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Ground motion estimation at Kabul city for Mw 7.5 Hindu Kush earthquake

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ABSTRACT: Within the last 16 years, Kabul, the capital and largest city of Afghanistan witnessed a development it had never seen. Many commercial and private high rise buildings in the mud-brown landscape of this city represent a new modernity. However, the seismological literature indicates that the safety assessment of the existing structures and those to build in future, with respect to ground motion variation is probably not studied. In this study, we used a stochastic point source modeling to estimate the ground motion variation at Kabul city by simulating the Mw 7.5 Hindu Kush earthquake that occurred on 2015 October 26 at a depth of 210 km. The earthquake was due to thrust faulting. The impact of this high magnitude earthquake was predominantly felt in Kabul and surrounding areas that killed around 267 people and damaged about 11,389 houses. We calculated the base-rock and surface acceleration at several sites in the epicentral region. The peak ground accelerations are compared with the acceleration records taken in Afghanistan. Although the strong motion instrumentation of Afghanistan is none, this study might be an important contribution of the seismic vulnerability of major settlements in Afghanistan.

1 INTRODUCTION

Kabul the capital of Afghanistan (34.55° N, 69.20° E), and the most populated (about 4.6 million, Kabul, World Population Review, 2017) and fastest growing city of the country is one of the largest cities (64th) in the world. Kabul city is located in the southern east earthquake region of Afghanistan, the region with most severe seismicity (Wheeler and others, 2005) in the country near where three main faults meet and form a junction (Figure 1). This region lies near the Eurasia and Indian plates boundary considered one of the most seismically active regions worldwide. This region has experienced great earthquakes and has caused immense damage to lives and properties. Pamir and Hindu Kush where continental deep earthquakes take place also lies near this region in about 300km on the North of Kabul. The M7.5 Hindu-Kush earthquake of October 26 2015 with the epicenter 45 km north of Alaqahdari-ye Kiran wa Munjan, Afghanistan at a depth of 212 km with a death tool of approximately 400 people, mostly in Pakistan. This earthquake was recorded at several regional accelerographic strong ground motion stations.

This earthquake caused tremendous shake to the nearest crowded city of Kabul. Damages to the old and new structures in Kabul city has been unofficially reported. Building damage due to foundation failures due to liquefaction were also reported in several parts of the city. The MMI intensity of his event at Kabul city has been estimated to be VI. Although, Kabul city is located far away from the epicenter of this event and other large earthquakes (about 300 km), non-structural damages have been reported in many parts of this city.

With the fast increasing density of population and large industrial establishments in recent times, the vulnerability of Kabul city to damaging earthquakes is increasing day by day. Occurrence of another great earthquake in/near this region, might be highly devastating for Kabul city. Therefore it is of great need to have a reliable estimation of seismic hazard due to probable damaging earthquakes

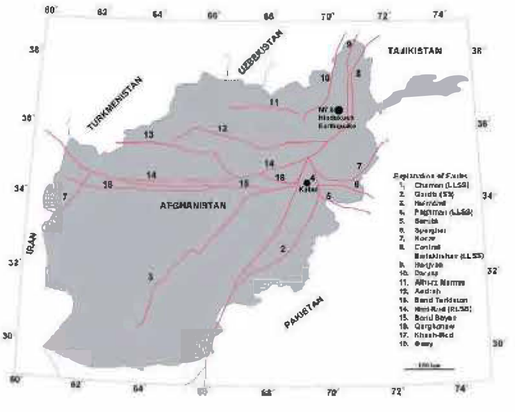

Figure 1. Active faults in Afghanistan, location of Kabul and M7.5 Hindu Kush earthquake. Faults map modified from (Wheeler and others, 2005).

occurring in this region. This requires good regional coverage of strong motion observations as well as detailed micro zonation studies for urban planning and design of infrastructures. There is lack of information on ground motion data of strong earthquakes as its application in engineering is concerned. The available quantified information on seismic hazard is sparse that earthquake engineers face problems in estimating the design ground motion at Kabul city. The lack of strong motion data can be remedied up to some extend by using analytical source mechanism models.

This study is performed to evaluate the ground motion at Kabul city for an earthquake of magnitude Mw 7.5 in Hindu Kush area of Afghanistan. The fault location and source parameters for this event is taken from the information released by the USGS. A modified version of stochastic point source model of Boore (1983) is used for simulating ground motion. First, acceleration time histories are simulated for bedrock conditions. Then the simulated response spectrum at bedrock and surface level are presented.

