DETERMINISTIC SEISMIC HAZARD ANALYSIS AND SELECTION OF TIME HISTORIES FOR DYNAMIC ANALYSIS FOR A SITE IN SWABI

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ABSTRACT

Pakistan lies in one of the most tectonically active regions of the world. The latest destructive 2005 Kashmir earthquake of magnitude 7.6 struck the northern part of Pakistan which caused death toll of about a hundred thousand people and monitory losses of about five billion US dollars. After this earthquake, most of research activities were directed to define earthquake hazard. However, amongst other problems in those studies, one hard decision is the use of attenuation relationship as no such equation is developed for Pakistan. These studies either do not consider the newly developed New Generation Attenuation (NGA) equations or use a single NGA equation. The purpose of this study is to utilize all NGA equations to define seismic hazard in terms of peak horizontal acceleration using Deterministic Seismic Hazard Analysis (DSHA) for a site near Tarbela Dam, Pakistan. The PGAs from all NGAs are weighted to get mean PGA for design. The site of interest, where previously recorded PGA was 0.16g for Kashmir 2005 earthquake-150 Km away from the epicenter, is surrounded by 8 faults. This site has a forty feet high slope inclined at 53° to the horizontal and made of dense gravels with a mixture of silt, clay, and sand. On top and bottom of the slope, boy's hostels are being built. This necessitates seismic hazard analysis to be evaluated and a suit of acceleration time histories be selected for dynamic analysis of the slope. Three time histories are selected in this study from real earthquakes that matches parameters with the controlling earthquake.

Key words: *Hazard analysis, Next generation attenuation equations, Time histories, Peak ground acceleration, Shear wave velocity.*

INTRODUCTION

Pakistan is amongst the most seismically active regions of the world. It lies in area of collision of the Eurasian and Indian tectonic plates (figure-1). The tectonic activity resulting from this collision, besides being responsible for the origin of the Himalayas, is cause of the seismicity of the region. The country has experienced many damaging earthquakes over the last hundred years, which include 1935 Quetta earthquake of magnitude 7.6, 1945 Makran Coast of magnitude 8.4 and 2005 Kashmir Earthquake of magnitude 7.6. Since after the 2005 Kashmir earthquake several efforts have been made to characterize seismic hazards in different cities of Pakistan.

Amongst other problems in such studies for Pakistan, one crucial issue concerns the decision about the use of appropriate attenuation relations. No predictive relationship has been developed for Pakistan due to lack of strong motion data. Researchers working on definition seismic hazard in Pakistan have, therefore, used attenuation relations developed for other regions. However, to the best of the authors' knowledge, none of these studies use recently developed Next Generation Attenuation (NGA) relationships, except for one study Naveed[1] et al. 2010, which used a single NGA equation.

A summary of these studies is: Ansari[2] (1995) used Public Works Research Institute Japan equation. Monalisa[3] et al. (2007) used Ambraseys[4] (2005) and Boore[5] et al. (1997) equation, Monalisa[3] et al. (2007) have used seven different equations for seismic hazard analysis that included attenuation relationships for Sadigh[6] et al (1987), Boore[5] et al (1997), Joyner & Boore[7] (1982), Campbell and Bozorgina[8] (1993), Ambraseys[9] et al. (1996), Tromans & Bommer[10] (2002), and Ambraseys & Bommer[11] (1991). Monalisa[12] et al. (2002) used Public Works Research Institute Japan equation. Boore[5] et al (1997) and Ambraseys[4] (2005) ground motion models also have been used in the seismic hazard assessment of Mangla Dam (2005). NESPAK (2007) developed seismic hazard map for

