



SEISMIC HAZARD EVALUATION FOR 500-kV EHV TRANSMISSION LINE IN PAKISTAN

Aniruddha Sengupta*

SUMMARY

This paper presents the results of a study conducted to establish the level of seismic hazard along a proposed 500-kV transmission line route in Pakistan. The corridor extends from Lahore and Faisalabad in the north and runs in a southwesterly direction following the Indus River valley to Jam Shoro in the south. A literature review was performed to obtain information on the regional tectonics and seismicity, and to identify locations of seismic activity in the region. Seismic source zones were delineated by superimposing the earthquake locations over the map of tectonic features. For each source zone, maximum magnitude and magnitude recurrence rate were obtained from earthquake database. Four magnitude-attenuation models for rock site were selected to determine the decay of earthquake energy with distance from the source. A probabilistic hazard analysis was performed using EZ-FRISK program and seismic hazard curves (expressed as annual probability of exceedance versus peak ground acceleration (PGA)) were developed for key sites along the transmission line corridor where the substations shall be located. The annual probabilities of exceedance and period of return were calculated from the hazard curves for each of the substation sites. For the critical structures along the transmission line route, a design PGA of 0.2g was assumed. The highest level of hazard at each site was predicted using Idriss's attenuation relationship. The lowest hazard was predicted using Sadigh's relationship. The results of the hazard analysis indicated that at all sites except the Moro substation, the period of return of motions equal to or exceeding 0.2g is well in excess of 10,000 years. At Moro, the return period for PGA=0.2g is 3,000 to 10,000 years. In conclusion, the level of risk that an owner would accept would result in lower design PGA's than 0.2g at all sites along the transmission line corridor.

KEYWORDS: *seismicity, ground motions, seismic hazard assessment, Transmission line, Pakistan.*

* Assistant Professor, Department of Civil Engineering, Indian Institute of Technology, Kharagpur, Kharagpur 721302 (INDIA). Ph: (091) (03222) 283454. Fax: (091) (03222) 255303.
Email: Sengupta@civil.iitkgp.ernet.in

INTRODUCTION

A study was conducted to establish the level of seismic hazard along a proposed 500-kV transmission line route in Pakistan. This corridor extends from Lahore and Faisalabad in the north and runs in a southwesterly direction following the Indus River Valley to Jam Shoro in the south (refer to Figure 1).

The work was largely bibliographic, using available geologic and seismologic literature, maps, records and earthquake data files relevant to the region. No fieldwork was completed as part of this study. The scope of the present study consisted of the followings:

1. Perform a literature review to obtain information on the regional tectonics and seismicity and perform a database search to identify locations of seismic activity in the region.
2. Delineate seismic source zones by superimposing the earthquake locations over the map of tectonic features.
3. Specify maximum magnitudes and determine magnitude recurrence rates via analysis of the earthquake database for each source zone.
4. Select a magnitude-attenuation model appropriate for the region to determine the decay of earthquake energy with distance from the source.
5. Perform a probabilistic hazard analysis and develop seismic hazard curves (expressed as annual probability of exceedance versus peak ground acceleration) for key sites along the proposed locations for the 500-kV substations along the transmission line corridor (refer to Figure 1).

The annual probabilities of exceedance and periods of return were calculated from the hazard curves for each of the substation sites. For the critical structures along the transmission line route, a design peak ground acceleration (PGA) of 0.2g was assumed. Critical transmission plant equipment is generally designed to withstand this level of ground shaking.

SEISMICITY

A search of both historical (non-instrumented) and modern (instrumented) seismicity data was performed for the region bounded by latitudes 20°N and 40°N and longitudes 60°E and 80°E. The Global Hypocenter Database produced by the U.S. Geological Survey and National Earthquake Information Center (USGS/NEIC, 1995) was consulted for the database search. This database contains information on over 900,000 earthquakes from 2100 B.C. through to-date and is comprised of information from 53 separate regional and worldwide catalogs. For this study, only earthquakes greater than or equal to magnitude 4.0 were considered and duplicate records were eliminated to the extent possible. Within the region searched, a total of approximately 5,500 earthquakes occurring between 1890 and to-date were identified. A plot showing the reported locations of earthquake epicenters ($M > 4.0$) during this period is presented in Figure 1.