2 TECTONIC SETTING AND SOURCE PARAMETERS OF MW 7.5 EARTHQUAKE

The tectonic setting of Afghanistan involves fundamentally the northward motion of the Indian plate sub-ducting beneath Eurasia plate in the Tibet and the movement of the Indian plate is accommodated in Afghanistan and Pakistan by the Chaman Fault through mainly sinistral faulting (Fig. 2). However, the tectonic setting is more complex in the vicinity of Hindu Kush Mountains. Fig. 3 shows a cross-section depicting the subduction of the Indian plate beneath the Eurasia plate in the vicinity of the Hindu Kush Mountains. It is clearly noted that the Indian plate is steeply bended and it is probably in the process of the detachment from the Indian Plate and sinking into the upper mantle, which would definitely affect the seismicity of the region for decades from now on.

The M_w 7.5 Hindu Kush earthquake of Afghanistan took place on 26 October 2015 and the instrumental data of the earthquake are given in Table 1 together with some estimations. The focal mechanism of the earthquake was due to thrust faulting with a dip direction and dip angle of 16° and 70°, respectively according the USGS. The rake angle was 273°, which implies almost thrust faulting with a slight sinistral component. The hypocenter depth of the earthquake was 210-213 km.

The M_w 7.5 Hindu Kush earthquake of Afghanistan was widely felt in northeastern Afghanistan, northwestern Indian, and northern Pakistan. It killed at least 115 people in Jalalabad and destroyed more than 4,000 homes in Jarm of Afghanistan. The event was more strongly felt in Pakistan and killed at least 289 people and destroyed more than 29,230 house there. The Intensity of this event was (VI) at

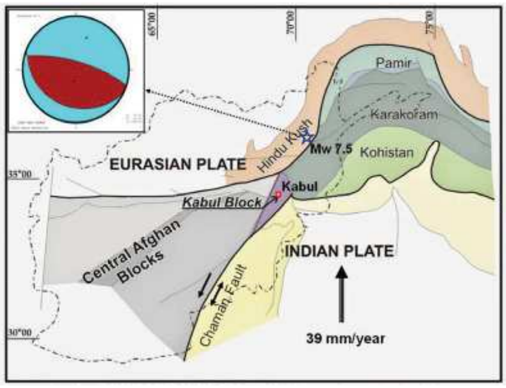

Figure 2. Tectonic setting of Afghanistan and focal mechanism of the Mw 7.5 Hindu Kush earthquake (modified from Kafarsky et al, 1975).

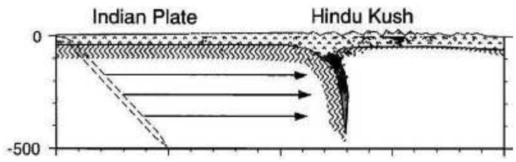

Figure 3. Illustration of subduction of Indian Plate beneath Hindu-Kush Mountains (modified from Pavlis and Das, 2000).

Table 1. Instrumental and estimated Data

Institute	Strike/dip/rake	Slip(cm)	Rupture Duration (s)	Fault length(km)
USGS	106/70/87	615	20+5	40
HARVARD	104/69/91		27.2	
GFZ	106/65/95			
This study*	-	380	31.5	88

*Based on Aydan (2012) empirical formulas for Mw 7.5

Bagrami and Jalalabad, (V) at Kabul and Mahmud-e-Raqi, (VII) at Abbottabad and Wah of Pakistan; (VI) at Rawalpindi, (V) at Amritsar, Badambagh and Palwal of India and at Dushanbe of Tajikstan. It was felt (III) at Tashkent, Uzbekistan. It was also felt (II) at Ghorahi and Kathmandu, Nepal, Doha of Qatar. The intensity and inferred strong motions data of this event are presented in Table 2. Although there is no acceleration data for this earthquake, accelerations recorded in Peshawar, Nilore (Islamabad) and DI Khan in Pakistan (Ahmad, 2015; Ismail and Khattak, 2016). The accelerations at these stations are listed in Table 3 and the acceleration records and their response spectra are shown in Figs. 4 and 5.

The epicentral distance of Peshawar City in Pakistan is quite similar to the epicentral distance of Kabul City. The earthquake caused damage to

Table 2. Intensities and inferred strong motions for M7.5 Hindu Kush Earthquake, 26 Oct 2015.

