower than UBC 1997. For the case study hospital building in San Francisco, the IBC 2003 design bases shear is higher by 24% than UBC 1997. For the case study hospital building in Sacramento, however, the IBC 2003 design base shear is 32% lower than UBC 1997. Variations in the design base shear as they relate to the different soil types are presented in Figs. 4 and 5. Location and occupancy use are made to be consistent with the assumptions for this case study.

The variations in design base shear can be summarized as follows:

- For the San Francisco office, IBC 2003 values are consistently slightly higher than UBC 1997 for soil types A, B and C and are almost equal for soil types D and E. IBC 2003 values range from being 15% higher for soil type A to 4% lower for soil type E.
- For the San Francisco Hospital, IBC 2003 is consistently higher than UBC 1997. The IBC 2003 values range from 38% higher for soil type A to 14% higher for soil type E.
- For the Sacramento office, IBC 2003 is consistently lower than that of UBC 1997. IBC 2003 values range

Table 7A Redundancy factor-office

	San Francisco		Sacramento	
	UBC 1997	IBC 2003	UBC 1997	IBC 2003
	<1.25	<1.1	<1.25	<1.25
Design category	E		D	
Roof	not reqd	1.266	not reqd	1.154
5th	not reqd	1.239	not reqd	1.215
4th	1.216	1.225	1.193	1.202
3rd	1.181	1.185	1.162	1.165
2nd	1.170	1.165	1.150	1.145
Remark	ok	not ok	ok	ok

Table 7B Redundancy factor-hospital

	San Francisco		Sacramento	
	UBC 1997	IBC 2003	UBC 1997	IBC 2003
	<1.25	<1.1	<1.25	<1.25
Design category	E		D	
Roof	not reqd	1.252	not reqd	1.173
5th	not reqd	1.274	not reqd	1.238
4th	1.244	1.256	1.220	1.230
3rd	1.219	1.224	1.174	1.178
2nd	1.198	1.193	1.159	1.155
Remark	ok	not ok	ok	ok

from 48% lower for soil type A to 41% lower for soil type E.

- For the Sacramento hospital, IBC 2003 is also consistently lower than that of UBC 1997. IBC 2003 values range from 38% lower for soil type A to 30% lower for soil type E.

4.4 Vertical distribution of base shear and drift ratio

The results for the vertical distribution of base shear are shown in Fig. 6 while the ratios of IBC/UBC for the vertical distribution of base shear are outlined in Table 8. For the Sacramento area, IBC 2003's vertical distribution of base shear is generally lower than UBC 1997, primarily due to IBC 2003's lower design base shear. IBC 2003's distribution at the roof level is generally lower in proportion to UBC 1997, mainly because UBC 1997 has an added value of F_t at the roof level.

The results for the vertical distribution of drift ratio are shown in Fig. 7. For the office buildings, IBC 2003 drift ratio results are generally lower than UBC 1997, mainly due to the lower design base shear derived using IBC 2003. For office buildings, both codes have the same allowable drift of 2% of the story height and the office buildings at the two locations pass this criterion under both codes. However, for the hospital buildings in the case study, the results vary. For the hospital building in San Francisco, IBC 2003 drift ratio results are higher than UBC 1997, making it fail it that criterion. This is mainly due to the lower allowable drift of 1% of the story height that IBC 2003 imposes. The hospital building in Sacramento passes this criterion despite the more stringent allowable drift, mainly due to the lower design base shear in that area.