The most seismically active areas are seen to be the Hindu-kush, Pamir, and Karakorum ranges in northeastern Afganistan and northern Pakistan near the China border, the Himalayas in northern India,

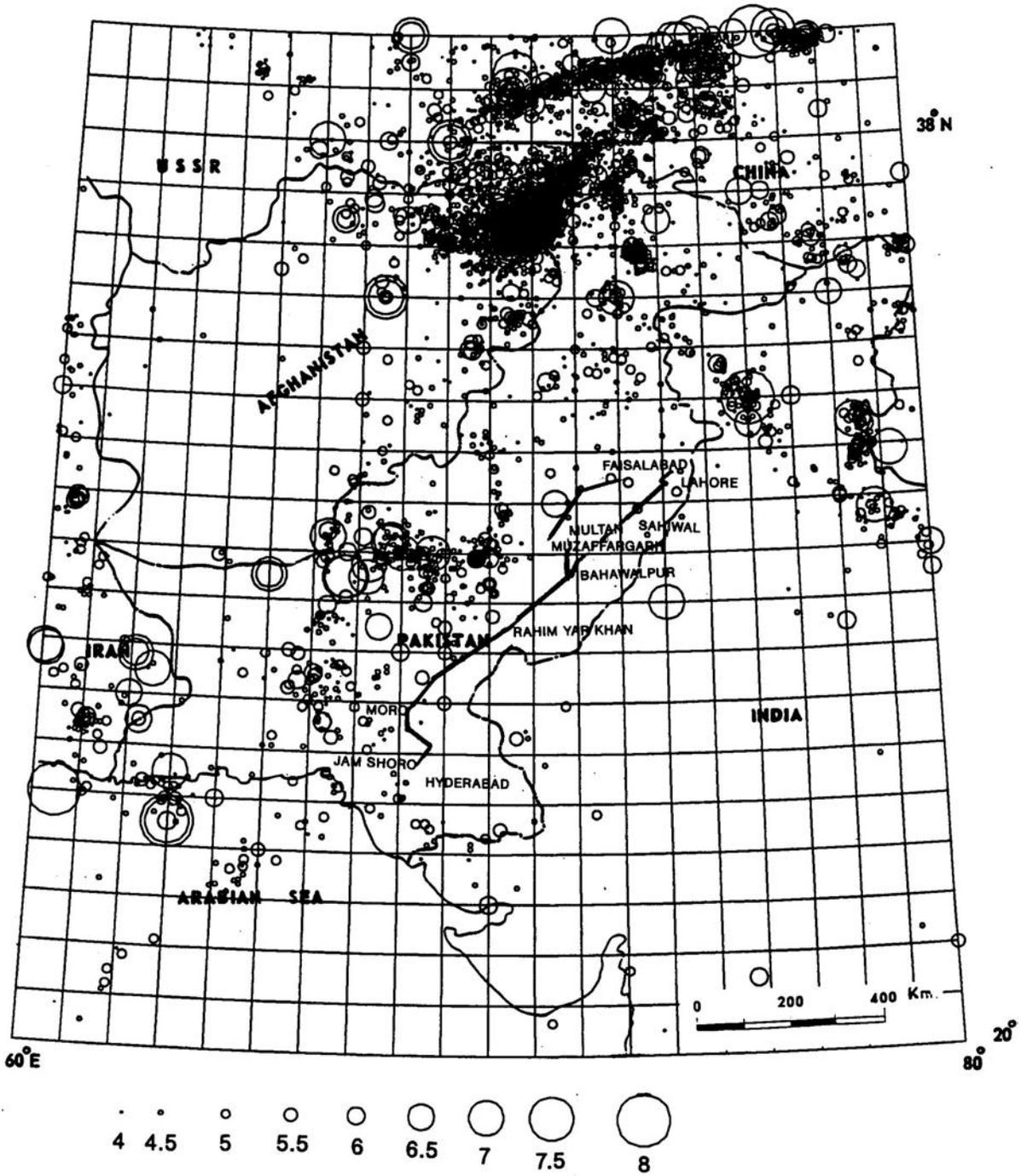


Figure 1. Locations of Transmission Line and Earthquake Epicenters ($M > 4.0$).