Locality	Network	Intensity (MMI)	PGA (cm/s^2)	PGV (cm/s)	Distance (km)
Charikar	DYFI	V	43	5.44	277
Kabul	DYFI	VI	70	9.74	306
Kabul	DYFI	V	51	6.77	309
Kabul	DYFI	V	42	5.44	316
Kabul	IU	VI	22	1.7	315
Dushanbe	DYFI	V	42	5.44	303
Garm	TJ	IV	53	1.9	315
Tashkent	DYFI	III	4	-	540
Peshawar	DYFI	V	45	5.85	339
Peshawar	DYFI	VI	70	9.74	341
Islamabad	DYFI	VII	139	21.71	391
Srinagar	DYFI	V	54	7.28	489
Islamabad	DYFI	VI	108	16.22	393
Islamabad	DYFI	V	37	4.7	384

Note: Data in this table is retrieved from USGS website.

Table 3. Strong motion data (from N. Ahmad)

Institute	Epicentral distance (km)	EW	NS	UD
Peshawar	280	0.05 g	0.053 g	0.038 g
Nilore	430	0.021 g	0.020 g	0.017 g
D.I. Khan	514	0.026 g	0.036 g	0.015 g

mud-brick or stone masonry with earthen mortar in Peshawar and Kabul Cities. The analyses of collapsed structures imply that the acceleration might be up to 0.158 g in Kabul City, which may correspond to spectral acceleration rather than the base acceleration. The heavy damage in Peshawar also support the high spectral accelerations shown in Figure 5. It should be also noted that the hypocenter of the earthquake is very deep. It is expected to high frequency waves would attenuate and long-period components would be more dominant. As the earthquake was felt at far-distant locations, the observations support this conclusion.

3 SIMULATION METHOD AND MODEL PARAMETERS

The stochastic seismological model originally proposed by Hanks and McGuire (1981) and later generalized by Boore (1983) for simulating synthetic acceleration time histories is used in this study. This model is a good alternate for simulating synthetic acceleration time histories with few known source and medium parameters. Here, ground motion is modeled as a band limited finite duration Gaussian white noise in which the radiated energy is assumed to be distributed over a specified duration.

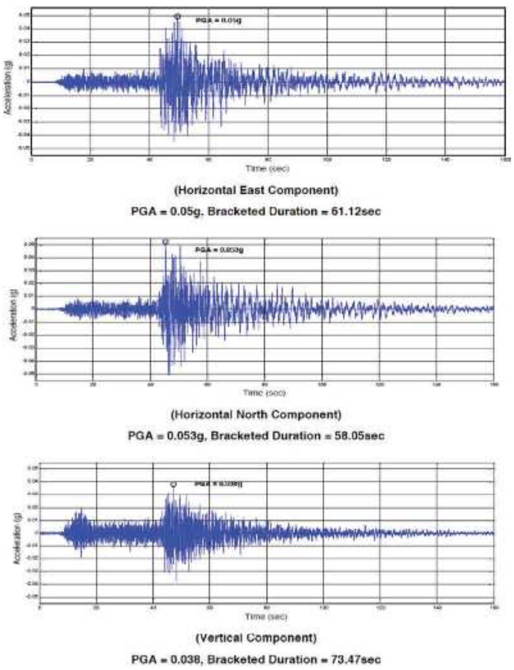

Figure 4. Acceleration records at Peshawar (from Ahmad, 2015).

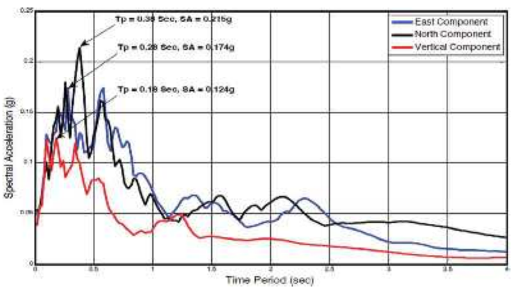

Figure 5. Response spectra of acceleration records at Peshawar (from Ahmad, 2015).