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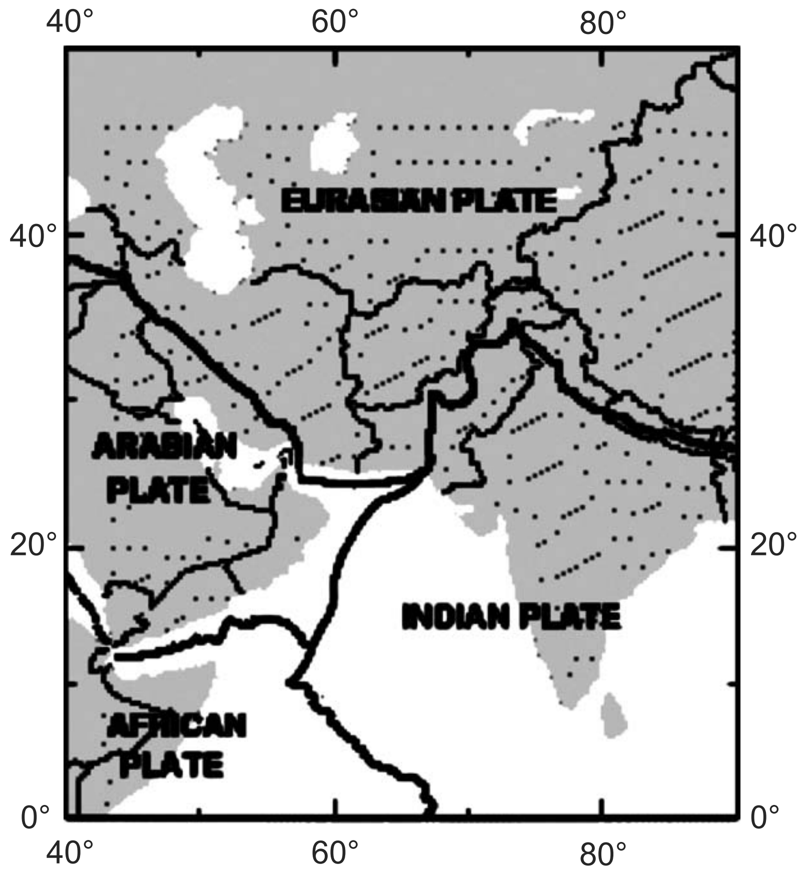


Figure 1: Tectonic map of the region

Pakistan to be used in Pakistan Building Code, Seismic Provisions. This map is based on Boore[5] et al. (1997) predictive equation. Pakistan Meteorological Department and NOARSA, Norway[13] (2007) jointly worked on seismic hazard analysis and zonation for Azad Jammu and Kashmir, Pakistan. This study is based on Ambraseys[4] et al. (2005) attenuation equation. Ahmed[14] et al. (2008) used Boore & Atkinson NGA model for developing seismic risk model for Mansehra city, Pakistan.

Attenuation relationships are always been updated when more strong motion data becomes available, therefore updated version should be considered rather than older version of the attenuation models. The Next generation attenuation equations have been developed by developers of the five pre-existing ground motion models used worldwide from large databank. Development and subsequently their availability supersede the previous models. Moreover these models are developed for shallow crustal tectonically active region and their applicability in other regions with similar tectonic environment has been demonstrated by a number of researchers. Due these reasons NGA models have been selected for this study.

In this study deterministic seismic hazard analysis (DSHA) has been carried out for a site located in Swabi, NWFP, Pakistan using all NGA equations in conjunction with Ambraseys[4] et al. (2005) equation. Three real time histories are selected based on controlling earthquake parameters obtained from DSHA. The site of interest has critical slopes which require peak horizontal ground acceleration for pseudo-static analysis of slopes and acceleration time histories for dynamic analysis.