the Quetta transverse ranges in Baluchistan, and the Makran region of southern Pakistan near the border with Iran. Seismicity in these areas is associated with fold and thrust belts that developed as a consequence of collision and deformation along the margins of the Indian and Eurasian tectonic plates. Further to the west, subduction of the Indian plate under the Arabian plate has produced the seismic activity in the Makran region (Quittmeyer and Jacob, 1979). Great earthquakes ($M > 8.0$) have occurred in historic times in each of these regions. The Indus Valley in eastern Pakistan and the northwest region of India is characterized by relatively low seismic activity.

A seismotectonic map showing the location of known faults, earthquake epicenters (database from Metrological Department, Geophysical Observatory, Quetta and from Farah and DeJong, 1979), and tectonic provinces in Pakistan was prepared by the Geological Survey of Pakistan (Kazmi, 1979) and utilized in the present study.

SEISMIC SOURCE ZONATION

By superimposing the seismotectonic province map (refer to Kazmi, 1979) on the seismicity plot shown in Figure 1, seismic source zones of equal activity and maximum and uniform source mechanism were developed and are shown in Figure 2. A total of six source areas were identified and are denoted herein as source zones 1 through 6. The highly seismic regions in northeastern Afghanistan, southern China, Tajikistan and eastern Iran were not included since they are all in excess of 400 km from the transmission line corridor and seismic activity therein is too distant to impact the overall level of hazard along the corridor. Zone 6 is characterized by very low seismic activity and contains no known tectonic features. Therefore, it is designated as a zone of background activity.

Recommended maximum magnitudes and average focal depths associated with each of the identified seismic source zones are as follows:

<u>Source Zone</u>	<u>M_{max}</u>	<u>Focal Depth (km)</u>
1	5.80	25
2	7.75	30
3	7.75	30
4	6.25	40
5	8.25	50
6	7.25	35

The estimation of maximum magnitudes was done for zones 2, 3, 4 and 6 by adding one-half magnitude interval to the maximum historical event. M_{max} for Zone 5 represents the maximum historical event. M_{max} of 5.8 for Zone 1 is the maximum observed from similar intraplate crustal zones worldwide. Focal depths were determined by averaging those reported in the database for each zone.

SEISMIC HAZARD EVALUATION

Methodology

A probabilistic seismic hazard evaluation involves obtaining, through mathematical and statistical processes, the relationship between a ground motion parameter (in this case peak acceleration) and its probability of exceedance at a site during a specified interval of time. The evaluation of seismic hazard at a site due to a particular source involves combining two probability functions:

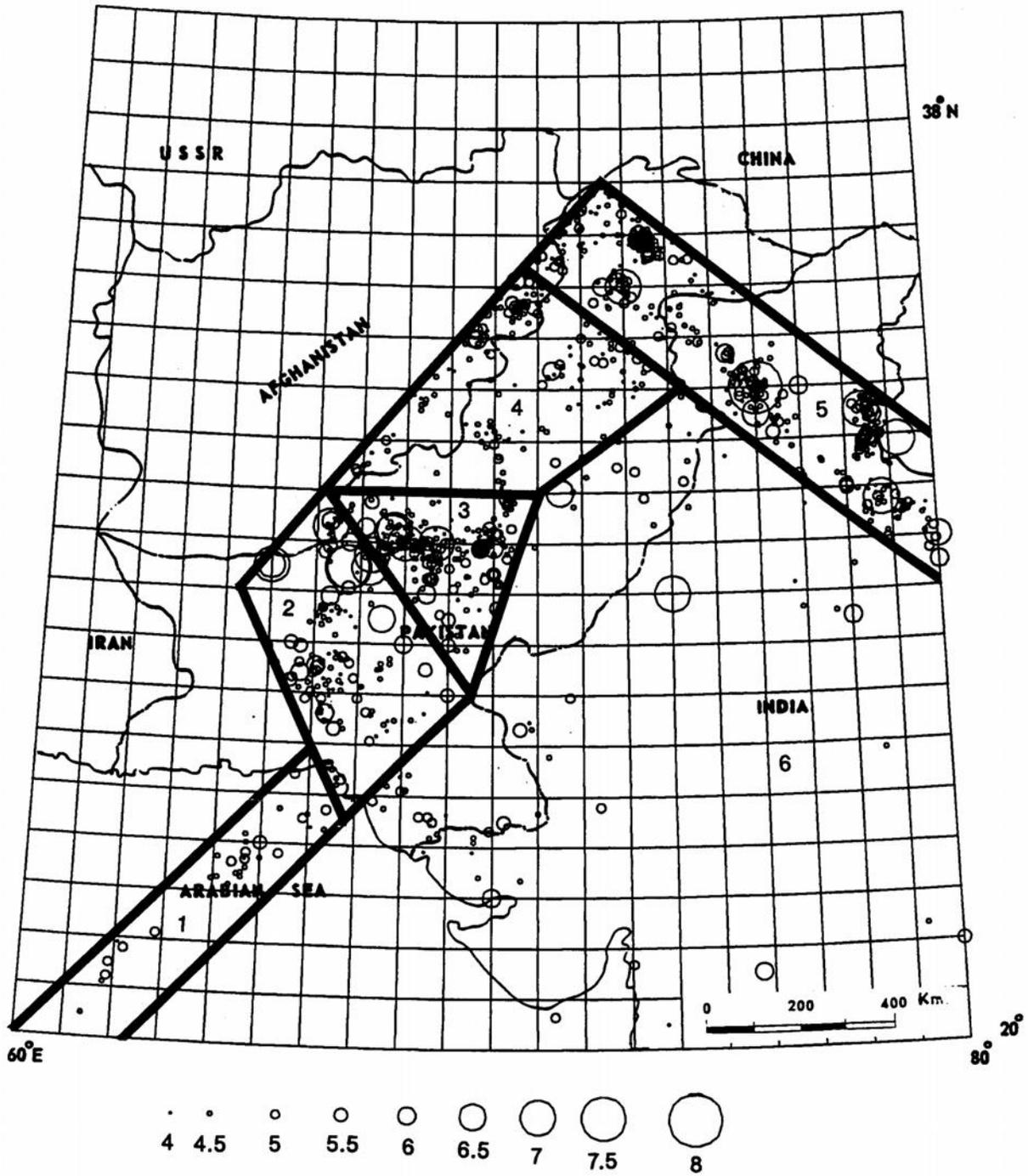


Figure 2. Seismic Source Zones.

1. The probability that an earthquake of a particular magnitude will occur within a source zone during a specified time interval, and
2. The probability that the ground motions from an earthquake of a given magnitude occurring at a certain distance will exceed a specified level at the site.

By combining the two probability functions for each source and adding the contributions from all sources, the annual probability of exceeding a specified level of ground motion at the site is determined.

A computer program EZ-FRISK (Risk Engineering, 1995) was utilized to compute these annual probabilities for proposed substation sites along the transmission line grid. The number of substation sites and their spacing along the transmission line corridor is sufficient to provide a complete picture of the level of seismic hazard at any point along the line. The locations for each of these sites, eight in total, are shown in Figure 1 and are tabulated as follows:

	<u>Site</u>	<u>Latitude (°N)</u>	<u>Longitude (°E)</u>
1	Sheikhupura/Lahore	31.7	74.0
2	Faisalabad	31.4	73.1
3	Sahiwal	30.7	73.1
4	Muzaffargarh/Multan	30.1	71.2
5	Bahawalpur	29.4	71.7
6	Rahim Yar Khan	28.4	70.3
7	Moro	26.4	68.0
8	Jam Shoro/ Hyderabad	25.5	68.2

The following data are required for the hazard analysis:

1. Geometry of each seismic zone.
2. Data on the earthquake recurrence statistics within each source, expressed as the annual number of earthquake events greater than some minimum magnitude and a seismicity rate. These are obtained from the Gutenberg-Richter a and b parameters.
3. Estimates of the upper bound earthquake that each source can support and average focal depths.
4. The ground motion attenuation model.