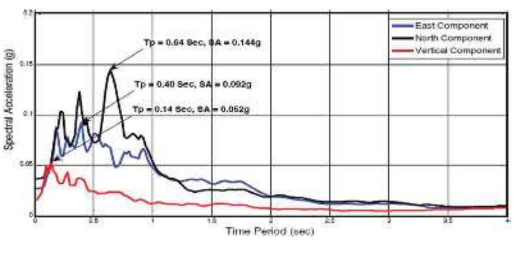

Figure 6. Response spectra of acceleration records at Peshawar (from Ahmad, 2015).

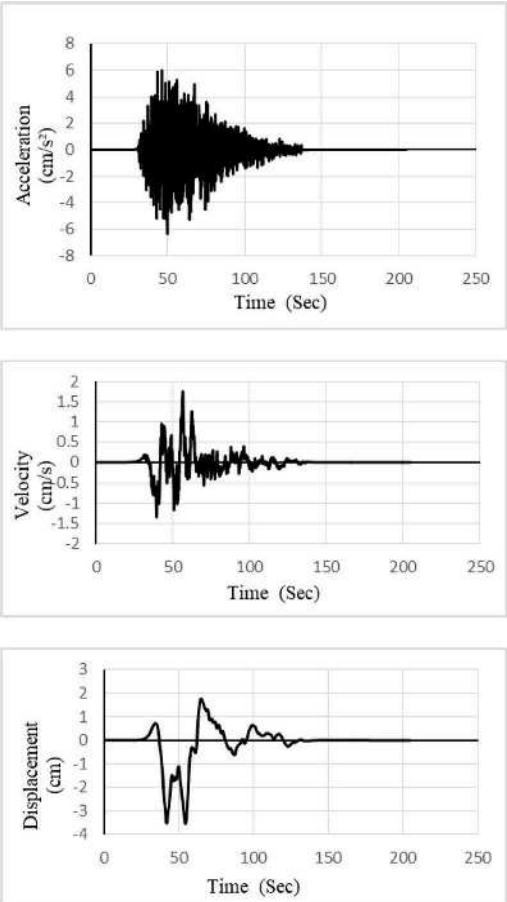

Figure 7. Acceleration, velocity and displacement time series, resulted from stochastic modeling for M = 7.5, R = 300 km.

Table 4. Model parameters used in simulation

Acceleration Fourier Amplitude Spectrum	$A(f,M_0,R)=S(f,M_0)D(f,R)P(f)$
Source Spectrum- *Brune Source Spectrum*	$S(f,M_0)=C(2\pi f)^2M_0*1/(1+f/f_c)^2$ $C=R_{\varnothing}FV/(4\pi\rho\beta^3R_1)$ $R_{\varnothing}=0.55$, $F=2$, $V=\sqrt{2}$ $\rho=2.8g/cm^3$
Corner Frequency	$Fc=4.9*10^6\beta\Delta_\sigma/M_0^-$ $\beta=3.5$ km/s $\Delta_\sigma=100$ bars
Attenuation	$D(f,R)=Dg(f,R)D(f)$
Geometric spreading	$Dg(R)=1/R$ ($R<70$ km) $Dg(R)=1/70;70<R<130$ km $Dg(R)=1/70(130/R)^{0.5}$ $R>130$ km
Q model-Anelastic Attenuation	$Q(f)=220f^{0.52}$
Low-Cut Filter	$P(f) = \exp(-\pi\kappa f)$ Kaapa (κ)=0.006 hard rock

In this method, various factors affecting ground motion source, path, and site factors are put together into a physically determined algorithm and is used to predict ground motion. This method is widely used in different regions of the world and is proved to be reliable for the seismic regions of the world where strong ground motion occurs. The model parameters used for simulation are given in Table 4.

The simulated acceleration, velocity and displacement time series from the stochastic modeling are shown in Figure 7. The PGA at Kabul city is about 6 cm/s^2 and may be due to its big distance from the source. Maximum of this value reported in one of the four stations in Kabul is 70 cm/s^2 and by another of the four stations equal to 22. The simulated result shows a smaller number comparing it to the least recorded acceleration. The simulated response spectra for Kabul city at bedrock is presented in Figure 8.

The simulated response spectra for Kabul city at ground surface is presented in Figure 9. The acceleration response spectra particularly flat up to 2 seconds.

