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Ground Motion Prediction Equations (GMPEs) for Pakistan: Preliminary Results

Muhammad Waseem[1], Yasir Mushtaq[1], Sarfraz Khan[1]*, Waqas Ahmed[1], Abdul Rashid Pasha[1] and Asif Khan[2]

[1]*NCE in Geology, University of Peshawar*

[2]*Vice Chancellor, University of Peshawar*

**Corresponding author's email: sarfraz_qau@yahoo.com*

Abstract

GMPEs are empirical equations used in seismic hazard analysis studies to predict ground motions. These GMPEs do not exit for Pakistan. In previous studies, GMPEs are adopted in different regions of the world. In this study, all the previously used GMPEs along some global ones are collected and evaluated with local strong motion data collected from different agencies.

In this study, strong motion data are collected from different agencies in Pakistan. Provided data is in the wave-form that was converted into digital form for use in the analysis. These strong motion records were used to compile a strong motion catalog. By using the software, we removed the noise and put the mean removal on the wave for filtering and finding the low and high pass value.

The analyses of standard deviation data show that Sharma et al. (2009) and Akkar and Bommer (2010) GMPEs results in high values of standard deviation compared to that of Boore and Atkinson (2008). This study clearly shows that internationally published GMPEs are not necessarily suitable for every region. Even a meager amount of strong motion data is used for evaluation of these GMPEs so only those conforming closer to local crustal conditions can be used for determination of seismic hazards.

Keywords: GMPEs; Pakistan; Spectral Ordinates; Style of Faults; Acausal filtering; Standard Deviation.

1. Introduction

In seismic risk assessment, the assessment of shaking intensity in future earthquakes plays an important role. Therefore, reliable assessment of ground shaking which makes the basis for the seismic-resistant design of structures is obtained mainly through empirical predictive relationships developed by the statistical analysis of the strong ground motion data recorded during earthquakes. Countries with a dense network of strong-motion recording instruments have enough data to model the ground motions as they propagate through earth's crust, and in the process succeeded in developing what is called attenuation relations or ground-motion prediction equations (GMPEs). Countries like Pakistan, however, have only a limited number of strong-motion instruments installed at its various parts. Until a decade back, these instruments were only a few. However, since October 8, 2005 earthquake, there has been now several such instruments installed in the country both by the Pakistan Meteorological Department and Atomic Energy Commission, including some by the observatory of WAPDA. However, a decade is not a long period to record enough earthquake records of variable magnitudes at variable distances from the epicenters. We collected a number of strong-motion records for northern Pakistan through the courtesy of the Pakistan Meteorological Department (PMD), which though may not be enough for developing Pakistan specific GMPEs, but are sufficient to assess the suitability of internationally published GMPEs to be used in hazard assessments in Pakistan (Fig. 1).

The purpose of the research is to evaluate global attenuation models for their suitability for Pakistan and develop a functional form of the possible attenuation relationships based on available data.

2. Compilation of strong motion catalog of Pakistan

In Pakistan, there is a lack of strong

motion data. After the 2005 Kashmir earthquake, there were greater realizations regarding the necessity of such data. In Pakistan, there are several agencies, which are involved in the recording of the earthquake from last 3 or 4 decades. These agencies have two types of data, i.e., Wave-form data and Mata data (detail of the records).

Strong motion meta data set was collected from several networks in Pakistan (i.e., Pakistan Meteorological Department (PMD), Pakistan Local Network (PLN), United State of Geological Survey (USGS), IDC, Atomic energy and WAPDA). These networks provide the data in wave-form (analog form) along with the detail of the record (date, time, magnitude, epicentral distance, latitude-longitude, style of faulting and the site condition of all the records). In this catalog, almost 100 records are reported with corresponding time, date and year (Table 1). Most of these records span from 2008-2010. There are three types of magnitude in the catalog: Local magnitude (ML); Body wave magnitude (mb); and Surface wave magnitude (MS). These magnitudes types need to be converted to a uniform type MW, using Scordilis (2006) relations, before the catalog can be used for input in attenuation relations and seismic hazard analysis.