Magnitude Recurrence Relations

The distribution of earthquakes in each zone is characterized by the Gutenberg-Richter relationship:

$$\log N_c = a - bM \quad (1)$$

where, N_c is the cumulative number of earthquakes greater than some magnitude (in this case equal to 4.0), and a and b are constants.

Review of the literature provided no useful information related to the magnitude recurrence parameters for these seismic zones. Statistical regression of the magnitude data for each source zone was performed to find the number of events per year as a function of magnitude. This data for zone 2 only is plotted in Figure 3. The a and b parameters for each source used in this study are as follows:

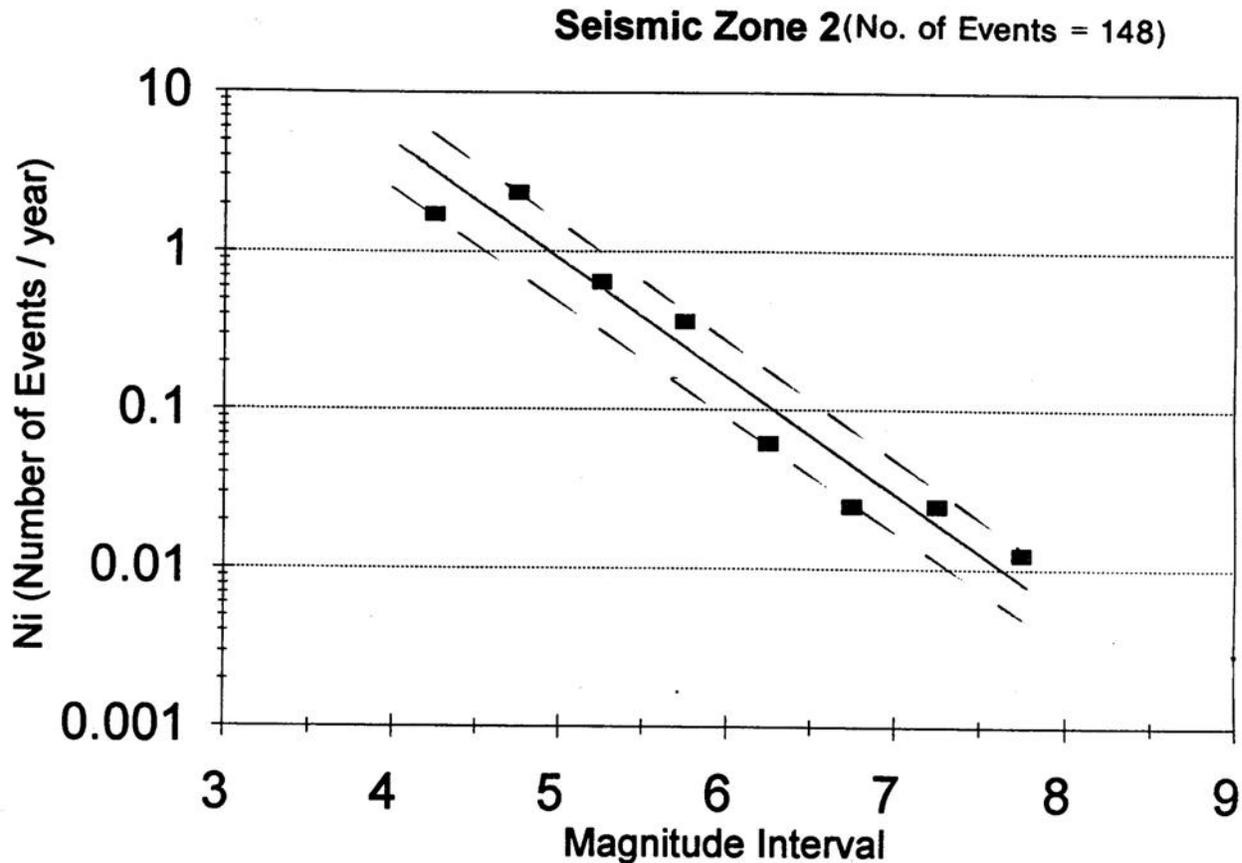


Figure 4. Magnitude Recurrence Data for the Seismic Zone 2.

