

## SITE-SPECIFIC DETERMINISTIC SEISMIC HAZARD ANALYSIS OF A COMMERCIAL BUILDING IN ATTOCK CITY, PAKISTAN

Sajid Ayaz<sup>\*1</sup>, Bilal Ur Rehman<sup>2</sup>, Mohammad Kamran Nazar<sup>3</sup>,  
M Fiaz Tahir<sup>4</sup><sup>\*1,2,3,4</sup>Department of Civil Engineering, University of Engineering and Technology Taxila Punjab Pakistan<sup>1</sup>sajidayaz37@gmail.com, <sup>4</sup>fiaz.tahir@uettaxila.edu.pkDOI: <https://doi.org/10.5281/zenodo.20711787>**Keywords**

Deterministic Seismic Hazard Analysis (DSHA), Peak Ground Acceleration (PGA), Maximum Credible Earthquake (MCE), Main Boundary Thrust (MBT), Attock, Pakistan, Seismic Hazard.

**Article History**

Received: 16 April 2026

Accepted: 28 May 2026

Published: 16 June 2026

Copyright @Author

Corresponding Author: \*

Sajid Ayaz

**Abstract**

This study presents a Site-Specific Deterministic Seismic Hazard Analysis (DSHA) for a proposed commercial building located in Mehria Town, Attock, Pakistan. The Attock region lies within a tectonically active zone influenced by the ongoing convergence of the Indian and Eurasian plates, making it vulnerable to moderate and strong seismic events. Major active fault systems in the surrounding area were identified and characterized, and shortest source to site distances were calculated using GIS and Google Earth tools. Peak Ground Acceleration (PGA) was estimated using two empirical attenuation relationships, Cornell, Banon et al (1977) [1] and Boore and Atkinson (2008) [2]. It was observed that among all the identified seismic sources, the Main Boundary Thrust (MBT) at epicentral distance 46.82 km with the maximum credible earthquake magnitude of Mw 7.6 was identified as the controlling seismic source. The highest estimated PGA for the site is 0.268g using the Cornell et al. relationship. The study results demonstrate that the study area is in moderate seismic hazard zone, and it is recommended to apply suitable seismic design measures following the Building Code of Pakistan (Seismic Provisions 2007).

**1. INTRODUCTION**

This study presents a Site-Specific Deterministic Seismic Hazard Analysis (DSHA) for a proposed commercial building located in Mehria Town, Attock, Pakistan. The primary objective is to assess the seismic hazard at the site by evaluating the influence of nearby active fault systems and estimating the expected level of ground shaking associated with the controlling earthquake scenario. The results are intended to provide seismic design parameters for the safe and economical design of the proposed structure.

Pakistan is situated in one of the most seismically active regions of the world due to the ongoing collision between the Indian and Eurasian tectonic plates. This tectonic interaction has resulted in the formation of several active tectonic structures, including the Himalayan Frontal Thrust (HFT), Main Boundary Thrust (MBT), Main Mantle Thrust (MMT), and associated regional fault systems. These structures continue to accumulate tectonic stresses that are periodically released in the form of earthquakes. An updated probabilistic seismic hazard assessment Waseem et al. (2023)[3] confirmed that the northern slopes of Pakistan (Potwar Plateau

and the adjoining foothills of the Himalayan mountains) have high seismic hazard. However, most of these studies are conducted for regional hazard assessment and code development rather than for particular project engineering design.

The Attock zone is situated in the tectonically active zone between the Potwar Plateau and the Himalayan fold and thrust belt. The seismogeological conditions of the area are complex, and the region exhibits moderate seismic activity. The Building Code of Pakistan (Seismic Provisions 2007) [4] that Attock is located in Seismic Zone 2B and has been affected by multiple fault systems that can generate moderate to large earthquakes. In a recent study, Qadri & Associate et al (2023) [5] have also employed Probabilistic Seismic Hazard Assessment (PSHA) for Attock city and validated its seismic consideration. That study, however, did not give an individual building specific deterministic ground motion estimate for a site nor did it assess the contribution of the nearby active faults to the seismic hazard for a site specific location.