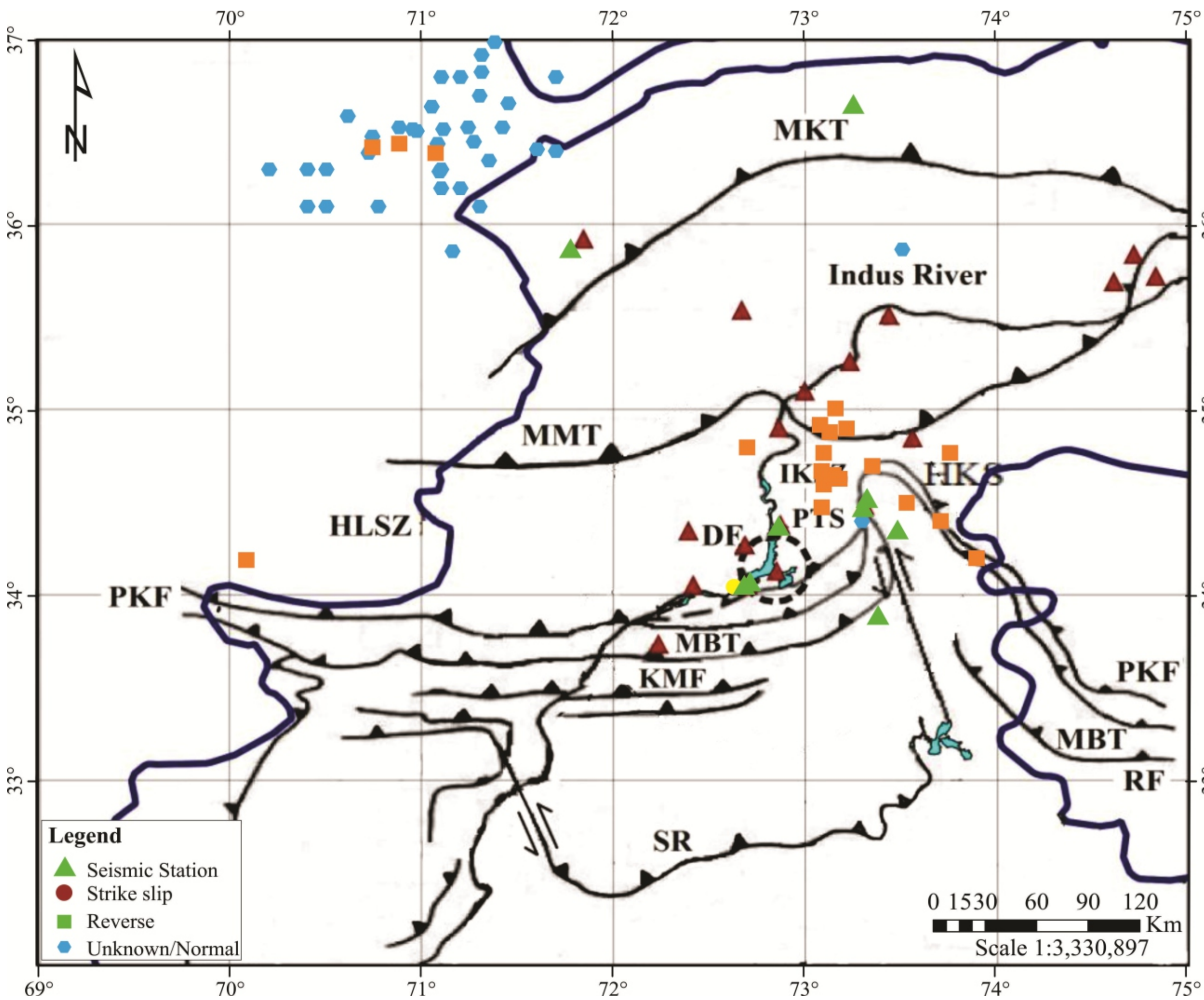


Fig. 1. Map showing the northern and northwestern part of Pakistan (modified from MonaLisa et al. (2005); their Figure 1). The red triangles show the location of TSN stations. DF–Darband Fault; HKS–Hazara Kashmir Syntaxis; HLSZ–Hazara Lower Seismic Zone; IKSZ–Indus Kohistan Seismic Zone; KMF–Khair-e-Murat Fault; MBT–Main Boundary Thrust; MKT–Main Karakoram Thrust; MMT–Main Mantle Thrust; PKF–Punjal Khairabad Fault; PTS– Punjal Thrust Structure; RF–Rawalakot Fault; SR–Salt Range.

3. Conversion of parameters for compatibility with used attenuation relationships

In order to use strong motion data for attenuation computations, the data need to be converted to digital form. After the conversion of data four columns were obtained. One column shows the time histories and rest of three columns are the displacements, velocity, and acceleration. For the interpretation of strong motion data, we use only acceleration time history.

All the records are processed in the USDP software for removing the mean and noise (Fig. 2 and Fig. 3). Acausal filtering is used with high pass and low pass (Fig. 4 and Fig.5). Pseudo-spectral acceleration with 5% damping values of the processed data is extracted for further analysis.

