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A Comparison of Saudi Building Code with 1997 UBC for Provisions of Modal Response Spectrum Analysis Using a Real Building

Tariq M. Nahhas

Civil Engineering Department, Umm Al-Qura University, Makkah, Saudi Arabia
Email: tmnahhas@uqu.edu.sa

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Abstract

The study uses an actual building to compare the modal response spectrum analysis results of Saudi Building Code (SBC) and the 1997 Uniform Building Code (UBC) used in Saudi Arabia before the introduction of SBC. A sample of four buildings with reported analysis of comparison between IBC and UBC is taken for confirming the comparison. Eight sample places from SBC map for Saudi Arabia together with two sample places of high seismic activity in USA were taken for the comparisons. The study used software package ETABS in this study for modeling and analysis. The results are dissimilar from the comparisons reported for test places of USA. It is concluded that at most places SBC base shear is higher for both ELFP and MRSA. However, the results cannot be generalized and considered always right. The same is factual for overturning moments. Consequently, we cannot report that SBC is more conservative than UBC for all scenarios.

Keywords

Seismic Analysis, Seismic Design, Building Codes, Response Spectrum, Building Structure

1. Introduction

Several academic studies have offered assessments of building codes provisions for seismic analysis. Reference [1], reported seismic design for building structures in Canada, the United States, Chile and New Zealand. The code provisions are implemented to a 9-storey building situated in area in each country having similar seismic circumstances. The comparable seismic loads are identified for this structure in Canada and Chile, whereas considerably lower seismic effects are used for the U.S. The use of the dynamic (response spectrum) analysis process caused in lighter and more flexible structures as compared to the corresponding static force system in all countries. Seismic stability necessities had greater influence on designs in Canada and New Zealand. Reference [2] advocated for higher emphasis on evaluation of international standards. The taken standards are Eurocode, IBC (American Society of Civil Engineers) and Indian code *i.e.* IS 1893:2002. These findings also support in knowing main elements which lead to reduced performance of structure subjected to earthquake. These results also guide to attain satisfactory safe performance under future earthquakes. The lateral seismic forces, applied to the center of gravity of the structure are measured manually for each floor in X and Z direction. The analytical output of the model buildings is shared graphically and in tabular form. Differences in the findings using three codes *i.e.* Eurocode, IBC (ASCE) and Indian code are reported. A comparative examination is done in terms of Base shear, Displacement, Axial load, Moments in Y and Z direction for particular columns. It also presents comparison of different codes for selected columns and beams for Displacement, Axial load, Moments in Y and Z direction floor wise.

Reference [3] reported a comparative research of various code-based record selection procedure suggested by Eurocode 8, ASCE41-13 and NZS1170.5:2004. Different procedures in the seismic evaluation of four steel buildings, planned according to different criteria are employed to report comparable findings. Reference [4] reported an assessment of seismic provisions of three seismic design codes, the Philippine code, Eurocode 8 and the American code, to the well-known residential frames of normal occupancy and compared regular and irregular reinforced concrete frames for four story building structures. The response spectrum and the seismic parameters of NSCP 2010 were taken for the horizontal load action with diverse load combinations. Based on the findings of column axial load bending moment interaction diagrams, EC8 was reported to be conservative when matched to NSCP 2010 and 2009 IBC. It was concluded in [4] that for the design and investigation of ordinary RC residential buildings with certain irregularity, EC8 provisions can be chosen as safer.

The most relevant paper in this regard is authored by Nahhas [5] reporting an assessment of the seismic forces generated from a Modal Response Spectrum Analysis (MRSA) by implementing the two building codes; the 1997 Uniform Building Code (UBC) and the 2000-2009 International Building Code (IBC), to the normal domestic buildings of standard occupancy. The UBC was reported to be considerably more conservative than the IBC for all the investigated cases. The UBC design response spectra have higher spectral accelerations. Therefore, the response spectrum investigation delivered a much higher base shear and moment in the structural members as compared to the IBC. These studies lead to the conclusion that normal office and domestic buildings designed using UBC 1997 are reflected to be overdesigned, and therefore they are relatively safer than the designs based as per IBC provisions. Reference [6], assessed the Turkish Earthquake Code and the Euorocode 8 with UBC based on (Modal Response Spectrum Analysis) MRSA using finite element investigation process for structural examination. This is the only research that likened two codes using MRSA. In this research, the IBC response spectra have been reported to be dissimilar from UBC and others. However, no MRSA data associating IBC and UBC have been reported.

Reference [7] also presented comparison of IBC and UBC. The findings reported in this study were taken using the ELFP but not MRSA. It is a key research on this topic and has significant but non-conclusive findings. The results are mixed for two predominantly designated sites in San Francisco and Sacramento. This research found that UBC is more conservative in some areas but the findings reported are not definite. Another paper [8] equated IBC with the Mexico's code.

It is important to note, that IBC does not permit the implementation of ELFP for computing the base shear and other inside forces for structures in the seismic design category D and above if the modal basic time period of a structure computed by FEM is larger than that by ELFP. In such areas, procedure as modal response spectrum examination, linear response history, nonlinear static procedure or non-linear response history analysis must be used [9]. In such areas, the normally employed used procedure is response spectrum analysis method (ASCE 7-05 Section 162) which is also acceptable by IBC. This paper has embraced the same for all cases.

This paper extends the work presented in [5] using a real building to compare the modal response spectrum analysis results of Saudi Building Code (SBC) and the 1997 Uniform Building Code (UBC) used in Saudi Arabia before the introduction of SBC. Eight sample places from SBC map for Saudi Arabia together with two sample places of high seismic activity in USA are taken for the comparisons. This study was important to ensure that the conclusion drawn by [5] that UBC being more conservative than IBC for academic frames is valid for SBC using the spectral accelerations from the maps provided in the code.

2. Test Locations

Eight test locations were randomly selected for KSA for comparing the Saudi Building Code (SBC) with UBC and are shown on the SBC map in **Figure 1**. The selected test locations in USA are shown in **Figure 2**. Both locations were in the areas of high earthquake probability.

3. Modeling

The software package ETABS was used in this study for modeling and analysis. The structures were modeled as special moment resisting frame system, which is a requirement of building codes for higher seismic zones. Slabs were modeled using shell elements to represent the real slab behavior, providing stiffness in all directions and transfer mass of slab to beams. A rigid diaphragm was assumed at all floor levels. The modal combination method used for all models was CQC (Complete Quadratic Combination). It is preferred over SRSS (Square Root of Sum of Squares) because the structural models of the sample buildings used in