DESCRIPTION OF LOCATION AND SEISMICITY OF THE SITE

The site is located in Swabi (34.25^{o} E ; 72.25^{o} N), 120 kilometers north-east of Peshawar and 40 km west of the Tarbela Dam (Figure 2).The general topography of the area is shown in Figure 3. The site is a 13m high steep slope, at the top and bottom of which hostels are being built (Figure 4). If a failure of

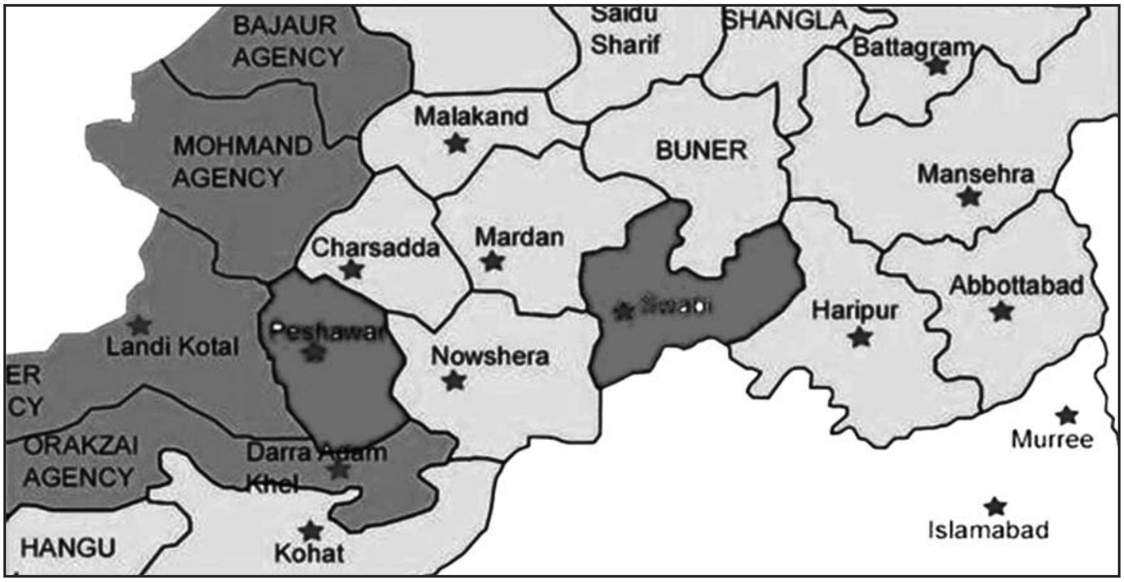


Figure 2: Geographical location of the site

Figure 3: Topography of the site

slope occurs, it can take over hundred lives of students. The slope is composed of silty gravels with sand and clay. The deposit is dense and corresponds to Class "C" soil classification of NEHRP. The foundation soil of the slope is of the same material as the slope. A shear wave velocity of 450 m/s has been assumed to correspond to the foundation soil. This shear wave velocity is used for peak ground acceleration calculations.

The site is located close to Tarbela Dam, which is densely instrumented with both seismographs and

Figure 4: Steep slope at the site showing hostels being built

strong motion accelerometers. The data obtained from Seismology Section of Tarbela Dam Project about seismicity of the area is: Average numbers of earthquakes recorded during a year are 6000. Average numbers of earthquakes originated within a radius of 160 km of Tarbela Dam are 1000. Maximum level of shaking ever observed at Dam site was a peak acceleration of 0.27g. This PGA, most probably recorded at the crest of the Dam has been amplified due to dam dynamic response. This shaking was caused by an Earthquake on May 20, 1996 of magnitude 5.2 and depth 5 Km originated in Topi (7 Km from Tarbela Dam and 35 Km from the site). October 8, 2005 Kashmir earthquake caused peak acceleration ranging from 0.1g to 0.16g at different locations of Dam.

The site is surrounded by a number of faults (Figure 5). Major tectonic features generating earthquakes at the site are Main Karakorum fault, Punjal fault, Main Mantle fault, Jehlum fault, Kalabagh fault, Main Boundary fault, Himalayan frontal fault, and Raisi fault.