From the catalog, high magnitude and short distance records are selected. Magnitude 4.0-4.9 Mw with distance 20-85 km and magnitude 5.0-5.5 Mw with distance 85-139 km were selected. Selected published attenuation relationships are used in this study. In these GMPEs, we inserted parameters i.e., magnitudes, epicentral distance and style of faulting from our region. Scherbaum et al. (2004) developed empirical conversion relationships through regression analyses. We converted the source to site distances given as Rjb in our dataset to Repi, Rhyp, and Rrup using conversion relations of Scherbaum et al. (2004). After inserting the parameter, the spectral ordinates are determined with time periods. These ordinates are further used for the analysis of our data. All the ordinates of selected three GMPE's are arranged with time periods and acceleration of our data to generate response spectra.

Table 1. Source agencies of strong motion Meta-data.

S.No	Station Name	Time Histories	Agency	Site condition
1	Chitral	48	PMD	Slates
2	Balakot	13	PMD	Rock
3	Swabi -Mehra	6	WAPDA	Slates
4	Garhi Mehra	8	WAPDA	Quartzite
5	Darband	7	WAPDA	Sandstone
6	Ambar	4	WAPDA	Limestone
7	Shinkiyari	15	WAPDA	Granite

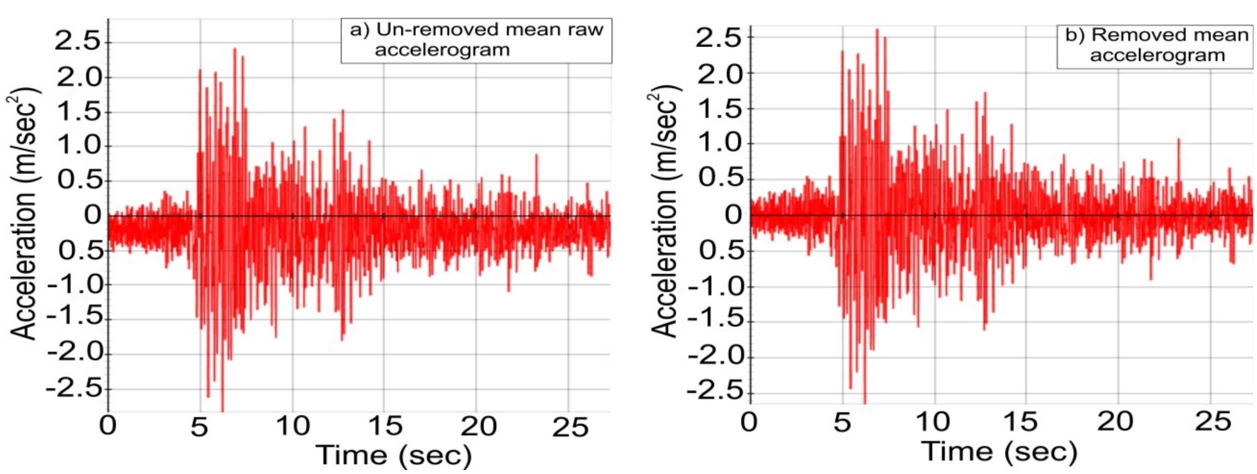


Fig. 2. Example of raw data and Mean Removed Accelerogram.

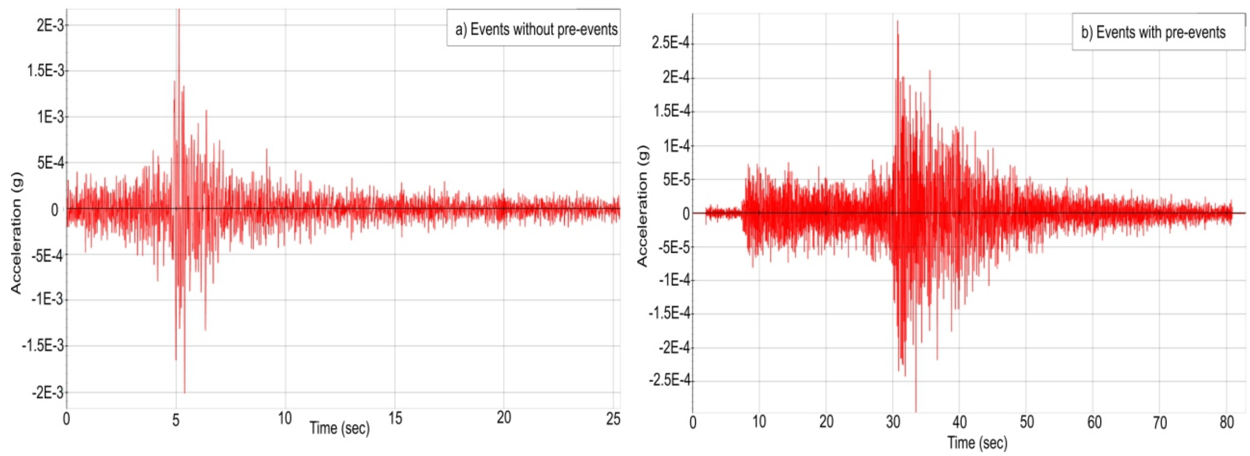


Fig.3. Example of raw data and Mean Removed Accelerogram.

