Journal of Himalayan Earth Sciences Volume 48, No. 2, 2015 pp.101-107

Seismic design response spectrum for the Islamabad Capital Territory (ICT)

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Abstract

Pakistan is a seismically active country and its capital Islamabad is located close to an active thrust fault (Main Boundary Thrust). After the 2005 Kashmir earthquake, earthquake engineers worked on the important aspects of ground excitation that effect the structures. Seismic hazard assessment approaches are introduced by the researchers together with earthquake engineers to mitigate the ground motion. The probabilistic approach has recently been used by different researchers for the estimation of strong ground motion parameters for the closely spaced grid of 1 km. Usually, peak ground acceleration (PGA) at a bedrock level is calculated in this approach, which is used in earthquake resistant design structures or seismic safety assessments. However, PGA alone does not apply to design against the seismic loads, and modern building codes emphasis on the use of spectral acceleration values (short period and 1 second).

In this context, the capital city Islamabad is re-studied for seismic hazard analysis and new design parameters required by IBC 2012 codes to define the seismic loading are derived. These parameters are correlated with the study of Bhatti et al. (2011) which indicate that not only F series sectors in Islamabad are prone to seismic hazard, but the whole of the capital is hazardous. Based on the results of response spectra for a short period and 1 sec period, the areas occupied in the basin part of the city are more prone to hazard and hence are not suitable to construct multistorey heavy structures.

Keywords: Probabilistic seismic hazard analysis; Short and 1 second spectral acceleration; Design spectra.

1. Introduction

Calculation of the risk to a structure from future earthquakes requires assessment of both the probability of occurrence of future earthquakes (hazard) and the performance (response) of the structure to earthquake induced shaking (Baker and Cornell, 2006).

For earthquake engineers, the most important aspect of ground excitation is their effects on structures. Design procedures ensure that safe structures are constructed, withstanding all kinds of loads anticipated during the life of a structure. In the past PGA has been used to describe ground motion severity, because the seismic force on a rigid body is proportional to the ground acceleration. However, it has been pointed out that single highest peak on accelerogram is a very unreliable description of the accelerogram as a whole (Housner, 1975). The design response spectra is defined as a plot of maximum acceleration (as a function of frequency or time-period of vibration) for specific damping ratio on the basis of a single degree of freedom system (SDOF) for earthquake excitations. They are useful in analyzing the performance of structures under earthquake loading.

The metropolitan area of the Islamabad in northern Pakistan lies between longs 72°45′ and 73°30′ E. and lats 33°30′ and 33°50′ N (Fig. 1). The Building Code, Seismic Provisions of 2007 classified the study area into Zone IIB, which now forms the basis of current engineering designs in the Islamabad region. Other regional level seismic hazard assessments that partially address the Islamabad area include NORSAR-PMD (2006) PGA 0.19g-0.21g and Hashash et al. (2012) PGA 0.39g. In comparison to these regional-level hazard assessments, recently some studies have been conducted specifically to the Islamabad area (e.g., Ali, 2009; Bhatti et al., 2011, PGA 0.24g-0.37g for the return period of 2500 years).

2. Methodology

2.1. PSHA

In the present study, evaluation of seismic parameters have been carried out using the seismic data over an area having 300 km radius around the administrative boundary of Islamabad. Parameters "a" (the number of magnitude of earthquake per year) and 'b' (the likelihood of different magnitude) have been calculated (MonaLisa et al., 2007) from the Guttenberg-Richter (Gutenberg and Richter, 1956) using instrumental and historical catalogue for North Pakistan. The Probabilistic seismic hazard analysis for the Islamabad region has been carried out by considering two seismogenic sources (Bhatti et al., 2011; MonaLisa et al., 2007).

The study area is divided by grid size of 0.1x0.1 km, hazard parameters are estimated at the site of interest of each grid using hazard computing program Crisis 2007 Ver.7.6, (Ordaz et al., 2007) using median values of two GMPE's (Boore and Atkinson, 2008; Akkar and Bommer, 2010) at bedrock level.