Therefore, here is a research gap in site-specific deterministic seismic hazard assessment for engineering project in Attock. The present study fills this gap by performing a fault-based DSHA for a proposed commercial building located in Mehria Town, Attock. Unlike probabilistic based approaches, DSHA evaluates the effects of the Maximum Credible Earthquake (MCE) associated with nearby active faults and will result in conservative design level ground motion estimates that are adequate for use in structural engineering practice.

Seismic hazard analysis provides quantitative estimates of expected ground motion parameters such as Peak Ground Acceleration (PGA), spectral acceleration, and seismic response characteristics required for earthquake-resistant design. Among the available approaches, Deterministic Seismic Hazard Analysis (DSHA) is widely used for critical structures and site-specific studies because it considers the maximum potential earthquake associated with known active seismic sources.

In the present study, nearby active faults were identified and characterized based on regional tectonic and geological information. Appropriate attenuation relationships were applied to estimate PGA values at the project site. The results provide important seismic design parameters for the safe and economical design of the proposed commercial building in accordance with the Building Code of Pakistan (Seismic Provisions 2007).

## 2. STUDY AREA AND GEOLOGICAL SETTING

The project site is located in Mehria Town, Attock, Punjab, Pakistan, at approximately 33°48'55.74"N latitude and 72°23'46.17"E longitude. The geographic location of the region is between the Potwar Plateau and vast Himalayan fold and thrust belt which are tectonically active. Geology of the region is primarily sedimentary rocks compressed during the Himalayan orogeny, folded, and faulted. The study area lies within the Attock basin which is bounded by Indus River to the north, Kalachitta Range to the south, Haro River to the east and of course, immediately north of the Main Boundary Thrust (Qadri et al., 2023) [5], and thus is in a structurally chaotic and seismically active environment.

The study area is bounded by various regional tectonic features such as Main Boundary Thrust (MBT), Salt Range Thrust (SRT), Jhelum Fault (JF) and Kalabagh Fault (KBF). These faults have the potential to produce moderate to large magnitude earthquakes and play an important role in the local seismic hazard. The Building Code of Pakistan (Seismic Provisions 2007) classifies Attock as Seismic Zone 2B which needs structural design to be earthquake resistant.

Figures 1, and 2 present the aerial location, architectural elevation, and current construction status of the proposed commercial building at Mehria Town, Attock, establishing the physical context and practical necessity of this seismic hazard evaluation.