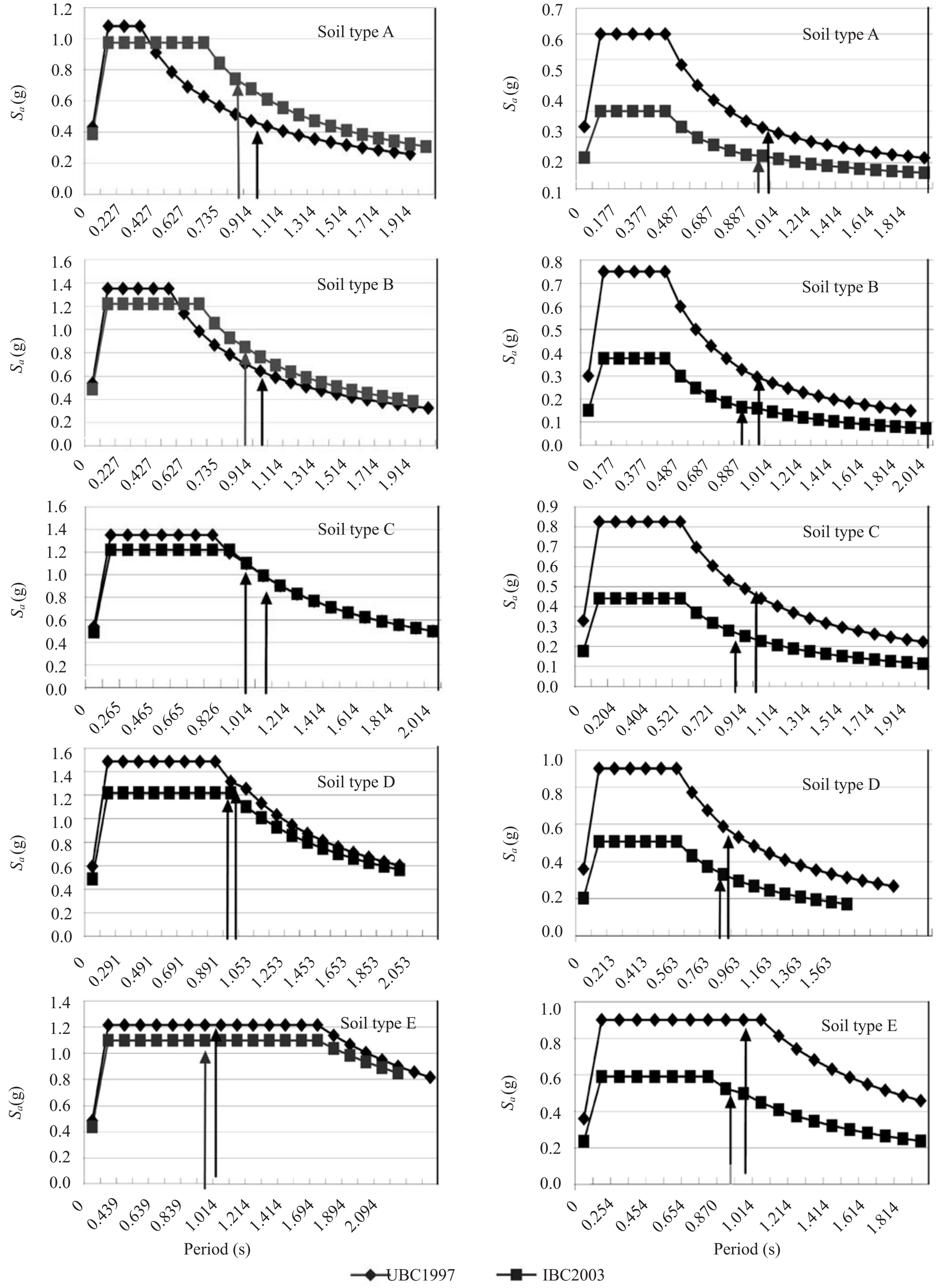
4.5 Redundancy factor and limits

A comparison of redundancy factors is shown in Fig. 8. IBC 2003's requirement for redundancy factors proves to be more stringent than the UBC 1997 requirement in two ways.

(1) It requires that ρ be computed for the entire structure at all levels in both directions, while UBC 1997 only requires ρ to be computed for the lower two thirds of the structure.