<u>Source</u>	<u>a</u>	<u>b</u>
Zone 1	3.350	0.738
Zone 2	3.350	0.738
Zone 3	3.876	0.780
Zone 4	3.010	0.860
Zone 5	4.274	0.860
Zone 6 (background)	2.734	0.714

Ground Motion Attenuation

It is a recognized fact that the intensity of shaking decreases as distance to the source increases and the attenuation model selected has a significant effect on the calculated hazard level. Four widely used,

empirically derived attenuation relationships were selected for this study: Idriss (1993), Sadigh, et al. (1993), Campbell (1993) and Campbell and Bozorgnia (1994). All of these relationships are based on worldwide databases and are appropriate for large magnitude events. The Idriss and Sadigh relationships were developed from recordings at rock sites. The Campbell and Campbell and Bozorgnia relationships were developed for deep soil sites. A comparison of these PGA attenuation curves for magnitude $M=7.0$ is presented in Figure 5. Except for near-field events (epicentral distances less than 10 km), all of these relationships show good agreement for the entire range of earthquake magnitudes of interest. Thus all four relationships were retained for the analysis.

Results

Seismic hazard curves, expressed as annual frequency of exceedance versus peak ground acceleration (PGA), were developed for each of the eight sites and but those for only the most critical site (Moro substation) are shown in Figure 6. The highest level of hazard at each site was predicted using Idriss's attenuation relationship (rock sites). The lowest hazard was predicted using Sadigh, et al. (also for rock sites). The two relations for soil were intermediate. All four relationships predicted fairly similar values of acceleration at all hazard levels.

DISCUSSION AND CONCLUSIONS

Ultimately, it is left to the owner and designer to select an appropriate level of risk for design. For high hazard dams, ground motion levels corresponding to return periods on the order of 5,000 to 10,000 years (1 to 2 percent probability of exceedance during a 100 year design life) are typically used (USCOLD, 1985). For transmission lines and substations where the consequence of failure is a service rather than life-hazard issue, the level of acceptable risk would undoubtedly be greater (e.g., a 500 to 1,000 year period of return). It is our understanding that the critical structures along the transmission line route were designed for a PGA equal to 0.2g. To put the results here into perspective applicable to risk assessment, one can use the hazard curves presented herein to calculate the annual probability of ground motions equal to or exceeding 0.2g.

The annual probability that ground motions at a site will equal or exceed 0.2g and the period of return for ground motions equal to or exceeding 0.2g are shown for each location in the following table.

	<u>Location</u>	<u>Annual Probability of Exceedance, PGA= 0.2g</u>	<u>Period of Return PGA= 0.2g (years)</u>
1	Sheikhupura/ Lahore	$< 1 \times 10^{-5}$	$> 100,000$
2	Faisalabad	$< 1 \times 10^{-5}$	$> 100,000$
3	Sahiwal	$< 1 \times 10^{-5}$	$> 100,000$
4	Muzaffargarh/ Multan	$< 1 \times 10^{-5}$	$> 100,000$
5	Bahawalpur	$< 1 \times 10^{-5}$	$> 100,000$
6	Rahim Yar Khan	2×10^{-5} to 8×10^{-5}	12,500 to 50,000
7	Moro	1×10^{-4} to 3×10^{-4}	3,000 to 10,000
8	Jam Shoro/ Hyderabad	1×10^{-5} to 3×10^{-5}	33,000 to 100,000