GROUND MOTION PREDICTIVE RELATIONSHIPS USED IN THE PRESENT STUDIES

In this study five Next Generation Attenuation (NGA) equations and Ambraseys[4] et al. (2005) predictive equation is used. The NGA equations are developed by Pacific Earthquake Engineering Research Center. NGA attenuation equations have been developed utilizing worldwide strong motion data from active tectonic regions for shallow crustal earthquakes. The worldwide strong motion data used in NGA development have also used recordings from Asia (Table-1). Their worldwide applicability has been demonstrated by different researchers. Campbell and Bozorgina[15] (2006) suggested that NGA equation developed by them is applicable to Europe. David M. Boore[16] (2010) recommended that NGA are applicable to shallow crustal tectonically active regions worldwide. Similarly Stafford[17] et al. (2008) has carried out studies suggesting that NGA ground motion models can be used in Europe. Shoja-Taheri[18] et al. (2010) compared ground motion data form NGA with strong motion data of Iran. They found that mean residuals are almost equal to unity showing Iranian data is consistent with NGA models. Bindi[19] et al. (2010) also showed that Italian strong motion data is consistent with NGA models.

In addition to NGA equations, Ambraseys[4] et al. (2005) equation is used in this study because it has been developed from shallow crustal earthquakes strong motion data from the Middle East and Europe. The data base used for developing this relationship is large and is of good quality.