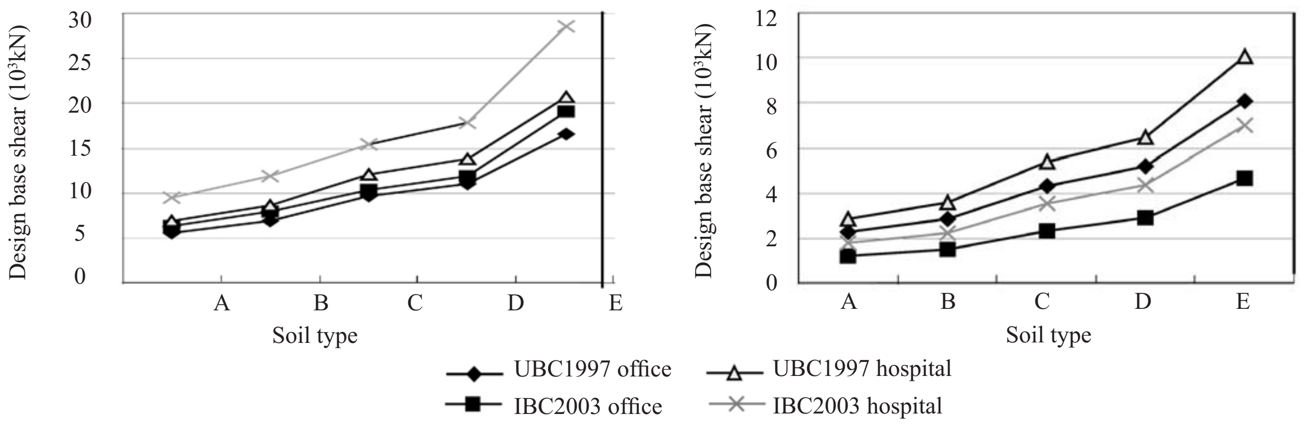
(2) For SMRF's in seismic design category E, it requires ρ not to exceed 1.1, which unlike UBC 1997, only requires ρ not to exceed 1.25 for SMRF's in general.

Unlike UBC 1997's definition of A_B, which is the ground floor area, IBC 2003's definition of A_x as the floor area of the diaphragm level immediately above the story, addresses variation in geometry of the structure. This attribute is, however, not obvious in



(a) San Francisco (b) Sacramento

Fig. 3 Design response spectrum for different soil types



(a) San Francisco (b) Sacramento

Fig. 4 Design base shear vs soil types - San Francisco

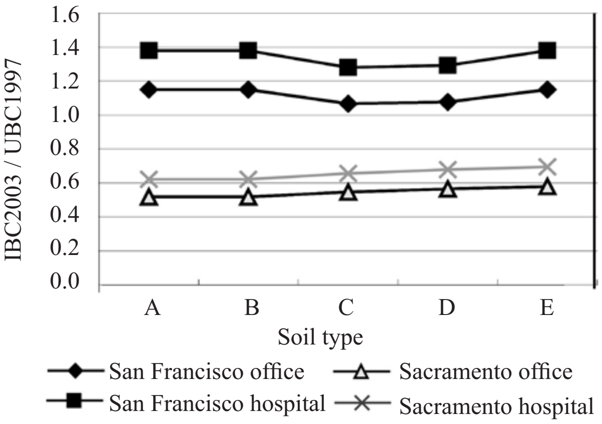
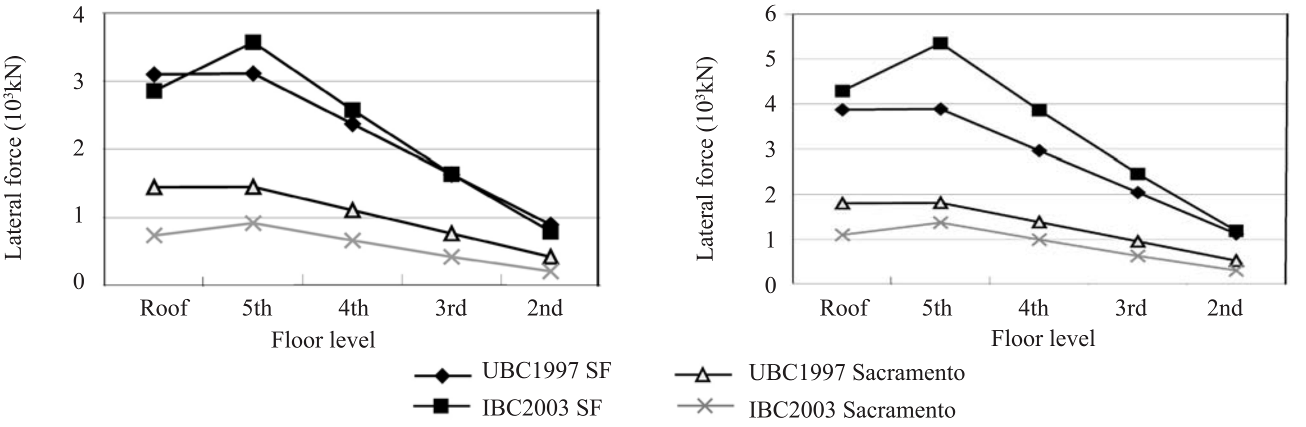