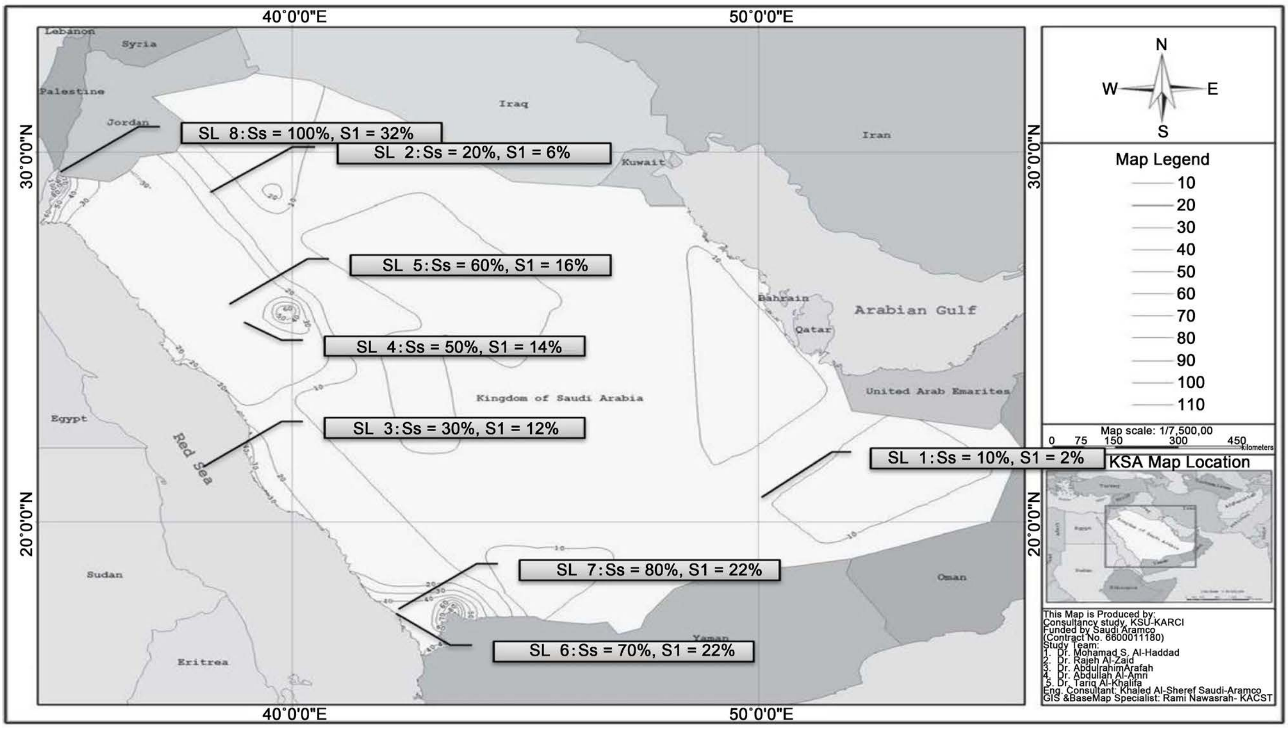

Figure 1. Sample test locations in Saudi Arabia.

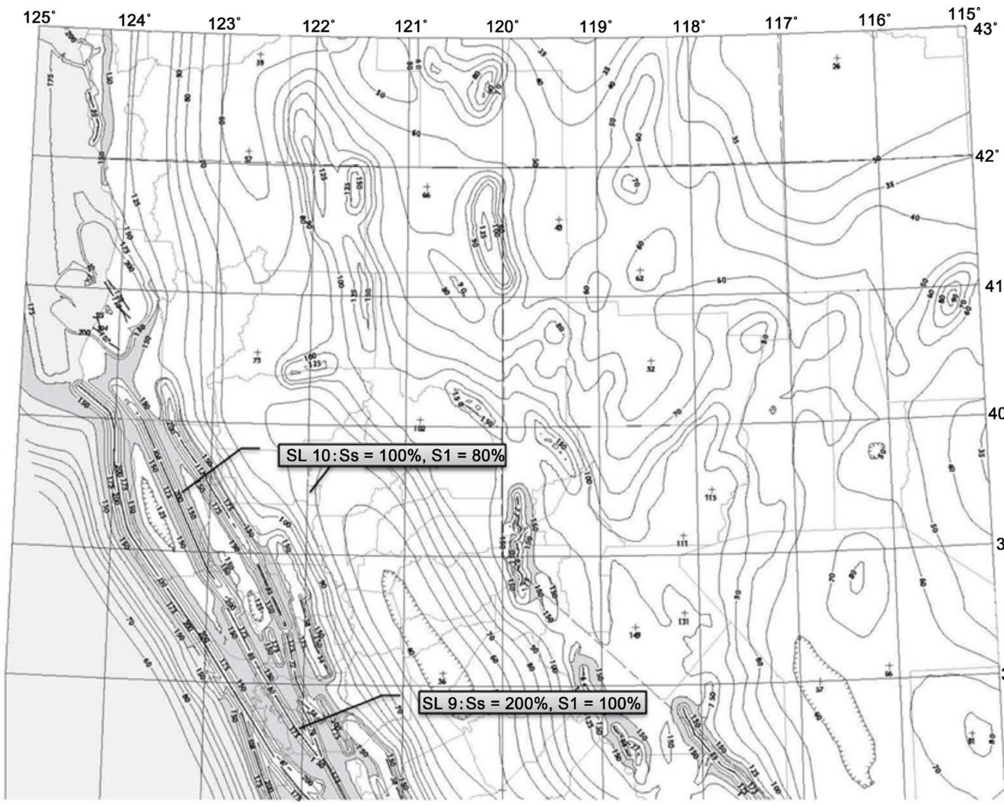

Figure 2. Sample test locations in USA.

this work are all 3-dimensional with the possibility of closely spaced modes. CQC results are generally much more accurate for structures with closely spaced modes [10]. The internal forces obtained using CQC are about the same as SRSS. It was verified for all the buildings used in this work.

4. Results of Verification

Before modeling the real building structures, verification was done through published problems in [5] which calculated base shear and moments using UBC and IBC at four US locations for four different building structures modelled as 3-D frames. The paper shows results for soil types A to E. This study reports exactly same results as published in the paper by Nahhas [5]. The results vary from building to building quantitatively but remain the same qualitatively. The paper shows that the maximum base shear varies from sample location 1 (area of low seismicity) to sample point 4 (area of high seismicity) in a logical manner. Also, the maximum base shear values increase with varying site class from A to E for each sample location except for sample location 4. For sample location 4, for all buildings, the maximum base shear for site class E is significantly lower than what is for site class D. An explanation has been provided in the paper for this anomaly. This is actually related to the modal contribution and the design response spectrum for the sample point 4. The design response spectrum for soil type D and E at sample point 4 have a large difference in the peak spectral acceleration. For site class D, it is close to 1.7 g whereas for site class E it is about 1.4 g. This discrepancy does not exist for other sample locations. This is how the code has been developed for this high area of seismicity.

5. Real-World Building

A real-world building was modeled using ETABS. The framing plan for the building is shown in Figure 3. Figure 4 shows the perspective view of the building structure. The important specifications of the structure are given in Table 1.

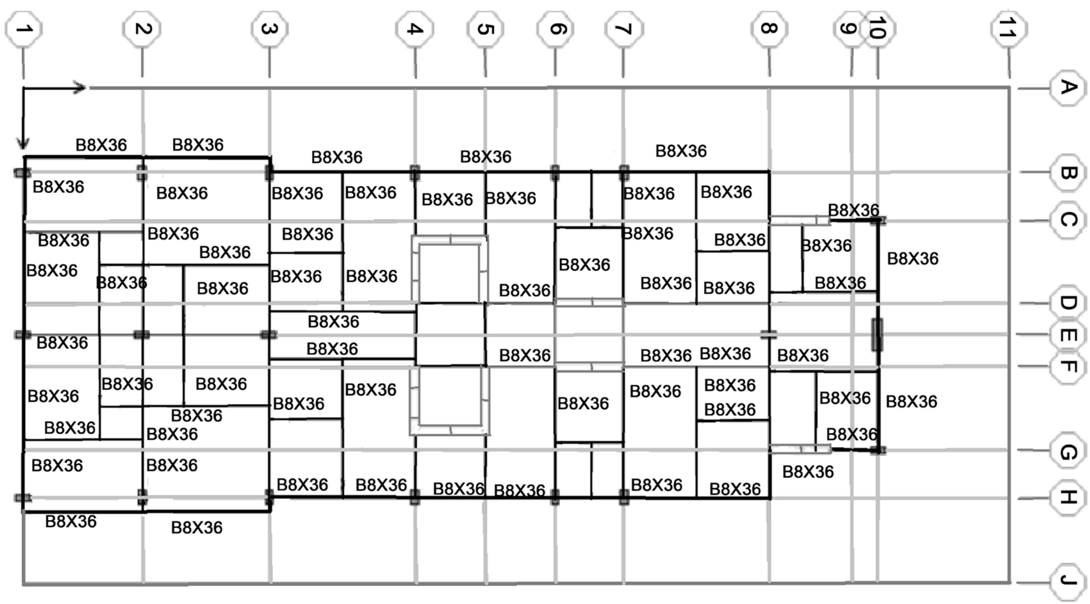

Figure 3. Framing plan of real building 1.