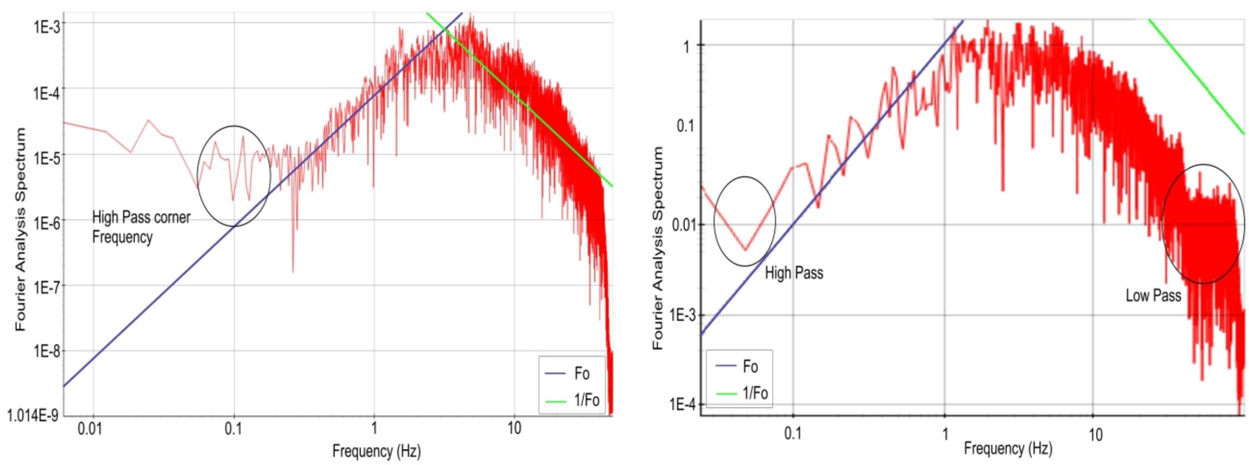


Fig. 4. Example of Acausal filtering shows High- and Low-cut pass frequencies with circles.

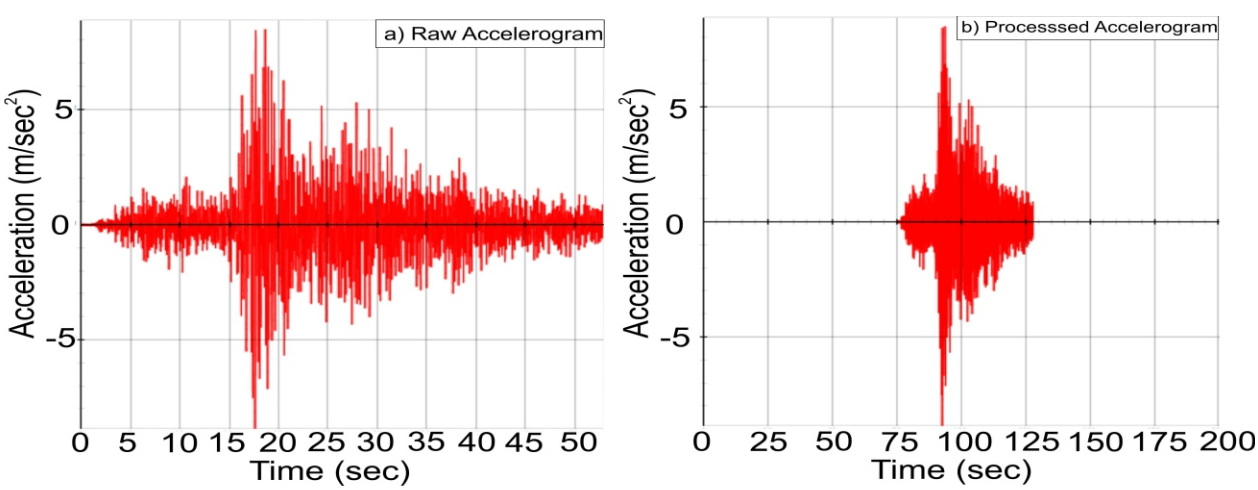


Fig. 5. Illustration of the filter and unfiltered profile.

4. Ground motion prediction equations with reference

Total events in the catalog are 100 out of which we select only 30 events because of the following reasons.