Fig. 5 Ratio of design base shear vs soil types



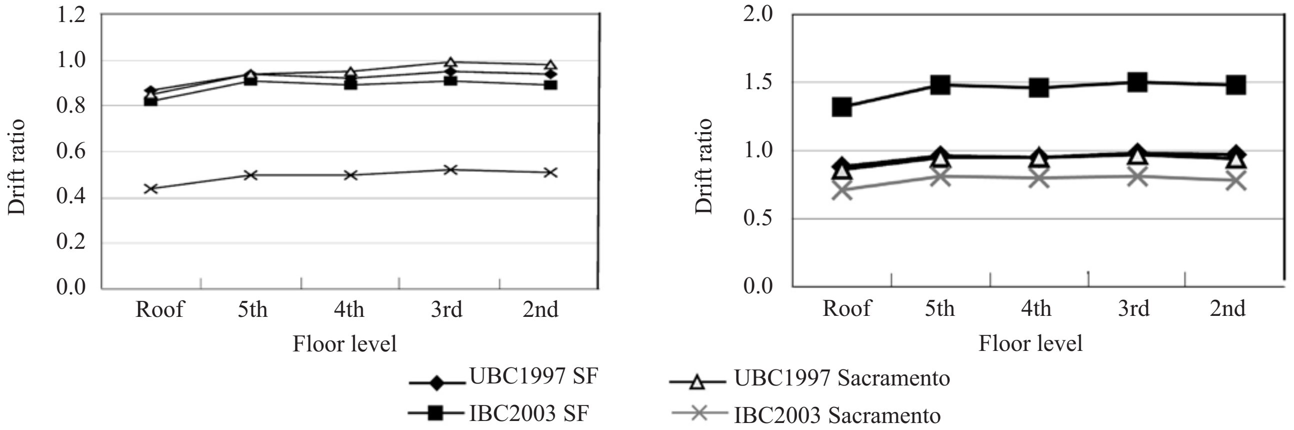
(a) Office (b) Hospital

Fig. 6 Vertical distribution of lateral forces-hospital

this case study since all the floors are of the same area. For the case study involving office buildings, the San Francisco office building does not pass the redundancy factor requirement for IBC 2003, mainly due to it being categorized under seismic design category E, which imposes a limit of 1.1. The Sacramento building passes this criteria being under seismic design category D, which imposes a limit of 1.25.

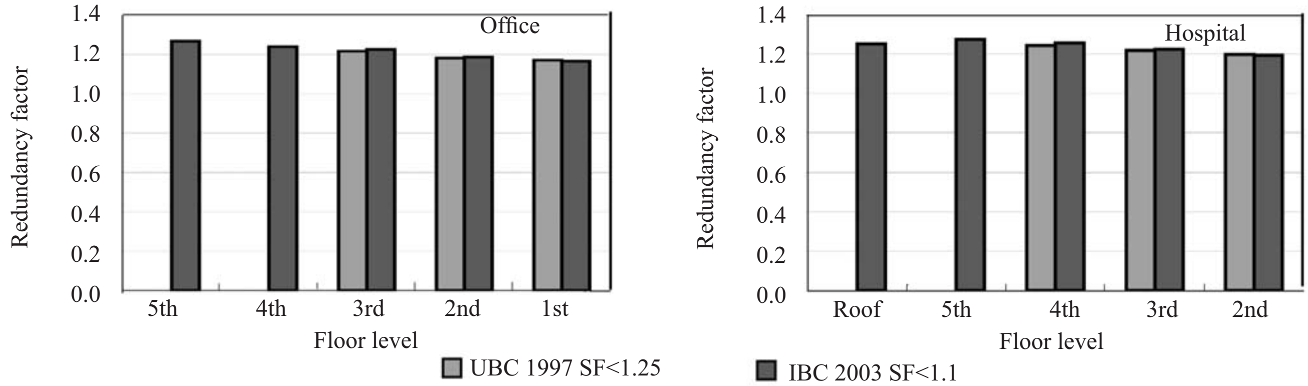
Table 8 Vertical distribution of design base shear