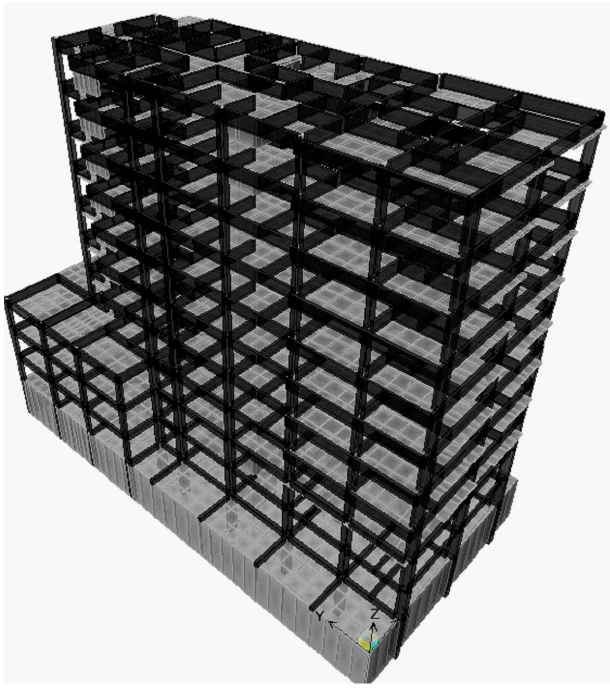

Figure 4. Perspective view of real building 1.

Table 1. Real building specifications.

Data Item	Specifications
No. of Floors	10
Story Height (m)	For Stories 1 - 2: 3.28 m
	For Stories 3 - 10: 3.35 m
Beam sections (mm)	200 × 600
	200 × 900
	250 × 600
	300 × 450
	300 × 600
	300 × 750
	300 × 900
	300 × 1050
Column Sections (mm)	250 × 600
	300 × 600
	300 × 750
	375 × 750
	450 × 750
	450 × 1350
Shear Wall Thickness (mm)	300
Slab Thickness (mm)	Slab: 150
	Stair: 200
Material	Reinforced Concrete
Excitation Direction	X & Y Direction

Table 2 shows the modal periods & participating mass for the structure. Results for 50 modes have been presented. The fundamental time periods of the structure are shown in Table 3 calculated using Equivalent Lateral Force Procedure (ELFP) as well as MRSA. The ELFP calculation has been done using UBC and SBC. In MRSA, the code does not specify any parameters so it is independent of the code. MRSA gives a higher time period (about 40%) when compared to the ELFP. It represents the mass participation along X-direction equal to 29.4% of the total mass as shown in Table 2. A much bigger mass participation is along Y direction and has a value of 63.42% for second mode with a time period of 1.228. Mode 3 with a time period of 1.014 (about the same as ELFP time period) is also significant with a participation of 35.79 %. Mode 4 has no significant participation and Mode 5 has a participation of 16.48% along Y. Table 2 shows that about 80% of the mass participation is accounted for in the first 10 modes. The remaining modes don not participate significantly. However, 44 modes together of the 50 modes account for about 99% participation.

Table 4 shows the parameters used to generate the design response spectra for the real building assumed to be located at 10 different locations. These locations are shown in Figure 1 and Figure 2. Out of the 10 different locations, 8 locations are selected in the various areas of the Kingdom of Saudi Arabia. Two of the ten locations have been selected in the severe earthquake area of California USA. The parameters are shown for both UBC 1997 code and Saudi Building Code 2007. For each of the ten different locations the five site classes, A, B, C, D and E are assumed to generate 50 cases of design spectra. Values of SBC parameters SS and S1 for these locations are also given in Figure 1 and Figure 2.

Since MRSA requires input of Design Spectra, the design spectra are generated for all site classes for all sample locations. Figure 5 shows the design spectra for Location 1. Five different design spectra are shown for five different site classes: A, B, C, D, E. Similarly, Figures 6-14 give the design response spectra for locations 2 to 10. It is important to note the following about these design spectra:

1) The response spectra for locations 1 and 2 correspond to Zone 0 with no earthquake activity according to UBC. Therefore, the UBC design spectrum is just a horizontal line with zero magnitude shown in red color. But for SBC, the location does represent probability of earthquake and therefore, a normal design spectrum is attained. This is an important finding in the context of the difference between UBC and SBC.
2) It can be seen that the design spectra shapes do not change much as we vary the site class from A to D but the peak value goes up ranging from 0.055g to 0.17 g.
3) The design spectra shapes and peak magnitudes change drastically as we move from one location to another. It ensures that the selected locations have quite different geological properties.
4) Looking at the peak acceleration of the design spectra, the following is observed:

Location 1: PSBC > PUBC (PUBC = 0)

Table 2. Modal periods & participating mass for real building.

Mode	Period	Individual Participation %			Cumulative Participation %		
		Along X	Along Y	Along Z	Along X	Along Y	Along Z
1	1.412	29.40	0.00	0.00	29.40	0.00	0.00
2	1.228	0.00	63.42	0.00	29.40	63.42	0.00
3	1.014	35.79	0.00	0.00	65.19	63.42	0.00
4	0.393	2.28	0.00	0.00	67.47	63.42	0.00
5	0.303	0.00	16.48	0.00	67.47	79.90	0.00
6	0.296	8.85	0.00	0.00	76.32	79.90	0.00
7	0.186	0.93	0.00	0.00	77.26	79.90	0.00
8	0.153	4.36	0.00	0.00	81.61	79.90	0.00
9	0.136	0.00	5.30	0.00	81.61	85.20	0.00
10	0.131	4.69	0.00	0.00	86.30	85.20	0.00
11	0.129	0.77	0.00	0.00	87.07	85.20	0.00
12	0.102	0.00	0.02	0.00	87.07	85.22	0.00
13	0.100	0.04	0.00	0.00	87.11	85.22	0.00
14	0.092	3.39	0.00	0.00	90.50	85.22	0.00
15	0.080	0.00	2.67	0.00	90.50	87.88	0.00
16	0.076	0.00	0.00	0.00	90.50	87.88	0.00
17	0.073	0.16	0.00	0.00	90.66	87.88	0.00
18	0.066	1.01	0.00	0.00	91.67	87.88	0.00
19	0.061	0.81	0.00	0.00	92.48	87.88	0.00
20	0.059	0.60	0.00	0.00	93.08	87.88	0.00
21	0.056	0.00	2.07	0.00	93.08	89.96	0.00
22	0.054	0.01	0.00	0.00	93.08	89.96	0.00
23	0.052	0.31	0.00	0.00	93.39	89.96	0.00
24	0.051	0.07	0.00	0.00	93.46	89.96	0.00
25	0.050	1.00	0.00	0.00	94.46	89.96	0.00
26	0.050	2.09	0.00	0.00	96.55	89.96	0.00
27	0.049	0.40	0.00	0.00	96.96	89.96	0.00
28	0.046	0.07	0.00	0.00	97.03	89.96	0.00
29	0.045	0.00	0.30	0.00	97.03	90.26	0.00
30	0.043	0.39	0.00	0.00	97.41	90.26	0.00
31	0.041	0.00	1.19	0.00	97.41	91.45	0.00
32	0.040	0.89	0.00	0.00	98.30	91.45	0.00
33	0.038	0.00	0.02	0.00	98.30	91.47	0.00
34	0.036	0.75	0.00	0.00	99.05	91.47	0.00
35	0.034	0.00	0.00	0.00	99.05	91.47	0.00
36	0.034	0.00	2.68	0.00	99.05	94.15	0.00

Continued

37	0.031	0.02	0.00	0.00	99.07	94.15	0.00
38	0.030	0.00	2.17	0.00	99.07	96.32	0.00
39	0.028	0.00	0.00	0.00	99.07	96.32	0.00
40	0.026	0.00	0.00	0.00	99.07	96.32	0.00
41	0.026	0.00	0.00	0.00	99.07	96.32	0.00
42	0.026	0.10	0.00	0.00	99.17	96.32	0.00
43	0.026	0.00	0.97	0.00	99.17	97.29	0.00
44	0.024	0.00	2.46	0.00	99.17	99.75	0.00
45	0.024	0.52	0.00	0.00	99.69	99.75	0.00
46	0.023	0.00	0.06	0.00	99.69	99.80	0.00
47	0.022	0.00	0.00	0.00	99.69	99.80	0.00
48	0.021	0.00	0.00	0.00	99.69	99.81	0.00
49	0.021	0.00	0.00	0.00	99.69	99.81	0.00
50	0.021	0.00	0.01	0.00	99.69	99.82	0.00

Table 3. Fundamental time periods of the real building.