ATTENUATION EQUATIONS, PGA, M = 7.0

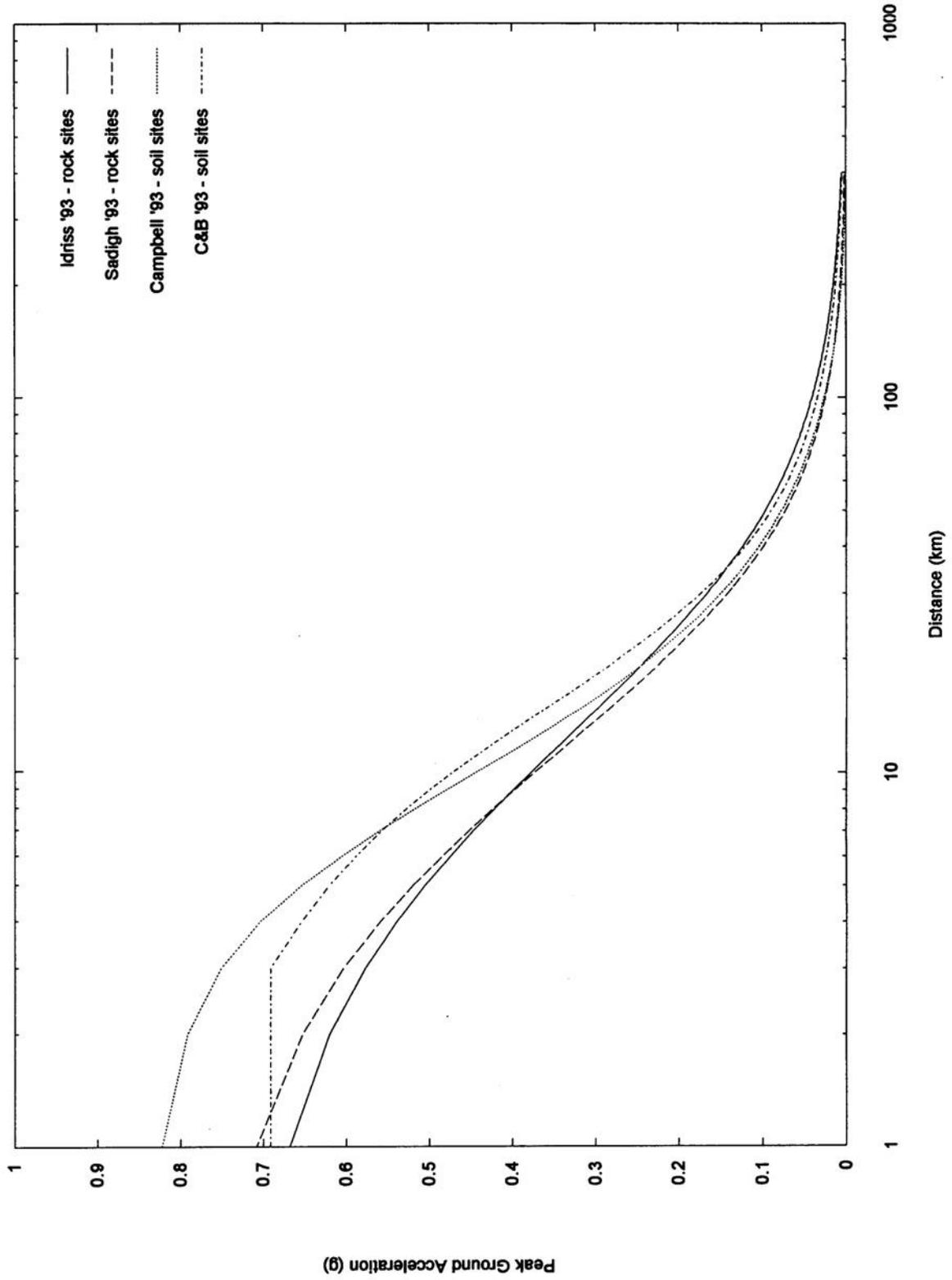


Figure 4. Comparison of PGA Attenuation Curves at M = 7.0.