Floor	San Francisco		Sacramento	
	Office	Hospital	Office	Hospital
	Ratio IBC/UBC			
Roof	0.92	1.11	0.51	0.61
5th	1.15	1.38	0.63	0.76
4th	1.09	1.30	0.60	0.72
3rd	1.00	1.21	0.55	0.66
2nd	0.89	1.06	0.49	0.59
Total V	1.03	1.24	0.57	0.68

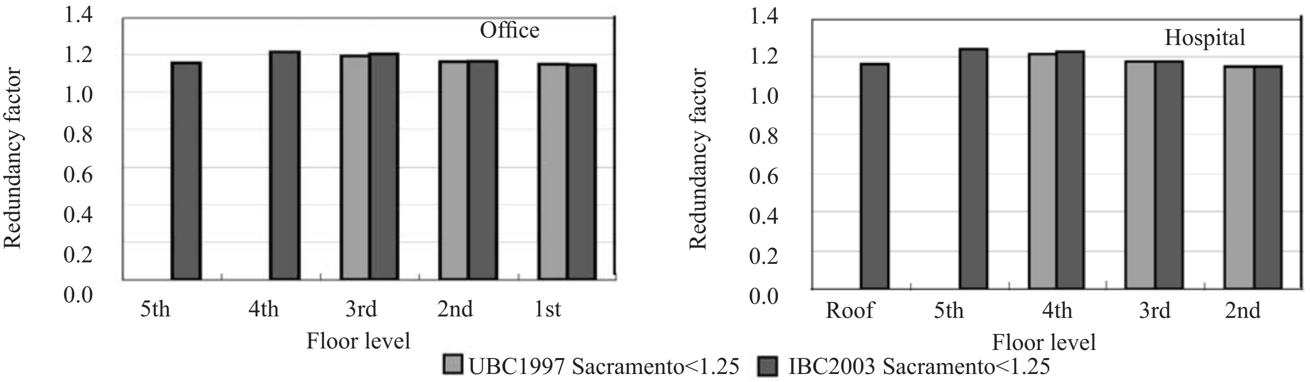


(a) Office (b) Hospital

Fig. 7 Vertical distribution of drift ratio



(a) At San Francisco



(b) At Sacramento

Fig. 8 Redundancy factor

5 Conclusions

This study provides some valuable insights into UBC 1997 and new IBC 2003 with regard to seismic design and analysis of Special Steel Moment Frame buildings. The numerical study supports the conclusion that for some criteria the differences between UBC 1997 and IBC 2003 are not just superficial. In fact, this study shows that in some instances, buildings modeled and designed using the UBC 1997 code do not pass the IBC 2003 standard for the criterion of redundancy factor ρ.

This study also shows that essential facilities such as hospitals designed using UBC 1997 may, in some cases, not pass IBC 2003's stringent requirement for drift limits. The study also shows that the difference between the codes for seismic design base shear varies depending on location and occupancy use. The difference in design base shear can be insignificant for a San Francisco office building, but can have a 24% higher IBC 2003 value for a San Francisco hospital building. The seismic design base shear for the Sacramento area generally gives a lower IBC 2003 value as compared to UBC 1997. In the Sacramento area, the IBC 2003 value for design base shear is lower than under UBC 1997 requirements by as much as 44% for the office building and lower by 32% for the hospital building in this case study. The vertical distribution of the seismic design base shear shows that the two codes have a different shape for force distribution at its rooftop and 5th floor levels.

A comparison of drift ratio indicates that IBC 2003's more stringent allowable drift for essential facilities can cause a building that would pass UBC 1997 to fail for this criterion under IBC 2003. It can also be concluded from these results, that for IBC 2003, the soil type can impact the redundancy factor limit, since it influences the seismic design category of the building, which in turn determines the redundancy factor limit. Whereas, the redundancy factor limit under UBC1997 is only dependent on the building type, regardless of its location or occupancy use.

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