ELFP(UBC)	ELFP(SBC)	MRSA (ETABS)
1.0138	1.0138	1.412

Table 4. Real building design spectra cases.

LOC ID	Site Class	Zone	UBC 1997		SBC 2007		
			Ca	Cv	Ss	S_1	TL
1	A	0	0	0	0.1	0.02	8
	B	0	0	0	0.1	0.02	8
	C	0	0	0	0.1	0.02	8
	D	0	0	0	0.1	0.02	8
	E	0	0	0	0.1	0.02	8
2	A	0	0	0	0.2	0.06	8
	B	0	0	0	0.2	0.06	8
	C	0	0	0	0.2	0.06	8
	D	0	0	0	0.2	0.06	8
	E	0	0	0	0.2	0.06	8
3	A	2A	0.12	0.12	0.3	0.12	8
	B	2A	0.15	0.15	0.3	0.12	8
	C	2A	0.18	0.25	0.3	0.12	8
	D	2A	0.22	0.32	0.3	0.12	8
	E	2A	0.3	0.5	0.3	0.12	8

Continued

4	A	1	0.06	0.06	0.5	0.14	8
	B	1	0.08	0.08	0.5	0.14	8
	C	1	0.09	0.13	0.5	0.14	8
	D	1	0.12	0.18	0.5	0.14	8
	E	1	0.19	0.26	0.5	0.14	8
5	A	1	0.06	0.06	0.6	0.16	8
	B	1	0.08	0.08	0.6	0.16	8
	C	1	0.09	0.13	0.6	0.16	8
	D	1	0.12	0.18	0.6	0.16	8
	E	1	0.19	0.26	0.6	0.16	8
6	A	2B	0.16	0.16	0.7	0.22	8
	B	2B	0.2	0.2	0.7	0.22	8
	C	2B	0.24	0.32	0.7	0.22	8
	D	2B	0.28	0.4	0.7	0.22	8
	E	2B	0.34	0.64	0.7	0.22	8
7	A	2A	0.12	0.12	0.8	0.22	8
	B	2A	0.15	0.15	0.8	0.22	8
	C	2A	0.18	0.25	0.8	0.22	8
	D	2A	0.22	0.32	0.8	0.22	8
	E	2A	0.3	0.5	0.8	0.22	8
8	A	2B	0.16	0.16	1	0.32	8
	B	2B	0.2	0.2	1	0.32	8
	C	2B	0.24	0.32	1	0.32	8
	D	2B	0.28	0.4	1	0.32	8
	E	2B	0.34	0.64	1	0.32	8
9	A	4	0.32	0.32	1.75	0.8	8
	B	4	0.4	0.4	1.75	0.8	8
	C	4	0.4	0.56	1.75	0.8	8
	D	4	0.44	0.64	1.75	0.8	8
	E	4	0.36	0.96	1.75	0.8	8
10	A	4	0.32	0.32	2	1	8
	B	4	0.4	0.4	2	1	8
	C	4	0.4	0.56	2	1	8
	D	4	0.44	0.64	2	1	8
	E	4	0.36	0.96	2	1	8

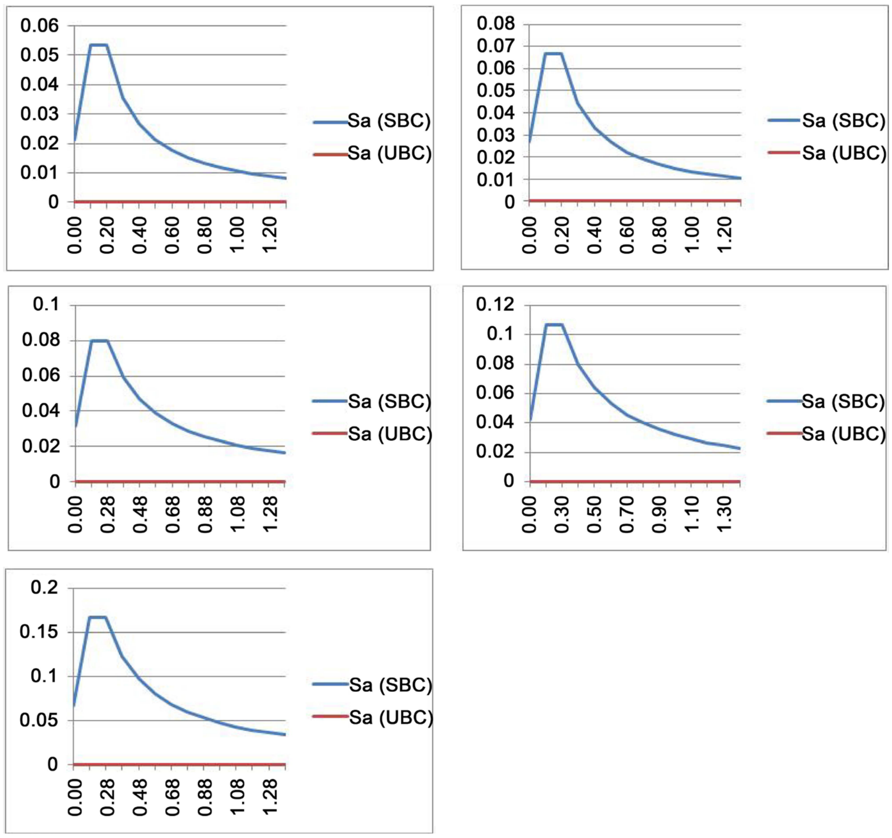

Figure 5. Design Response Spectra for Location 1 (Site classes: A, B, C, D, E).

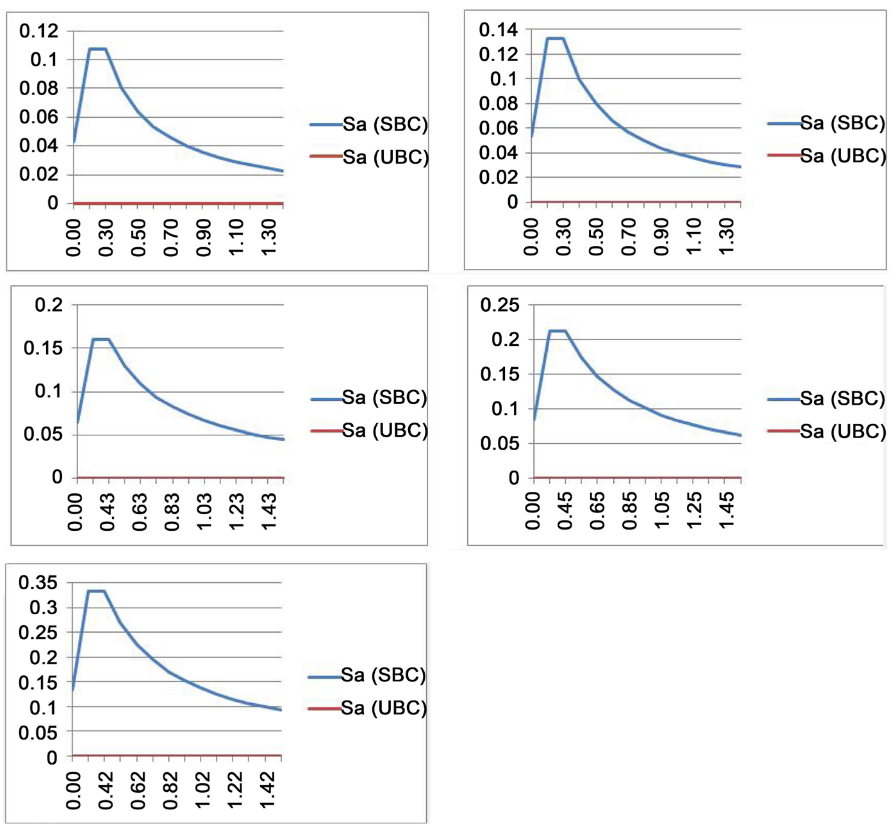

Figure 6. Design Response Spectra for Location 2 (Site class: A, B, C, D, E).