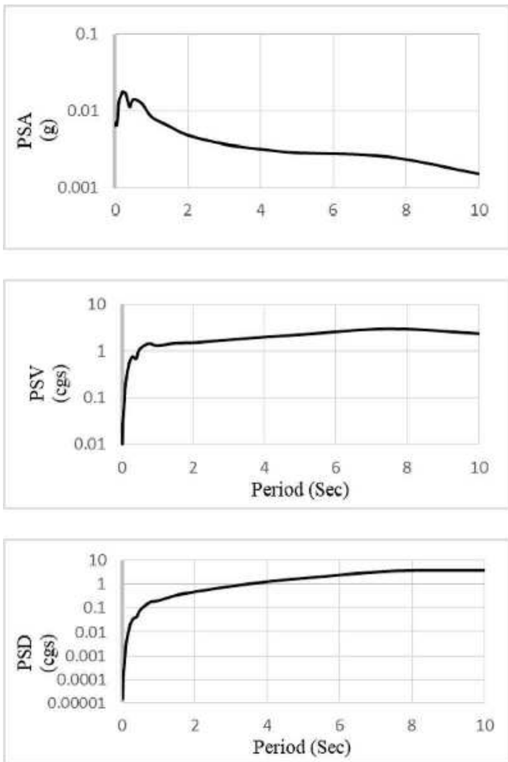

Figure 8. Response spectra at bedrock

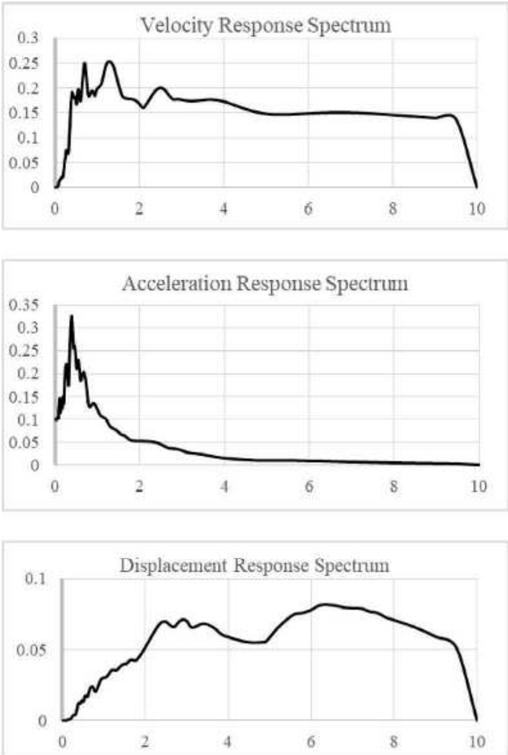

Figure 9. Surface level response at 5% damping

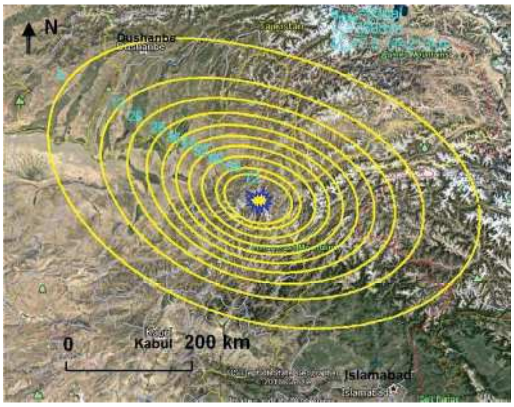

Figure 10. Estimated maximum ground accelerations for the Mw 7.5 earthquake.

4 STRONG MOTION ESTIMATION BY EMPIRICAL APPROACH

The method presented previously utilizes Green Function Method while its parameters are based on some empirical relations. Here, we utilize the method proposed by Aydan (2012) and Aydan et al. (2009a,b) to estimate the distribution of maximum strong motions. The method itself here is used for estimating the maximum ground acceleration using the empirical relations for inter-plate earthquakes as the 2016 October 26 earthquake occurred at the plate boundary between the Indian Plate and Eurasia plate. The estimations of the maximum ground acceleration at the ground surface at the epicenter is only 95 gals and it attenuates to 4 gals beyond 250 km. Nevertheless, the directional effects in the attenuation of maximum ground acceleration are well evaluated.