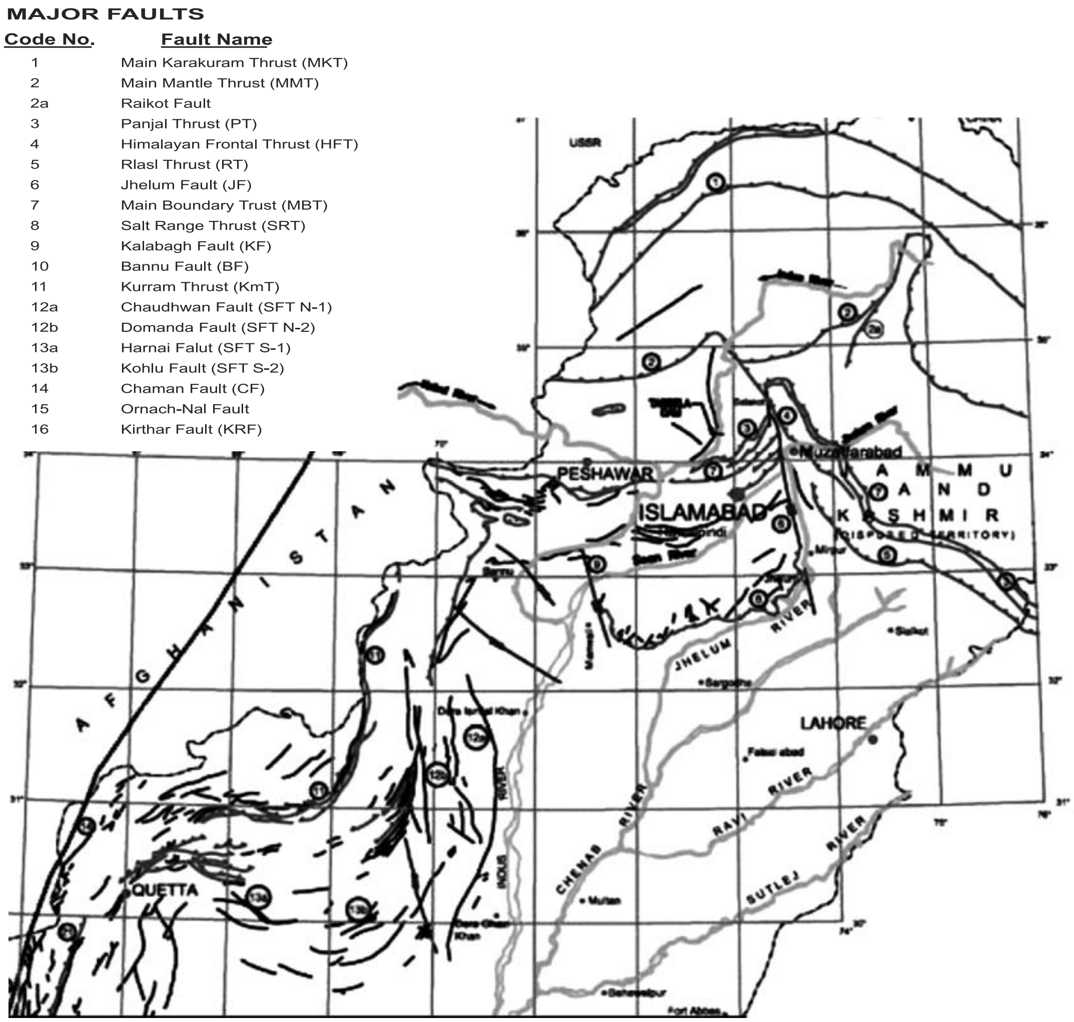


Figure 5: Faults surrounding the site

Table 1: Showing the Comparison of the Subsets in derivation of NGA Models

S. No	Ground Motion Model	Total Earthquakes	Earthquakes in Asia	Total events	In Asia	% of Events in Asia
1	Abrahamson-Silva	135	24	2754	1345	48.80 %
2	Boore & Atkinson	58	8	1574	452	28.70 %
3	Campbell & Bozorgina	125	8	1561	435	27.86%
4	Chiou & Young's	125	125	1950	857	43.94%
5	Idriss	11	72	942	717	76.11 %

Pakistan Meteorological department in collaboration with NORSAR, Norway[13] (2007) compared Ambraseys[4] et al. (2005) equation with Ambraseys[9] 1996, Boore[5] et al 1997, Sharma[20] 1998, Jain[21] et al. 2000, Sharma and Bungun[22] 2006, Khademi[23] et al. 2002, Akkar and Bommer[24] 2006, and preferred the use of Ambraseys[4] et al. (2005) equation. The reason for preference over the other models has been given in

Table 2: Faults types around the site

S. No	Name of the Fault	Type of the fault
1	Main Karakorum Thrust	Reverse
2	Main Boundary Thrust	Reverse
3	Main Mantle Thrust	Reverse
4	Punjal Thrust	Reverse
5	Himalayan Frontal Thrust	Reverse
6	Raisi Thrust	Reverse
7	Jehlum Fault	Strike-Slip
8	Kalabagh Fault	Strike-Slip

Table 5: Different Distances

S. No	Name of the Fault	Rjb (Km)	Rrup (Km)
1	Main Karakorum Thrust	85.37	86.00
2	Main Body Thrust	28.80	28.80
3	Main Mantle Thrust	36.00	36.00
4	Punjal Thrust	29.12	29.12
5	Himalayan Frontal Thrust	62.89	63.79
6	Raisi Thrust	95.70	96.29
7	Jehlum Fault	65.86	65.86
8	Kalabagh Fault	84.83	84.83

the Report (Seismic Hazard Analysis and Zonation of Pakistan, Azad Jammu and Kashmir, 2007)NGA and Ambraseys[4] et al. (2005) equations are plotted in figure 1 for magnitude 8.0 earthquake for strike slip fault.

DETERMINISTIC SEISMIC HAZARD ANALYSIS OF THE SITE

Procedure described by Reiter[25] (1990) for DSHA has been followed in this research. All faults within 100 Km radius are considered for analysis. These faults are described in table 2. The faults considered in this study are all potentially active faults (Building Code of Pakistan, Seismic provision, 2007).

Maximum Magnitude

Maximum magnitudes that each fault can produce are found using four magnitude-rupture length relationships. These relationships are developed by Bonilla[26] et al. (1984), Nowroozi[27] (1985), Wells & Coppersmith[28] (1994), and Slemmons[29] (1989). The rupture length considered in these relationships is taken to be half of the total length of the fault.