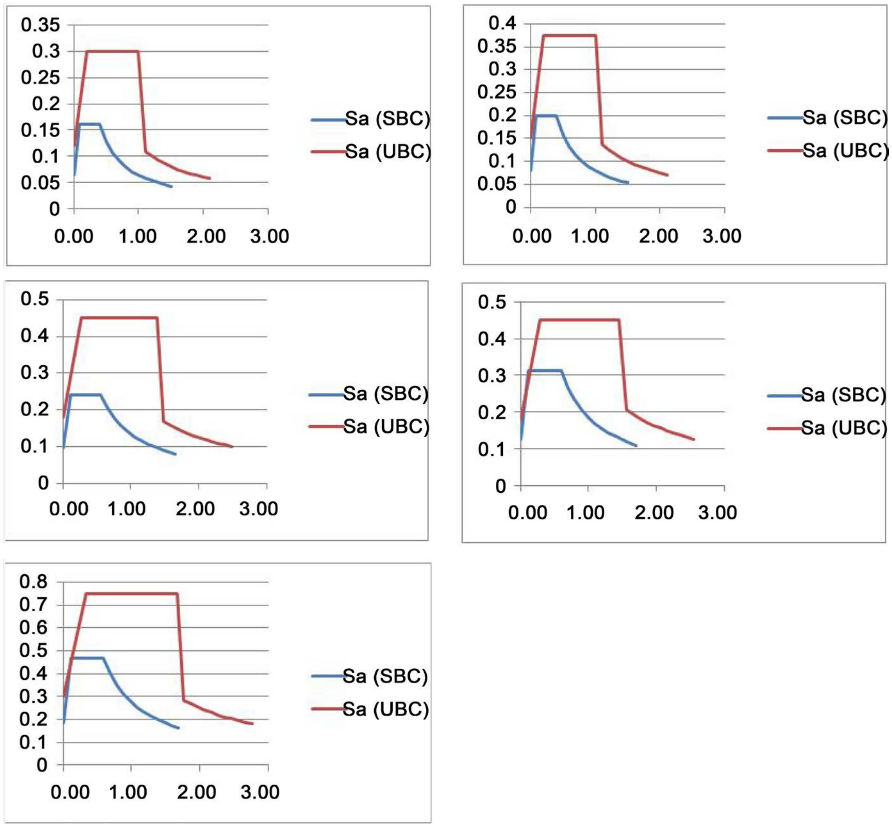

Figure 7. Design Response Spectra for Location 3 (Site class: A, B, C, D, E).

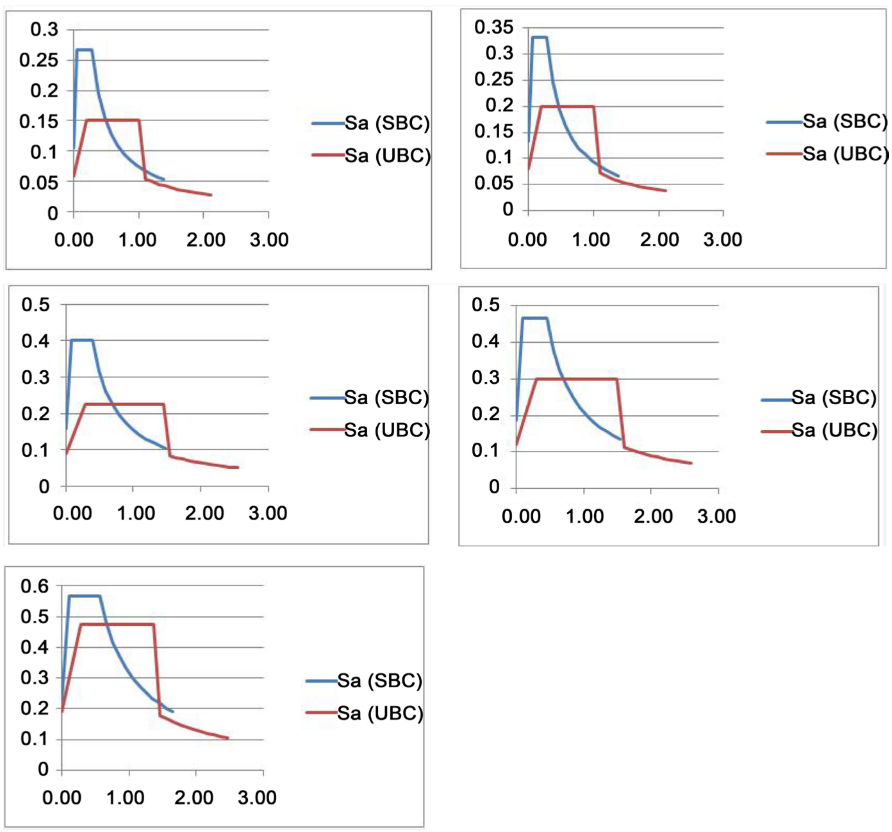

Figure 8. Design Response Spectra for Location 4 (Site class: A, B, C, D, E).

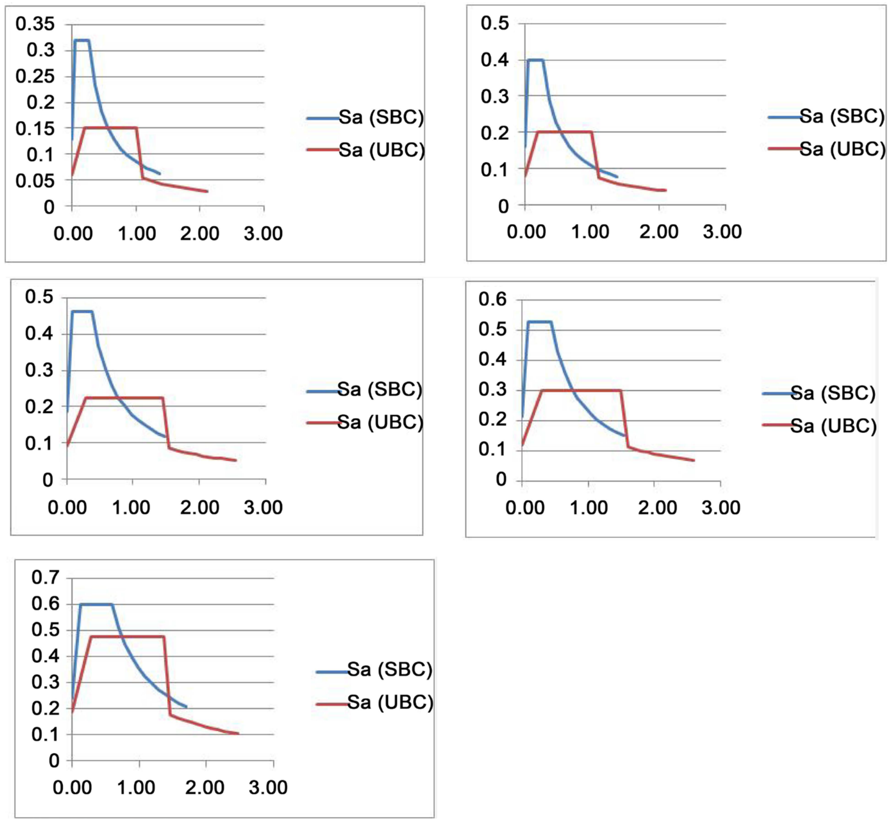

Figure 9. Design Response Spectra for Location 5 (Site class: A, B, C, D, E).