- Selection of high magnitudes, i.e. Mw 4.0-6.0. Secondly, we considered that one earthquake is recorded on more than one stations.
- Select those records which are recorded on a different station.
- Minimum source to site distance is taken.

A list of 30 attenuation relations was selected (after Bommer et al., 2010). After careful distillation, we select three relationships to be used in this study, which we consider compatible for northern Pakistan. These three GMPEs include attenuation relationships appropriate for active shallow crustal regions similar to the tectonic setting of the Indian plate crust in northern Pakistan. Note that northern Pakistan is characterized by both shallow, intermediate and deep earthquakes. However, intermediate to deep earthquakes are mostly associated with extreme northern parts of Pakistan related with the Hindu Kush seismic zone, outside the presently studied area. Therefore, the GMPEs adopted for use in this study are considered appropriate for shallow active crustal regions.

We calculated standard deviations and mean standard deviations for all the three GMPEs selected i.e., Sharma et al. (2009), Akkar and Bommer (2010) and Boore and Atkinson (2008) for selected events in the magnitude ranges of 4.0-4.9, 5.0-5.5, and distance range within 100 km and 200 km, respectively which are given in Table (2).

5. Style of faulting

Another difficulty that was faced is the style of faulting information for the earthquake in the Pakistan data set as focal mechanisms are not reported by different local agencies. Therefore, another source is applied such as Global Centroid Moment Tensor (GCMT) project (http://www.globalcmt.org/GCMTsearch.html). GCMT catalog contains a focal mechanism for the earthquake magnitude greater than 5.0. Since, Pakistan strong motion datasets contain very few events of M>5.0, fault types of other event are assigned based on the available fault information. Epicenters in the datasets were superimposed on the available fault mechanism from past earthquake in the vicinity to come up with the best estimate of the style of faulting for some of the earthquakes. The sources of some events are from the Hindukush region, which lies outside of the Pakistani boundaries.

The catalog contains a number of faults, i.e., Normal, Reverse and Strike-slip. In the catalog, the maximum number of records are associated with reverse faulting. Only two records are strike-slip, and rest of the records are normal (Table 3).

Depth is also a major factor in the catalog. Most of the records are from the shallow earthquake with depth up to 30 km. Earthquakes with 70 and up to 150 km are also common. The NW Pakistan (Chitral) is an exception where earthquakes with depth ranges of 150-283 km are recorded due to the close vicinity of deep subduction in the Hindu Kush seismic zone.

Figure 1 shows reverse and strike-slip faults are near to the recording stations whereas the majority of those at distances greater than 50 km are not known in terms of the focal mechanism. The last column in the catalog contains a PGA value. This PGA value is for the recording station generated by the event. The number of events and records of different magnitude ranges is listed in Table 4.

6. Response spectra

The term response spectra are curved which obtain by using the digital data. Figure 6 (a) and 6(b) shows results of this study in the form of a response spectrum. We calculated response spectra for a given magnitude of Mw 4.5 with a source-site distance of 59.09 km. We calculated response spectrum based on our strong motion data compiled in this study and compared it with spectra calculated using the three GMPEs. Figure 6 (a) shows that Akkar and Boomer (2010) GMPE yields a response spectra with spectral ordinate peak approaching

Table 2. Comparison of standard deviations obtained for magnitude ranges 4.0- 4.9 and 5.0-5.5 and distance Range of 100-200 km for the three GMPEs selected for this study.

Attenuation Relationship	Standard Deviation	
	Mw 4.0-4.9	Mw 5.0-5.5
Akkar and Bommer (2010)	0.89782	-4.20429
Boore and Atkinson (2008)	-1.05229	-8.12253
Sharma et al. (2009)	-5.09656	-4.807162

Table 3. Showing fault types associated with earthquake events in the compiled catalog.

Fault name	Reverse	Strike slip	Normal
MBT	3	--	--
Balakot Shear Zone	2	--	--
Puran Fault	1	--	--
Oghi Fault	7	--	--
Punjal Thrust	6	--	--
MMT	10	--	--
Unknown	2	--	60
Batal Thrust	1	--	--
Nowshera Fault	--	2	--
Mansehra Thrust	1	--	--

Table 4. The number of events and records in different magnitude ranges.