Although, the damaging effects of the 2015 Hindu Kush earthquake was felt widely, the strong motions in Kabul City due to larger earthquakes are much more important. The major fault near Kabul City is the famous Chaman fault, which passes at about

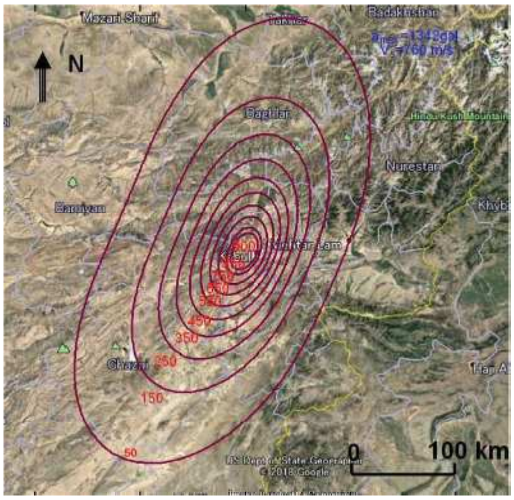

Figure 11. Estimated maximum ground acceleration contours for an earthquake of Mw 7.24 on the Chaman Fault near Kabul.

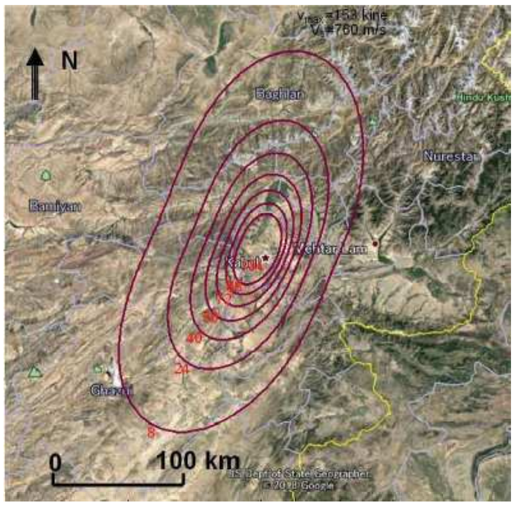

Figure 12. Estimated maximum ground velocity contours for an earthquake of Mw 7.24 on the Chaman Fault near Kabul.

Table 5. Characteristics of anticipated earthquake

Length (km)	Strike/ dip/rake	Mw	Slip (cm)	Rupture Duration (s)
90	206/90/0	7.24	274	23

16 km NW of the city. This fault joins to the Hari-Rud fault to the north of Kabul City. The Chaman fault is segmented and the nearest segment to Kabul City is 90 km long (see Figure 1). Figure 11 and 12 show the estimated contours of maximum ground acceleration and maximum ground velocity for bed-rock by assuming that the fault has a strike, dip and rake angle with a hypocentral depth of 20 km as given in Table 5. The shear wave velocity of bedrock is taken as 760 m/s.

As noted from the figures, the ground accelerations could be greater than 0.9 g for Kabul City. Similarly, the maximum ground velocity would be about 153 kines at the epicenter and it is about 104 kines at Kabul City. In view of recent earthquakes with dense strong motion coverage in Japan, USA, Italy and Turkey, these values should be such that they must be the basis for the earthquake-resistant of structures in Afghanistan.

5 DISCUSSION AND CONCLUSION

In this study, we simulated strong ground motions induced in Kabul city by the Mw = 7.5 Hindu Kush earthquake and source to site distance of 300 km using SMSIM, a FORTRAN program that account for attenuation and local site conditions. The response spectra at base and surface level is calculated for Kabul city. The simulated spectral pseudo-acceleration with 5% damping is presented in Figure 9. The maximum acceleration at the surface is about 25% and is matching the recordings taken in Kabul city. Although the simulated results are smaller compared to the actual recordings, other construction factors might also contribute to the significant damage of buildings in Kabul city.

In addition, strong motion records taken in Peshawar and D.I. Khan induced by the 2015 Hindu Kush earthquake have been summarized. These results may be also of great significance to check the estimations. This signifies the importance of a thorough multi-hazard assessment on buildings in Afghanistan. Although the strong motion instrumentation of Afghanistan is none, the results presented here can be used in seismic analysis and design of infrastructural facilities in Kabul. Nevertheless, the most important aspect is to be well-prepared against the worst scenarios such as the possibility of a great earthquake on the Chaman fault. The strong ground motions can be quite high and these would have an important implications in the earthquake preparedness of Afghanistan with a hope that the devastating 2005 Kashmir earthquake would not be repeated again. Furthermore, it is no need to say that the establishment of a strong motion network in Afghanistan is a must in order to check the assumptions as well as to have instrumental data of strong ground motions for the seismic design of structures.

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