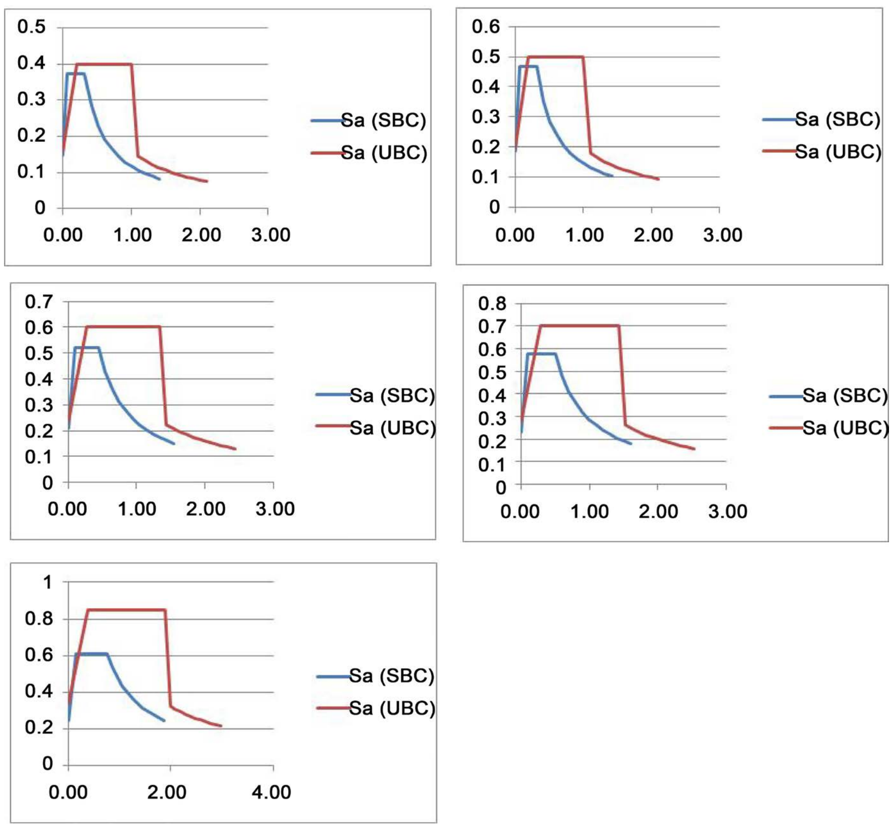

Figure 10. Design Response Spectra for Location 6 (Site class: A, B, C, D, E).

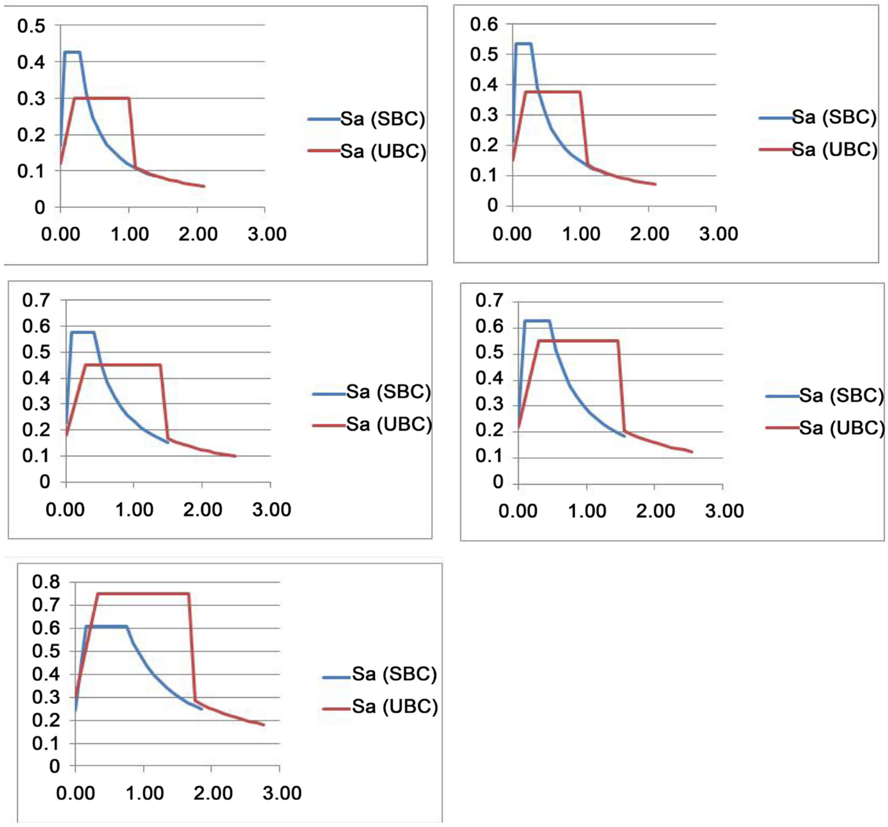

Figure 11. Design Response Spectra for Location 7 (Site class: A, B, C, D, E).

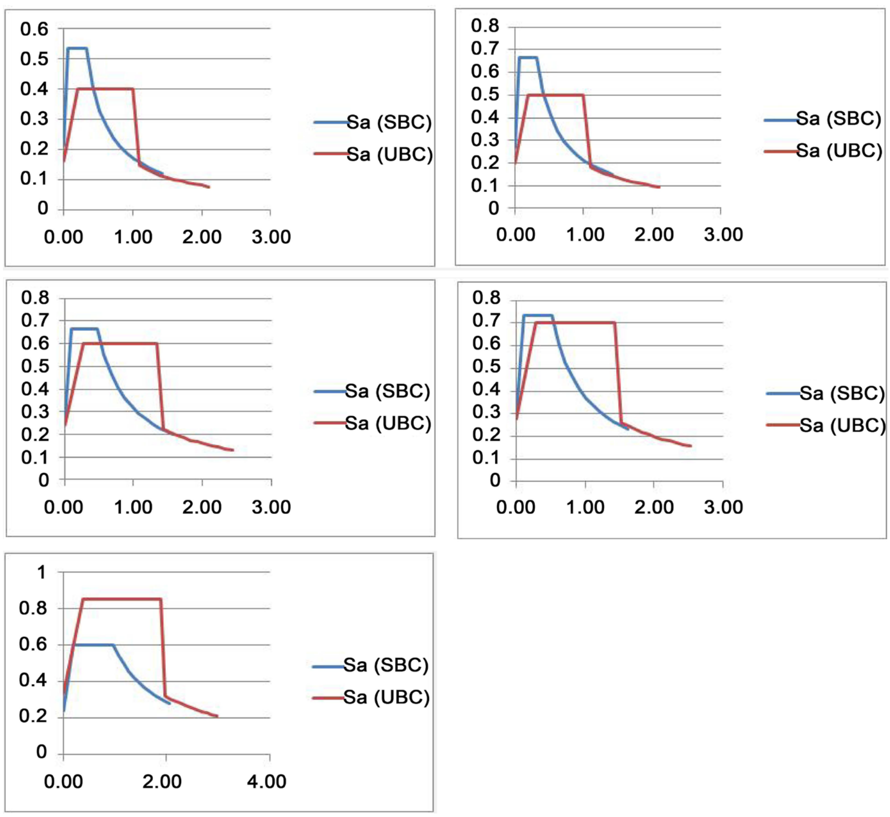

Figure 12. Design Response Spectra for Location 8 (Site class: A, B, C, D, E).