TOTAL HAZARD, PGA (Site 7 - Moro)

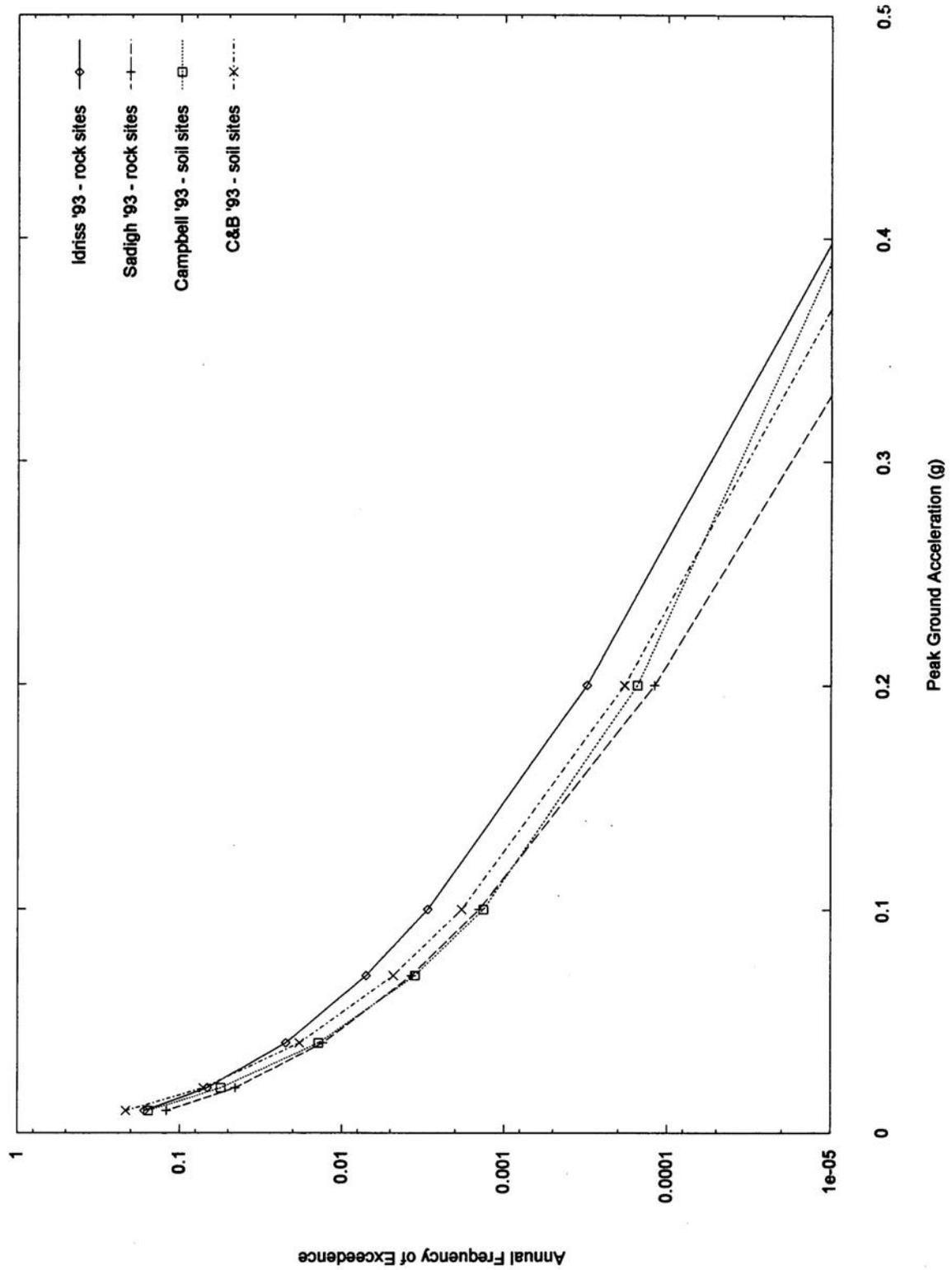


Figure 5. Hazard Curves for Moro Substation.

From the above table, it is evident that at all sites except the Moro substation, the period of return of motions equal to or exceeding 0.2g is well in excess of 10,000 years. At Moro, the return period for $PGA = 0.2g$ is 3,000 to 10,000 years.

In conclusions, the level of risk that an owner would accept would result in lower design PGA 's than 0.2g at all sites along the transmission line corridor.

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