Magnitude (Mw)	2.0-4.0	4.0-4.4	4.5-4.9	5.0-5.4	5.5-5.9	6-6.4	6.5-7.6
No. of Events	07	06	10	06	11	03	04
No. of Records	07	30	27	11	17	03	09

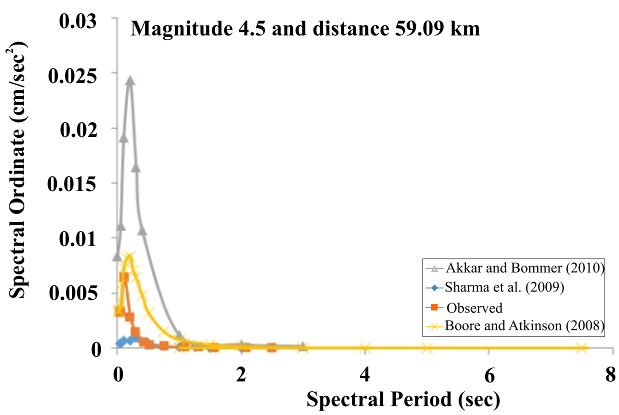


Fig. 6. (a) Graph showing the response spectra for the observed and calculated values.

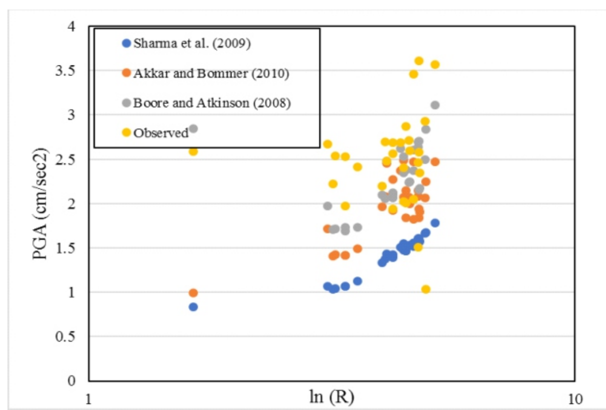


Fig. 6. (b) Graph showing the response spectra for the observed and calculated values.

0.025 that is too high compared to other spectra. Likewise, the GMPE by Sharma et al. (2009) yields very low peak spectral ordinate values. The spectra based on the compiled dataset in this study is closest to the response spectrum calculated using GMPE of Boore and Atkinson (2008).

We draw the response spectra along the spectral period and spectral acceleration on the graph. Such as the PGA calculation is defiantly used for the response spectrum. First of all, both spectral acceleration is taken on the excel sheet along with the respected time period then comparing both time histories along with their spectral acceleration. These values are calculated by using the formula of the standard deviation by the empirical equation of Sharma et al. (2009).

By using the attenuation equation and put up all the required parameter for obtaining the spectral ordinate along the time history (Fig. 7).