2.2. Design Spectrum

The response spectrum method is a popular dynamic analysis method and yields conservative results. The method was originally proposed by Biot (1943) and popularized as a design tool by Housner (1959). Response spectra plotted for any single event is jiggered. When an ensemble of spectra from different earthquakes is plotted together than crest and troughs compensate each other and a smooth response spectra curve is achieved. Hence design spectra are representative of a suite of earthquakes recorded at a site. However, in Pakistan, time history accelerograms are scarce. The design response spectrum curve is developed as indicated in Figure 2 (ASCE 7-05 Chapter 11). Time period T is plotted on abscissa and spectral acceleration S_a is plotted as ordinate.

$$S_a = S_{DS}\,(0.4 + 0.6\,\frac{T}{T_0})$$
$$[\text{for } T < T_0, \text{ where } T_0 = 0.2\,\frac{S_{D1}}{S_{DS}}] \ldots\ldots\ldots (1)$$

$$S_a = S_{DS}$$
$$[\text{for } T_0 \leq T \leq T_S, \text{ where } T_S = \frac{S_{D1}}{S_{DS}}] \ldots\ldots\ldots (2)$$

$$S_a = S_{D1} / T$$
$$[\text{for } T_s \leq T \leq T_L, \text{ where } T_L = 8 \text{ sec}] \ldots\ldots\ldots (3)$$

$$S_a = S_{D1}\,T_L / T^2$$
$$[\text{for } T > T_L] \ldots\ldots\ldots (4)$$

Based on these formulas a design response spectrum has been calculated as shown in Table 1 and Figure 3a-3c for return period of 475 years and 2500 years.

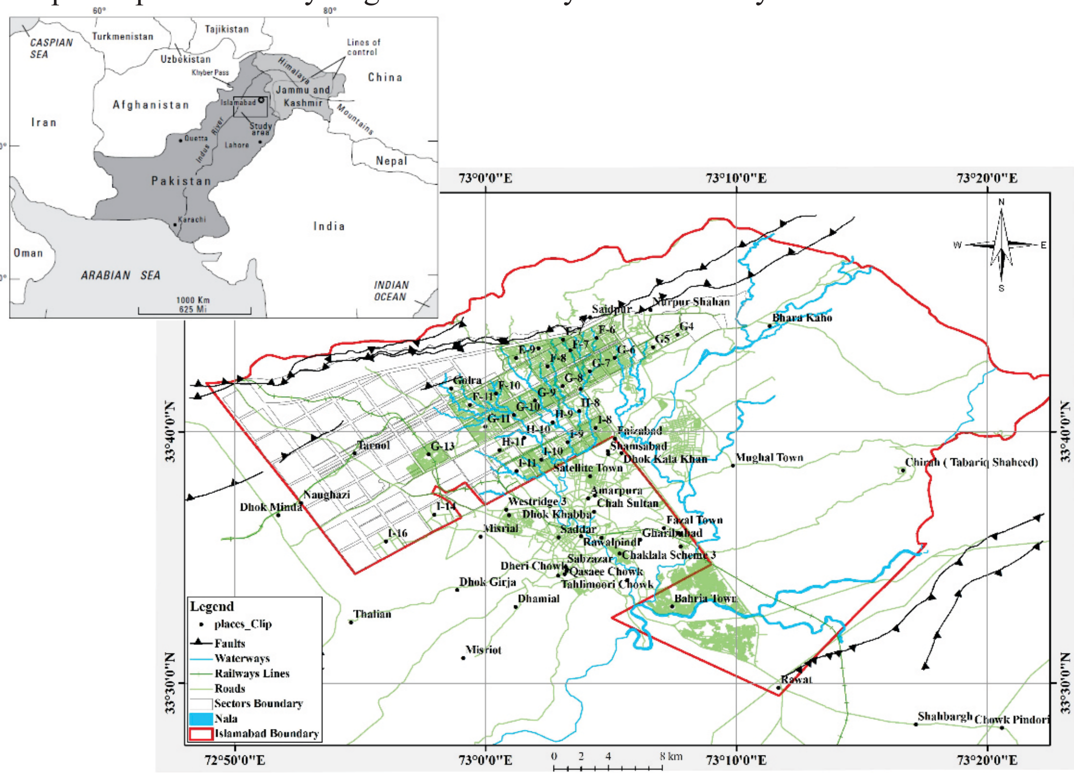

Fig. 1. Location map of the studied area.

3. Results and discussions

3.1. Mapped acceleration parameters

Parameters i.e., short spectral acceleration (SS) and spectral acceleration value at a structural period of 1.0 sec (S1) are determined from published maps. SS determined for MCE at a structural period of 0.2 sec (ASCE 7-05).