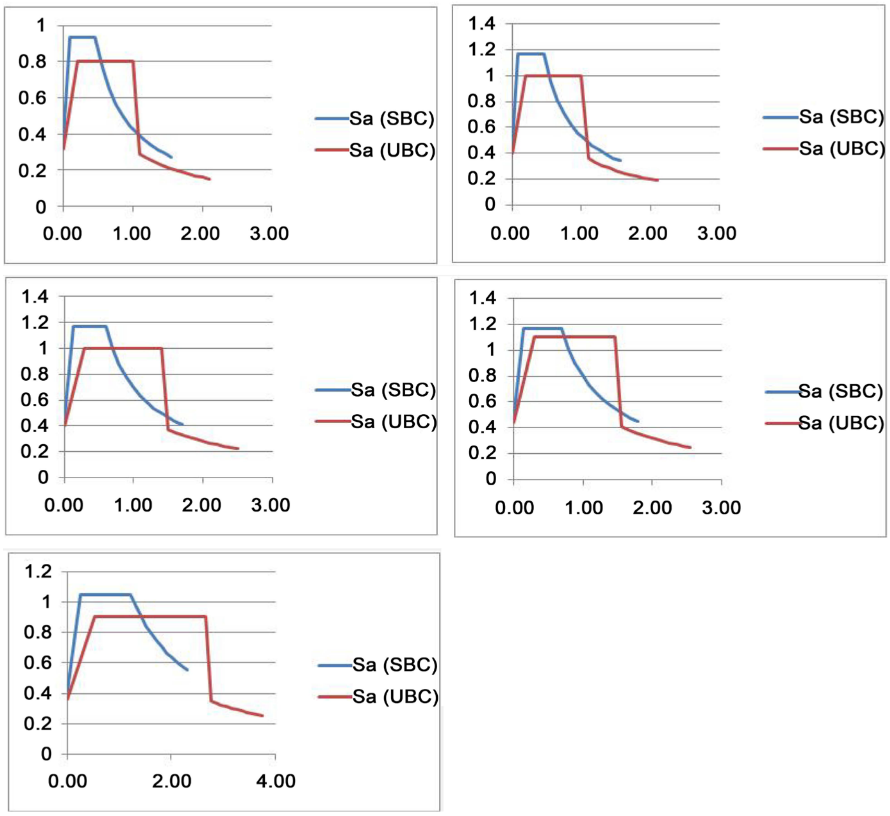

Figure 13. Design Response Spectra for Location 9 (Site class: A, B, C, D, E).

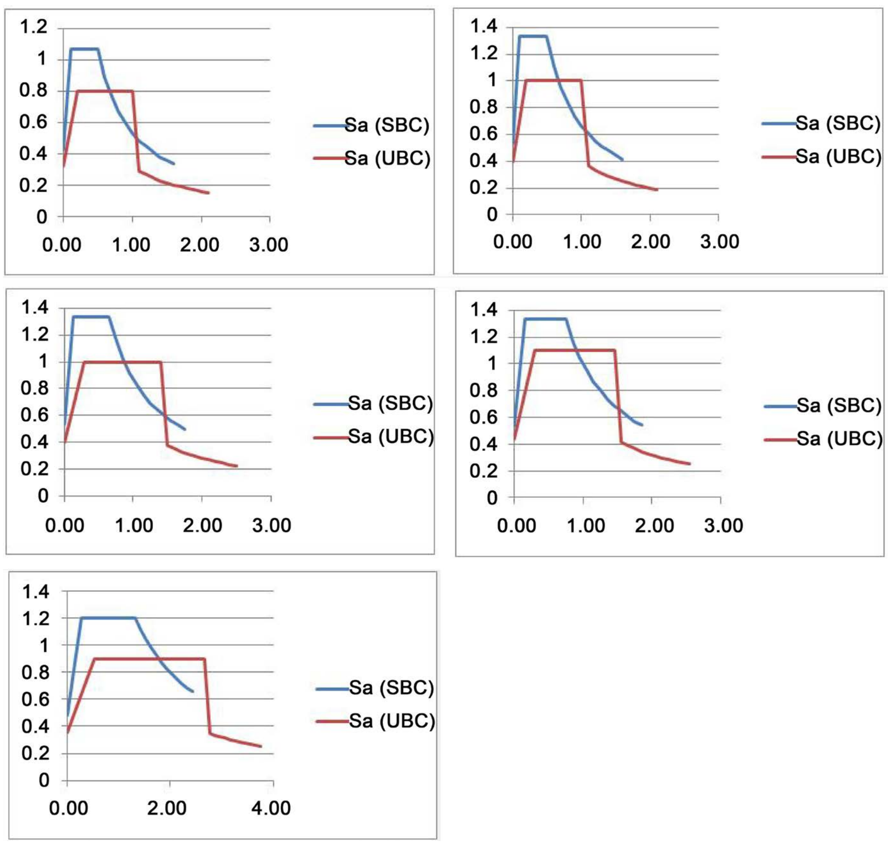

Figure 14. Design Response Spectra for Location 10 (Site class: A, B, C, D, E).

Location 2: PSBC > PUBC (PUBC = 0)

Location 3: PSBC < PUBC

Location 4: PSBC > PUBC

Location 5: PSBC > PUBC

Location 6: PSBC < PUBC

Location 7: PSBC > PUBC (Site class A, B, C, D), PSBC < PUBC (Class E)

Location 8: PSBC > PUBC (Site class A, B, C, D), PSBC < PUBC (Class E)

Location 9: PSBC > PUBC

Location 10: PSBC > PUBC

All cases were analyzed using ETABS program. A total number of 50 analyses were made and the results were evaluated for the purpose of comparison. It was found that huge amount of data has to be manually evaluated and compared. ETABS does not have any option to compare results of various different analyses with different input data for the design response spectrum. The analyses results are summarized as follows:

1) Figure 15 summarizes the data of analysis for the base shear for UBC and SBC EFLP for the real building. It can be seen that at most locations SBC base shear is higher. However, it is not always true.

2) Figure 16 compares the base shear for UBC and SBC using MRSA for the real building. Again, it can be seen that at most locations SBC base shear is higher. However, again it is not always true.

3) Figure 17 compares the overturning moments for UBC and SBC using MRSA for the real building. Again, it can be seen that at most locations SBC base shear is higher and again it is not always true.

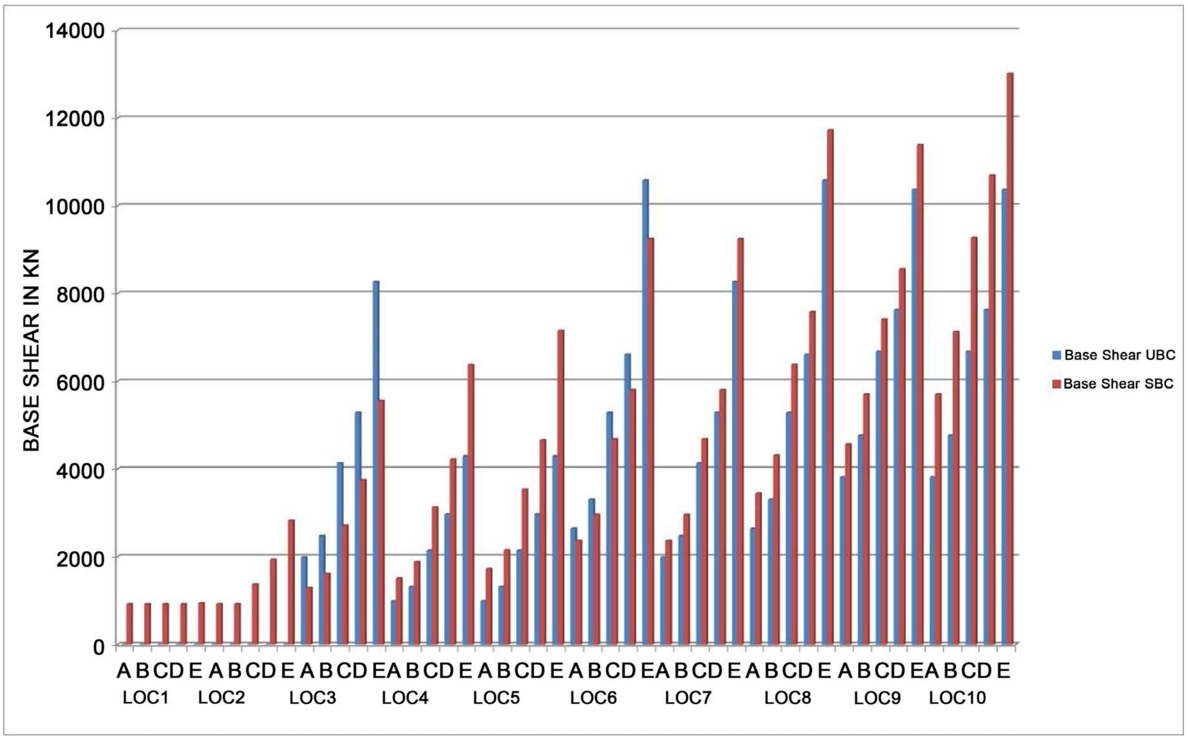

Figure 15. ELFP Base shears for UBC and SBC.