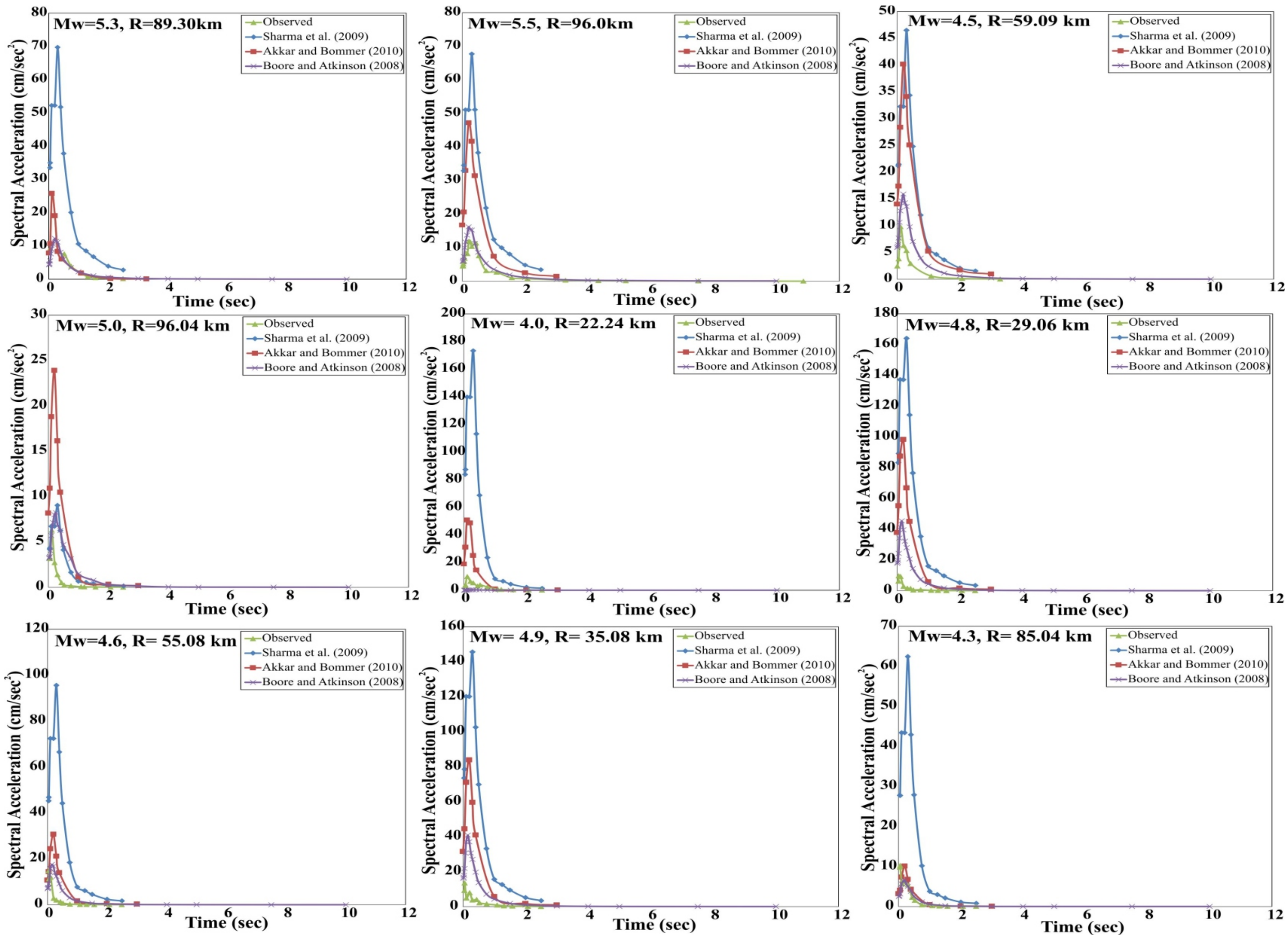
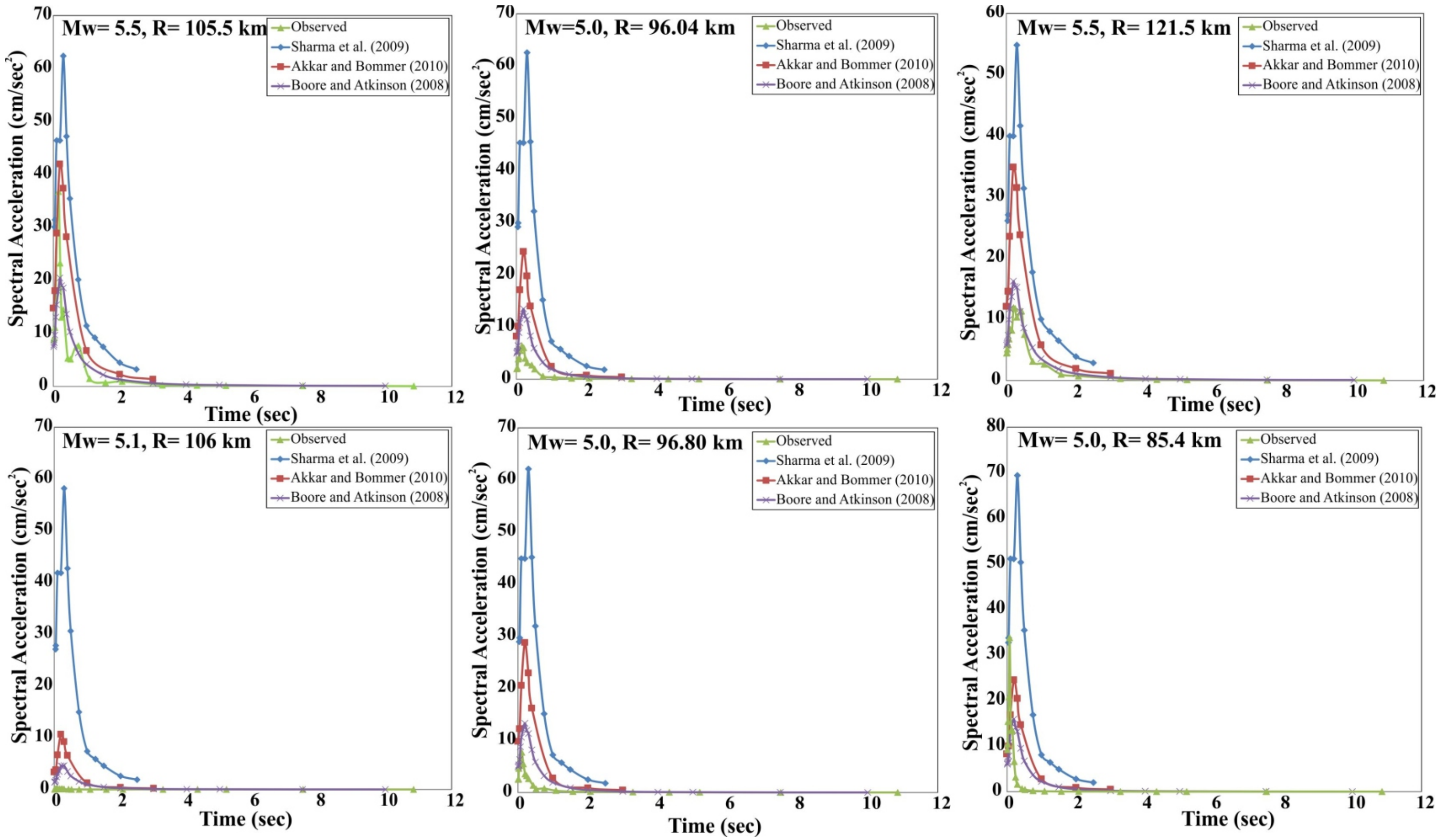