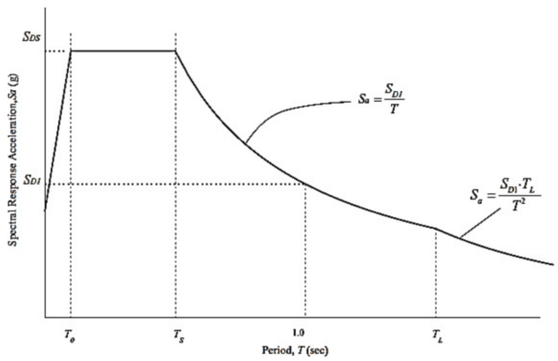

Fig. 2. Typical Design Response Spectrum (adopted from ASCE 7-05).

Such maps are not available for Pakistan. In this study however, PSHA is performed to determine these parameters in more detail. These parameters are compared with the parameters determined by Bhatti et al. (2011) (as given in Table 2) for different parts of Islamabad. If any structure in sector F-11 of Islamabad is considered, as did by Bhatti et al., (2011) then:

S_s= 0.77 g S_1=0.21 g

Site class is determined from the properties (Table 3) based on shear wave velocities, from rock to very soft soil respectively. For every structure to be constructed, site class will be determined after performing a detailed soil investigation according to ASCE 7-05, chapter 20 which is also reproduced as chapter 4 in BCP 2007. Since a typical design spectrum is being made, therefore the most general site class will be assumed that is encountered in Islamabad which is SD and SC.

Table 1. Comparison of Design Response Spectrum computed in this study and Bhatti et al. (2011) for F-11, Islamabad.

	2500 years Bhatti et al. (2011)	2500 years Current Study	475 years Current Study
T (sec)	Sa (g)	Sa (g)	Sa (g)
0.000	0.262	0.35	0.25
0.001	0.277	0.35	0.25
0.003	0.311	0.37	0.27
0.005	0.345	0.38	0.28
0.007	0.378	0.39	0.29
0.009	0.412	0.40	0.31
0.010	0.429	0.40	0.31
0.020	0.598	0.46	0.38
0.023	0.650	0.47	0.40
0.115	0.650	0.87	0.62
0.2	0.375	0.87	0.62
0.4	0.188	0.87	0.43
0.6	0.125	0.69	0.28
0.8	0.094	0.52	0.21
1.0	0.075	0.42	0.17
1.2	0.063	0.35	0.14
1.4	0.054	0.30	0.12
1.6	0.047	0.26	0.11
1.8	0.042	0.23	0.09
2.0	0.038	0.21	0.09
2.5	0.030	0.17	0.07
3.0	0.025	0.14	0.06
3.5	0.021	0.12	0.05
4.0	0.019	0.10	0.04
4.5	0.017	0.09	0.04
5.0	0.015	0.08	0.03
5.5	0.014	0.08	0.03
6.0	0.013	0.07	0.03
6.5	0.012	0.06	0.03
7.0	0.011	0.06	0.02
7.5	0.010	0.06	0.02
8.0	0.009	0.05	0.02
8.5	0.008	0.05	0.02
9.0	0.007	0.04	0.02
9.5	0.007	0.04	0.02
10.0	0.006	0.03	0.01

Table 2. Comparison of the results obtained by Bhatti et al. (2011) with current study.

Location		RP	Ss	S1	S	Fa	Fv	Sms	Sm1	Sds	Sd1	To	Ts
F-11	Current study	475	0.77	0.21	D	1.192	1.198	0.923	0.256	0.615	0.170	0.055	0.277
F-11	Current study	2500	1.31	0.39	D	1	1.62	1.308	0.624	0.872	0.416	0.095	0.477
F-11	Bahtti et al., 2011	2500	0.831	0.047	D	1.17	2.4	0.971	0.113	0.65	0.075	0.023	0.115

Table 3. Soil properties (Adopted from ASCE 7-05).