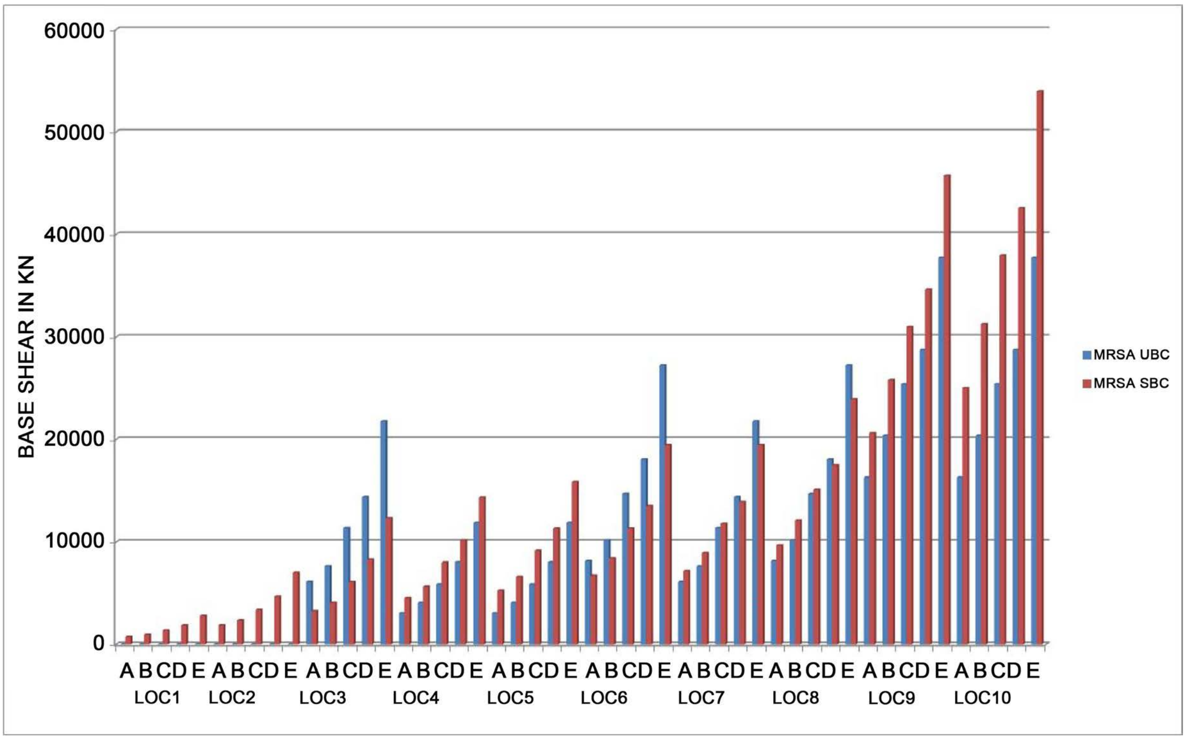

Figure 16. MRSA Base Shears for UBC and SBC.

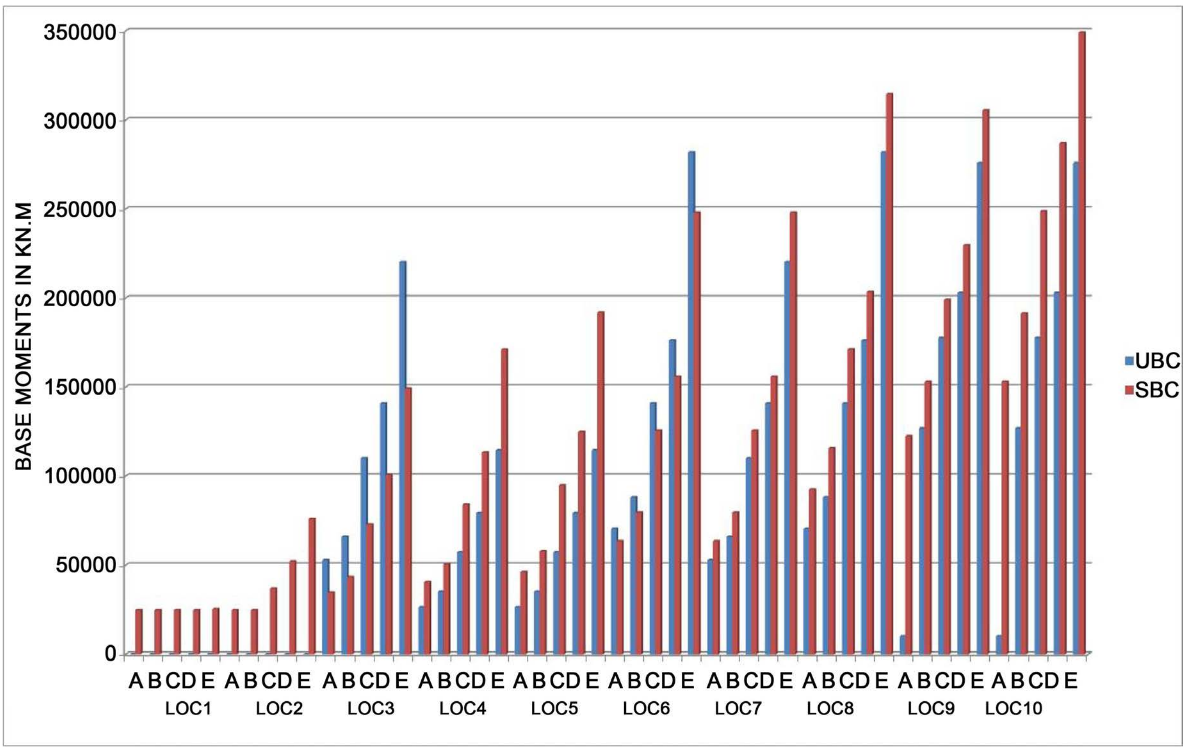

Figure 17. Comparison of overturning moments at base for UBC and SBC.

6. Conclusions

This study of a real building compares UBC and SBC and reports results. The findings are not in agreement with a previous similar study comparing UBC and

IBC. The results were obtained by using the same models. The comparisons of IBC, UBC published in previous work were first verified also. The design response spectra of SBC were evaluated and compared with UBC. The effect of soil class, and geographical location on the design response spectra was generated in accordance with SBC. The effects were studied and the response spectra were presented. Code compliant analyses for a real-world building were performed for eight soil types and geographical locations of Saudi Arabia to compare the base shear and internal forces in the structure. The design spectra shapes and peak magnitudes change drastically as we move from one location to another. It ensures that the selected locations have quite different geological properties.

The study concludes that about 80% of the mass participation is accounted for in the first 10 modes. The remaining modes do not participate significantly. Therefore, it is recommended that SBC requires MRSA using first 15 modes maximum.

The ELFP calculation was done using UBC and SBC. MRSA gives a higher time period (about 40%) when compared to the ELFP. It is recommended that SBC provides guidelines to relate MRSA with ELFP. Some more research is required to provide such guidelines.

It is found that at most locations SBC base shear is higher for both ELFP and MRSA. However, it is not true always. The same is true for overturning moments. Therefore, we cannot conclude that SBC is more conservative than UBC for all cases. It is recommended that further research pursued to look more deeply into cases where the SBC base shear is lower than UBC base shear. SBC seismic maps may not be very accurate. It is also advisable to develop proper guidelines to handle such cases in SBC.

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