Fig. 7. Graph showing the plot of Response Spectra of discussed equations.


Mw= 5.5, R= 105.5 km
Mw=5.0, R= 96.04 km
Mw= 5.5, R= 121.5 km
Mw= 5.1, R= 106 km
Mw= 5.0, R= 96.80 km
Mw= 5.0, R= 85.4 km
Observed
Sharma et al. (2009)
Akkar and Bommer (2010)
Boore and Atkinson (2008)
Spectral Acceleration (cm/sec²)
Time (sec)

(Continue)

7. Results and discussions

Strong motion data are collected from different agencies in Pakistan. Provided data is in the wave-form that was converted into digital form for use in analysis. These data included metadata files containing dependent and independent parameters of the records such as event time, date, magnitude and source to site distance. Site conditions (soil, alluvium or bedrock) and focal mechanisms were not included in all metadata, which was included by using geological maps covering recording station sites as well as the epicentral area.

These strong motion records were used to compile a strong motion catalog. For conversion to digital form, the digital data undergo in the process by using the software termed USDP (Boore and Akkar, 2003). By using the software, we removed the noise and put the mean removal on the wave for filtering and finding the low and high pass value.

These processed data are used as input for the attenuation relationships, also referred to as ground-motion prediction equations (GMPEs). There are a number of attenuation relations provided in the literature. Cotton et al. (2006) and Bommer et al. (2010) provide criteria to evaluate and select appropriate GMPEs for use in the seismic hazard analysis. We initially used 35 GMPEs listed by Boomer et al. (2010) and then used the criteria of Cotton et al. (2006) to shortlist 3 GMPEs for use in this study. These GMPEs include Boore and Atkinson (2008), Akkar and Bommer (2010) and Sharma et al. (2009). Based on the functional form of the selected GMPEs, we converted our data into appropriate forms, so that, these datasets can be directly inputted to these equations. For example, we needed to homogenize the magnitudes in our catalog which were given in a wide variety (ML, mb, and Ms) to be converted into a uniform magnitude type, i.e. Mw. In this study, we used an original catalog of 100 records, and only those records with the high magnitude and minimum distance to the recording stations were included further all records are in the cm square unit. Some equations use the gravitational value (g), but the records are in cm square. Therefore, GMPE's units are converted to the cm square. By using the selected three GMPE's parameters like magnitude, source to site distance and site condition from our catalog were used as input parameters. All the GMPEs are having the table of the coefficient with time. The spectral ordinates obtained using GMPEs were compared with spectral ordinates derived from our data. By comparing response spectra based on our strong motion data, with those obtained using the three selected GMPEs, it was found that the GMPEs by Sharma et al. (2009) and Akkar and Bommer (2010) overestimates spectral ordinates whereas those derived using GMPE by Boore and Atkinson (2008) compare closely with the strong motion data collected from Pakistani recording stations.

8. Conclusion

- The analyses of standard deviation data show that Sharma et al. (2009) and Akkar and Bommer (2010) GMPEs results in high values of standard deviation compared to that of Boore and Atkinson (2008).
- This study clearly shows that internationally published GMPEs are not necessarily suitable for every region. Even a meager amount of strong motion data is used for evaluation of these GMPEs so only those conforming closer to local crustal conditions can be used for determination of seismic hazards.
- The latest strong motion network installed by PMD and WAPDA will take time in the generation of sufficiently strong ground motion records. In this study, we developed magnitude verses distance curves drawn from different records; the graphs show that the data of already installed records is of sufficient quantity to propose a preliminary attenuation relationship for Pakistan. But these time histories need to be carefully processed and filtered using the appropriate software.
- The older instruments at some stations are not working according to standard condition recommended for their operation. However, newly installed strong-motion seismometers overcome these deficiencies. There is a great need of detailed metadata listing all fundamental parameters for the recording stations.
- There is lack of organization among agencies. The earthquake database is not spreader, and due to lack of coordination, it is not reliable.

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