Site Class	Profile	V_S (fps)	SPT Values	S_u (psf)
S_A	Hard Rock	> 5000	--	--
S_B	Rock	2500-5000	--	--
S_C	Soft rock and very	1200-2500	> 50	> 2000
S_D	Stiff Soil	600-1200	15-50	1000 - 2000
S_E	Soft Clay Soil	≤ 600	< 50	< 1000
S_F	Soil requiring Site Specific Evaluation			

3.2. Adjusted MCE spectral response acceleration parameters

S_S and S_1 are initially calculated for rock site and are modified for site class by following formulas.

$$S_{MS} = Fa\ S_S \ldots\ldots (1)$$

$$S_{M1} = Fv\ S_1 \ldots\ldots (2)$$

Fa and Fv are site coefficients defined in Table 2. In our case Fa is 1.192 and Fv is 1.198, and SMS =1.192 x 0.77= 0.923 and SM1 =1.198 x 0.21 = 0.256.

3.3. Design spectral acceleration parameters

Design earthquake spectral acceleration response parameters at short period and 1 sec period are determined as following:

$$S_{DS} = \frac{2}{3} S_{MS} \ldots\ldots (3)$$

$$S_{D1} = \frac{2}{3} S_{M1} \ldots\ldots (4)$$

In our case SDS = 0.66 x 0.923 = 0.615 g and SD1 = 0.66 x 0.256 = 0.1704 g. Similarly, values of Ss and S1 are calculated for all of the study area and plotted in Figure 4a and 4b for return period of 475 years and Figure 4c and 4d for return period of 2500 years.

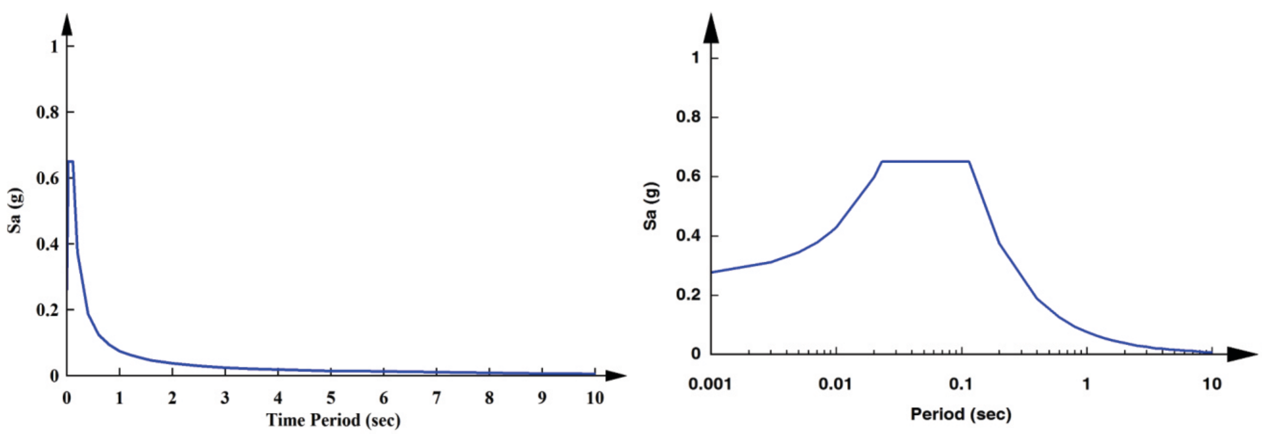

Fig. 3a. Design response spectra for F-11, Islamabad for return period of 2500 years (Bhatti et al. 2011).