Source to Site Distances

Different distance measures are used in the attenuation relationships. Some attenuation equations consider the shortest distance of the surface projec-

Table 4: Maximum moment magnitude expected

S. No	Name	Moment Magnitude (Mw)				Maximum moment magnitude (Mmax)
		Bonilla et al (1984)	Nowroozi (1985)	Wells & Coppersmith (1994)	Slemmons (1989)	
1	Main Karakorum Thrust	7.9	7.6	7.5	7.6	7.9
2	Main Body Thrust	8.1	7.8	7.7	7.7	8.1
3	Main Mantle Thrust	8.1	7.8	7.7	7.7	8.1
4	Punjal Thrust	7.4	7.1	7.0	7.2	7.4
5	Himalayan Frontal Thrust	7.8	7.5	7.5	7.5	7.8
6	Raisi Thrust	7.8	7.5	7.4	7.5	7.8
7	Jehlum Fault	7.2	7.0	7.0	7.1	7.2
8	Kalabagh Fault	7.1	6.8	6.7	7.0	7.1

Table 6: PGA values

S. No	Attenuation Relationship	M.K.T	MMT	Punjal Thrust	H.F.T	Raisi Thrust	Jehlum Fault	MBT	Kalabagh Thrust
1	Boore & Atkinson NGA	0.091	0.203	0.176	0.118	0.074	0.086	0.230	0.061
2	Abrahamson and Silva NGA	0.093	0.175	0.138	0.105	0.080	0.064	0.210	0.048
3	Campbell & Bozorgina NGA	0.069	0.160	0.123	0.083	0.060	0.062	0.160	0.048
4	Chiou & Youngs NGA	0.090	0.214	0.172	0.111	0.074	0.061	0.252	0.042
5	Idriss NGA	0.072	0.172	0.146	0.090	0.060	0.053	0.214	0.037
6	Ambraseys et al (2005)	0.144	0.304	0.203	0.161	0.119	0.074	0.346	0.053

Table 7: Parameters of selected time histories

S. No	Name	Magnitude	Recording Station	Joyner & Boore distance (Km)	Shear Wave Velocity (m/s)	PGA (g)	Scaling Factor
1	Chi-Chi Taiwan	7.62	CWB-99999 TCU0 29	28.05	473.09	0.201	1.17
2	Chi-Chi Taiwan	7.62	CWB99999 ILAo67	33.28	553.04	0.198	1.19
3	Chi-Chi Taiwan	7.62	CWB99999 CHY010	19.93	473.90	0.227	1.03