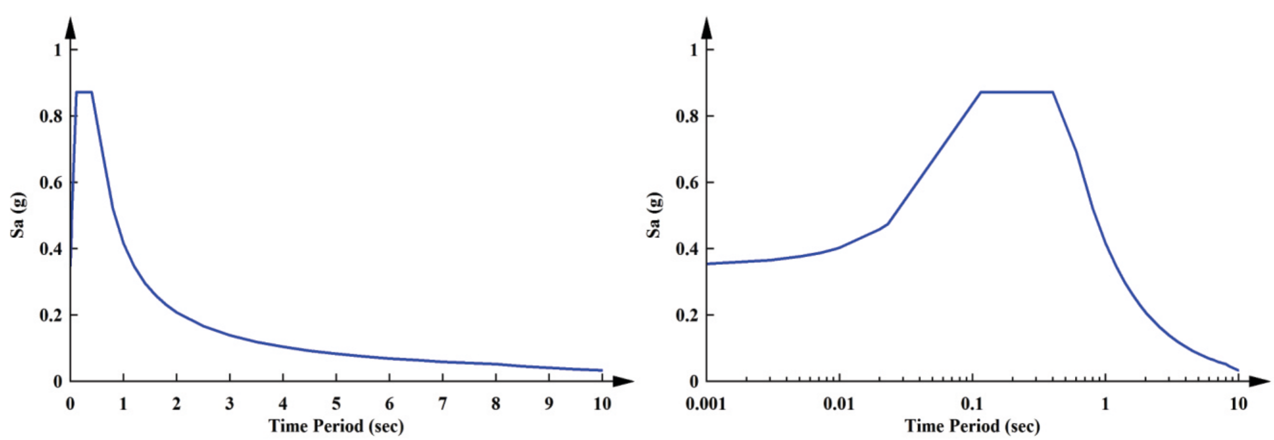

Fig. 3b. Design response spectra for F-11, Islamabad for return period of 2500 years (Current study).

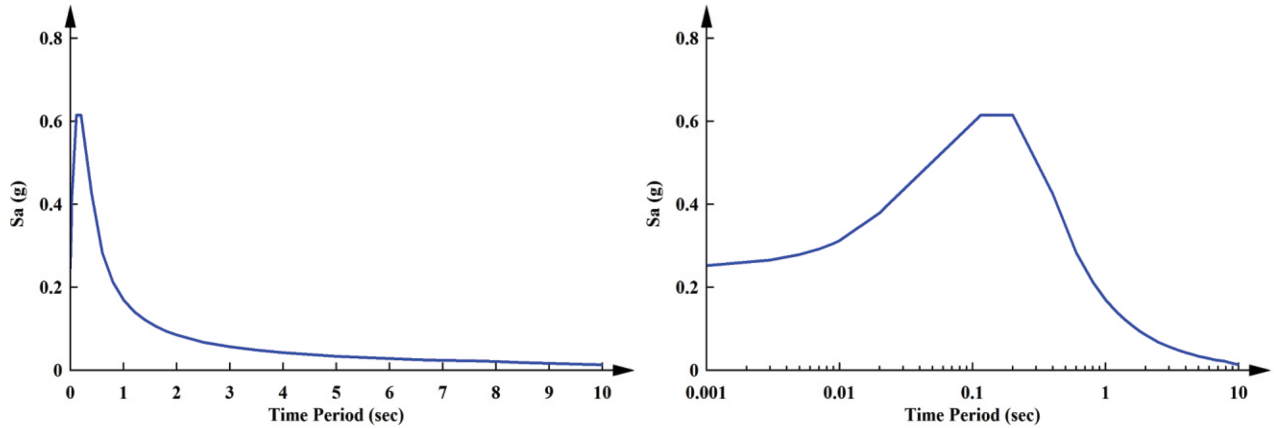

Fig. 3c. Design response spectra for F-11, Islamabad for return period of 475 years (Current study).

These results show that the whole of study area is prone to seismic and not just F series sectors as indicated by Bhatti et al. (2011). Design spectra are correlated (Fig. 5) with the results of Bhatti et al. (2011) that reveal a large difference of peak values of Sa. Design spectrum, once plotted with a log scale on x–axis, is easier to read in the lower limits of the time period. Sometimes design spectrum drawn on a linear scale is not comprehendible; therefore it is better to plot time period on a log scale.

4. Conclusion

Seismic hazard in the study area is not uniform and it varies from 0.30-0.32g (return period of 475 years) and 0.50-0.52g (return period of 2500 years) in different parts of the study area. These values do not confirm the present seismic zone 2B (0.16 g to 0.24 g) for study area according to UBC 97 criteria. Since ASCE 7-05 and IBC 2006 does not mention seismic zones therefore spectral accelerations S_s and S_1 has been computed over a grid of 1km x 1km. Variation in values of spectral acceleration from point to point adequately highlights the importance of new criteria. The entire Islamabad city is prone to earthquake hazard with more emphasis on basin part and therefore, this part is not suitable for the heavy construction of multistorey structures.

Acknowledgement

This study is part of a Ph.D. dissertation at the National Center of Excellence in Geology (NCEG), University of Peshawar. The instrumentation used in this study and all logistic support for the fieldwork was provided by the NCEG, which is gratefully acknowledged.

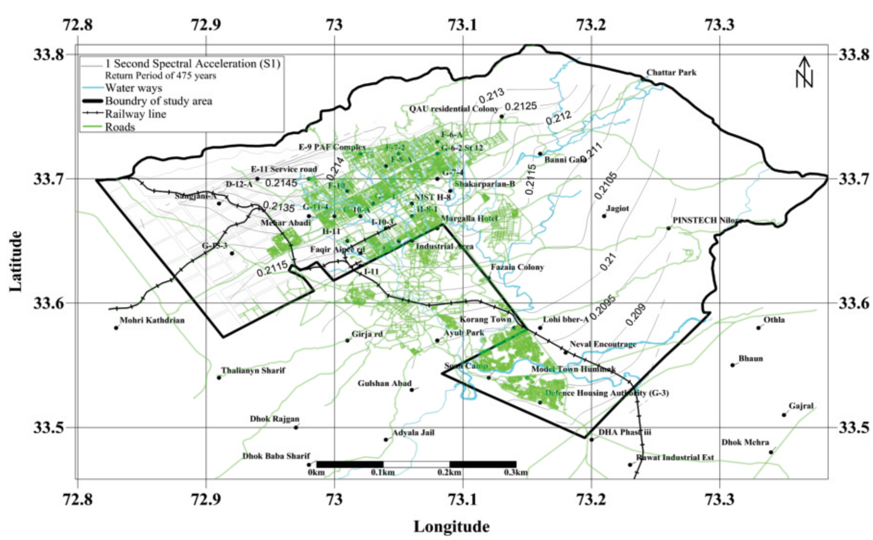

Fig. 4a. Spectral acceleration values for 1 second period (S1) calculated for study area for return period of 475 years.

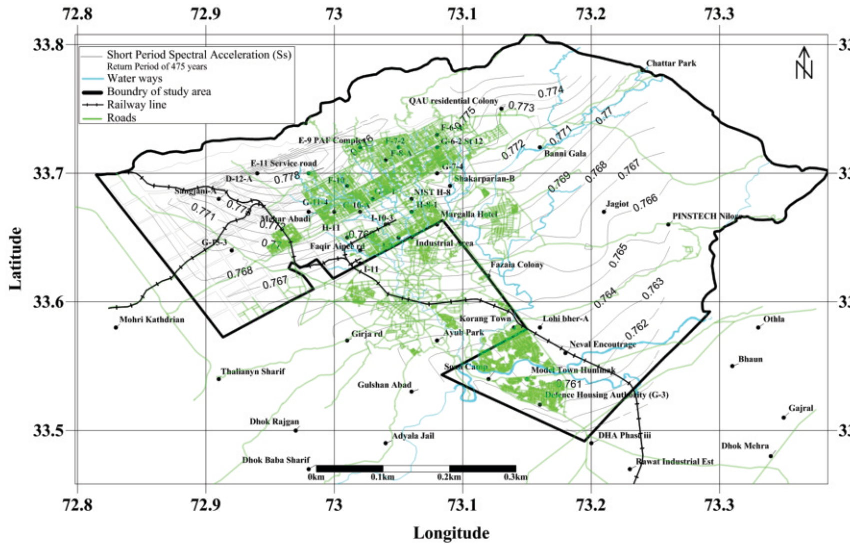

Fig. 4b. Spectral acceleration values for short period (S_s) calculated for study area for return period of 475 years.