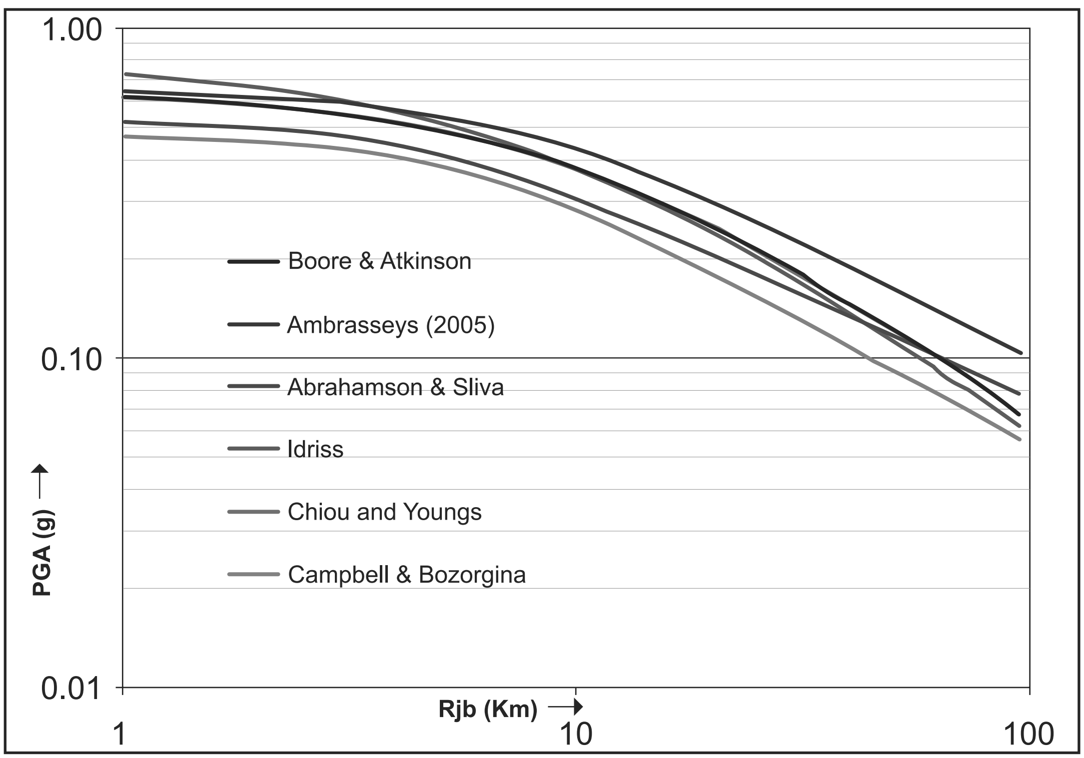
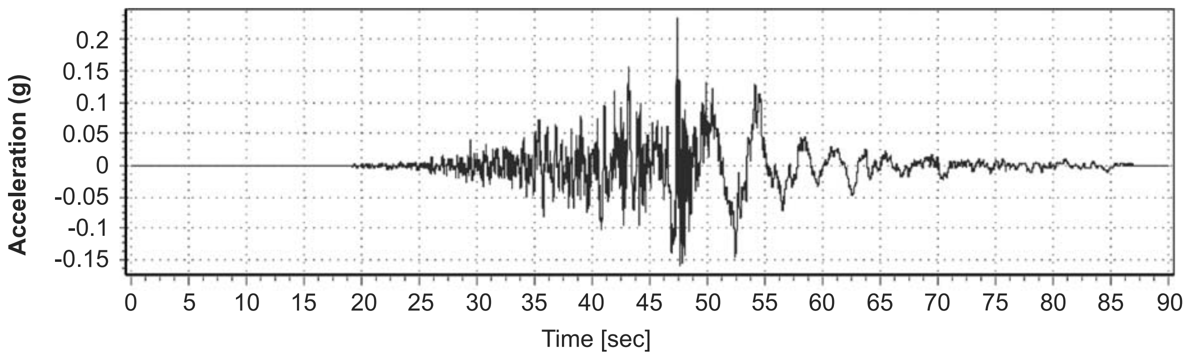
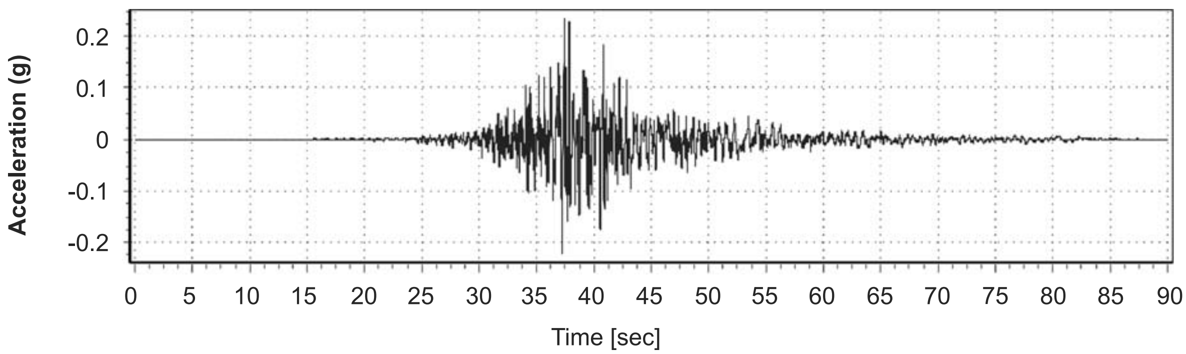