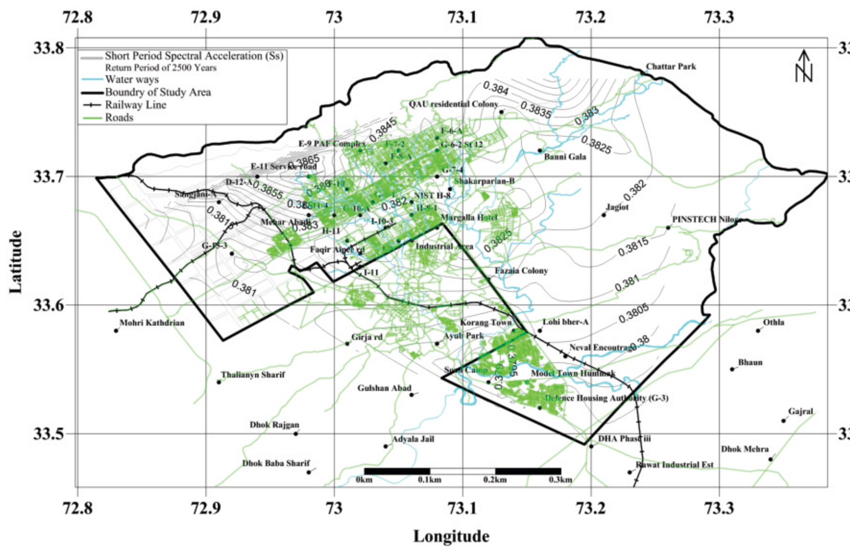

Fig. 4c. Spectral acceleration values for 1 second period (S_1) calculated for study area for return period of 2500 years.

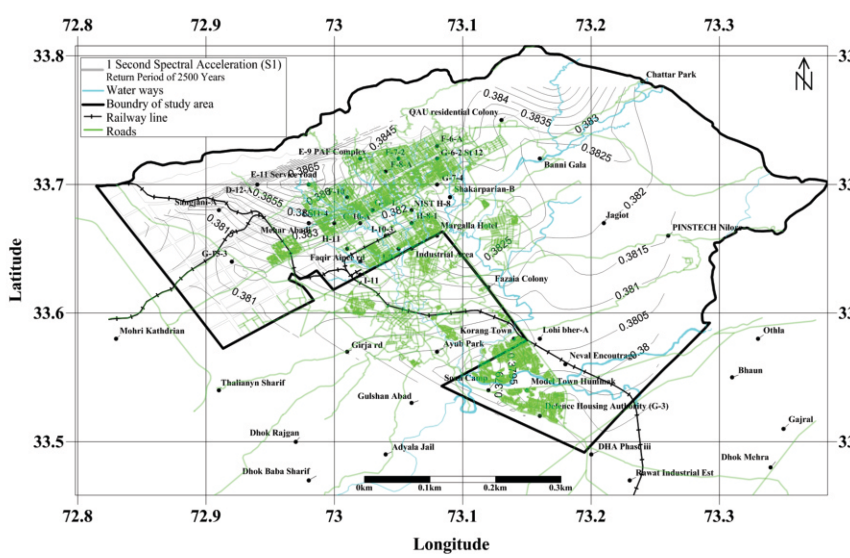

Fig. 4d. Spectral acceleration values for short period (S_s) calculated for study area for return period of 2500 years.

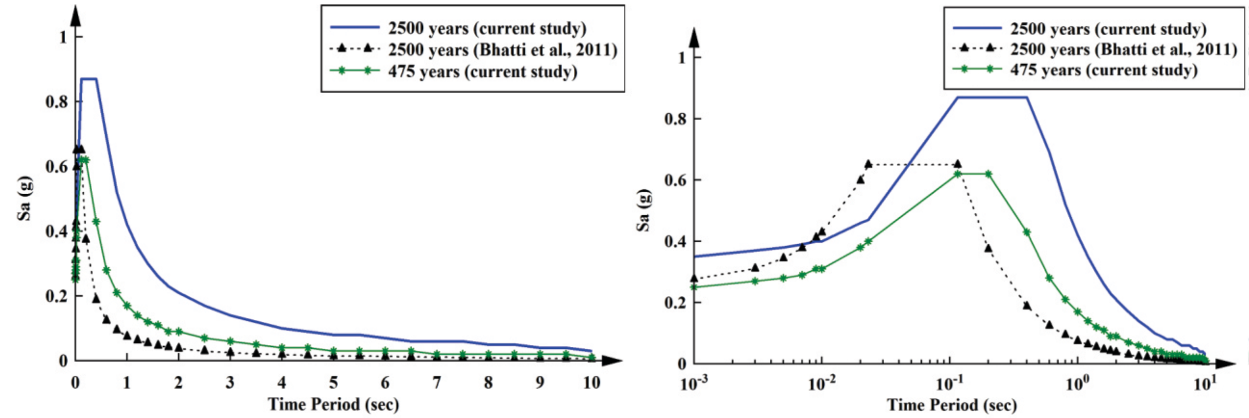

Fig. 5. Comparison of design RS by Bhatti et al. (2011) and current study for F-11, Islamabad for return period of 2500 years.

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