Figure 6: Comparison of attenuation relationships used in this study for Mw=8.0



Time History No. 1



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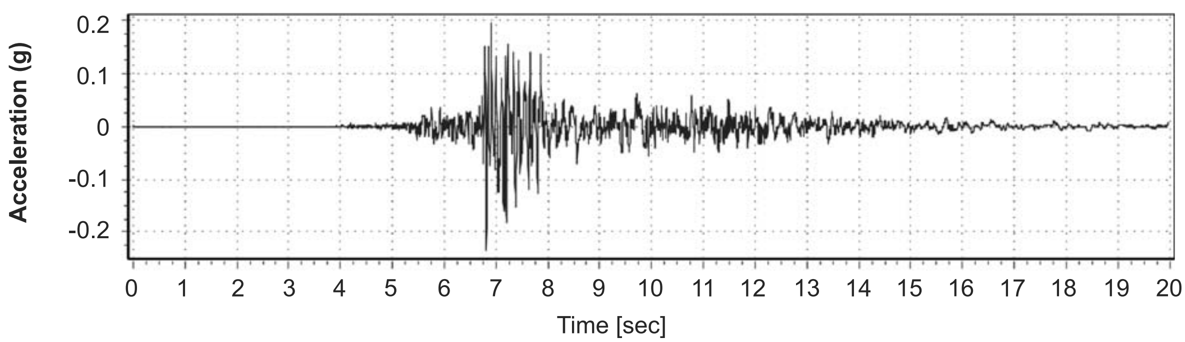

Time History No. 3

Figure 7: Three different time histories

tion of the fault to the site called Joyner and Boore distance (Rjb) while others use shortest distance to rupture of the fault (Rrup). These distance measures are given in table 5.

PGA Calculations

All six attenuation equations are used to calculate peak ground acceleration using data from table 4 and Table 5. These PGA values estimated for the site are summarized in Table 6.

Controlling Earthquake

Of all the faults, MBT produce highest PGA values for all the predictive equations. Giving equal weights (i.e. 1/6) to all the PGA values calculated from all the attenuation equations used in the study yield a mean PGA of 0.235 g for the site.

SELECTION OF TIME HISTORY

Acceleration time histories are required for dynamic analysis of the slope to evaluate factor of safety against sliding in the event of controlling earthquake. Three acceleration time histories are selected from databank of PEER (Pacific Earthquake Engineering Research Center) website (http://peer.berkeley.edu/nga/). These time histories are selected from Chi-Chi (1999) Taiwan earthquake of magnitude 7.62 from a reverse fault (figure). Table 7 summaries different parameters of selected time histories. Scaling factor of 1.17, 1.1.9, and 1.03 are used to match the controlling earthquake peak acceleration 0.235g.

CONCLUSION

All NGA equations in conjunction with Ambraseys[4] (2005) attenuation relationships are used to calculate seismic hazard at a site in Swabi, Pakistan. The site consists of critical slopes that require seismic analysis. DSHA is used to ascertain the controlling earthquake and its parameters. Three real time histories are selected to match, at best, the controlling earthquake parameters. Main boundary thrust fault governs the controlling earthquake producing PGA of 0.235g from a magnitude 8.1 at a distance of (Rjb) 28.8 km. Three time histories selected for dynamic analysis are taken from recordings of Chi-Chi 1999, Taiwan earthquake.

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