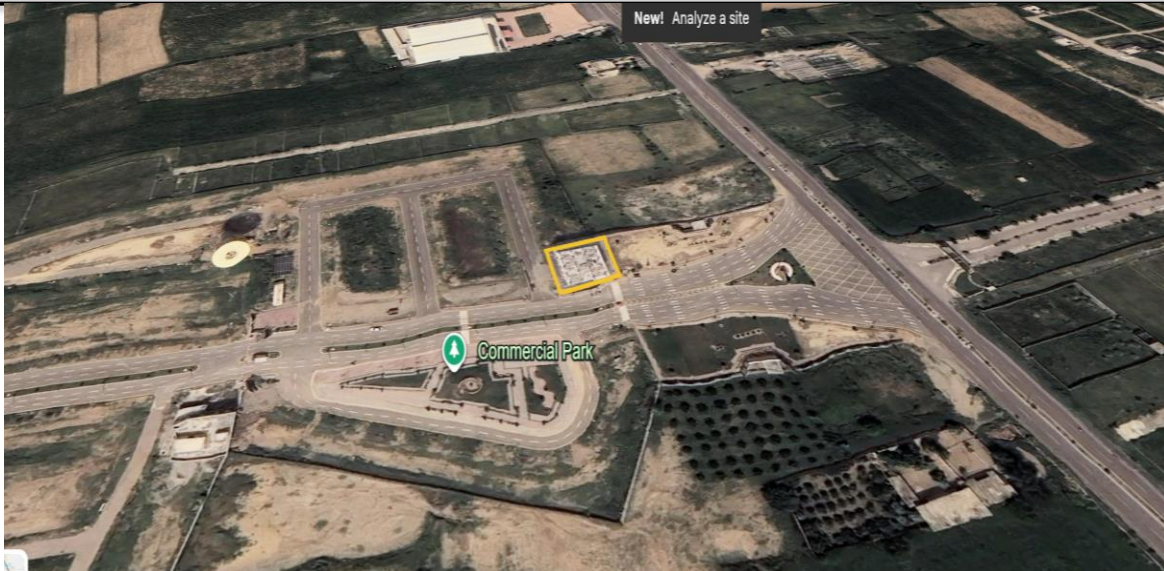


Figure 1: Aerial view of the proposed commercial building site in Mehria Town, Attock, Punjab, Pakistan ( $33^{\circ}48'55.74''N$ ,  $72^{\circ}23'46.17''E$ ), obtained from Google Earth imagery.



Figure 2 Existing physical condition of the proposed commercial building site in Mehria Town, Attock.

### 3. OBJECTIVE

The main objectives of this study are as follows:

1) To identify and characterize the active seismic sources in the surrounding region at Attock including major regional and local fault systems that may influence the site.

2) To evaluate the seismic hazard at the site using Deterministic Seismic Hazard Analysis (DSHA) by considering the Maximum Credible Earthquake (MCE) associated with the controlling fault(s).

- 3) To estimate the expected ground motion parameters, including Peak Ground Acceleration (PGA) and other relevant seismic intensity measures at the proposed site.
- 4) To determine the controlling earthquake scenario by analyzing the shortest distance and most critical fault source contributing to seismic risk at the site.
- 5) To provide seismic input parameters for structural design, ensuring safe, economical, and code-compliant design of the proposed commercial building in accordance with the Building Code of Pakistan (Seismic Provisions).
- 6) To support risk-informed engineering decisions by integrating regional seismotectonic conditions into the design process for improved structural safety and resilience.

#### 4. METHODOLOGY

The DSHA framework used in this study is based on Reiter (1990) which outlines four steps. The first step is the identification and characterization of all active seismic sources in the region that could affect the project site, in terms of fault geometry, type, activity, and maximum earthquake potential. The next step is to pick the maximum credible earthquake magnitude and shortest source to site distance for each source to define a controlling earthquake in the second step. In the third step, parameters of the ground motion are estimated at the site using suitable empirical attenuation relationships, in particular the Peak Ground Acceleration (PGA). The fourth step involves defining the seismic hazard at the site as the worst case ground motion generated by all sources and all attenuation models, and using that

as the design-level ground motion parameter. The following steps were followed:

1. Identification of active fault sources.
2. Determination of shortest source-to-site distance.
3. Selection of Maximum Credible Earthquake (MCE).
4. Application of attenuation relationships & Estimation of Peak Ground Acceleration (PGA).

#### 4.1 Identification of Seismic Sources

The regional tectonic setting was reviewed using available geological maps, published research papers, and seismic hazard studies. Any active fault systems within 200 km of project site were identified and assessed with regard to their potential effects on the ground motion at the project site. Fault traces and distances have been mapped and measured in ArcGIS Pro, using data from ESRI, USGS and NOAA databases. From all the identified faults a geospatial distribution was made with green dot indicating "Attock" project location and red circle indicating 200 km search boundary as shown in figure 4.

As shown in Figure 3, many active faults are visible around the project site which range in distance from as near as 40 km between Tarbela Fault to as far as 134.7 km between Salt Range Thrust and the Project site. Eight major active faults were chosen for detailed study based on the spatial review and the seismotectonic significance of each fault. These faults vary in type, distance, and magnitude potential, and together define the seismotectonic environment of the study area.

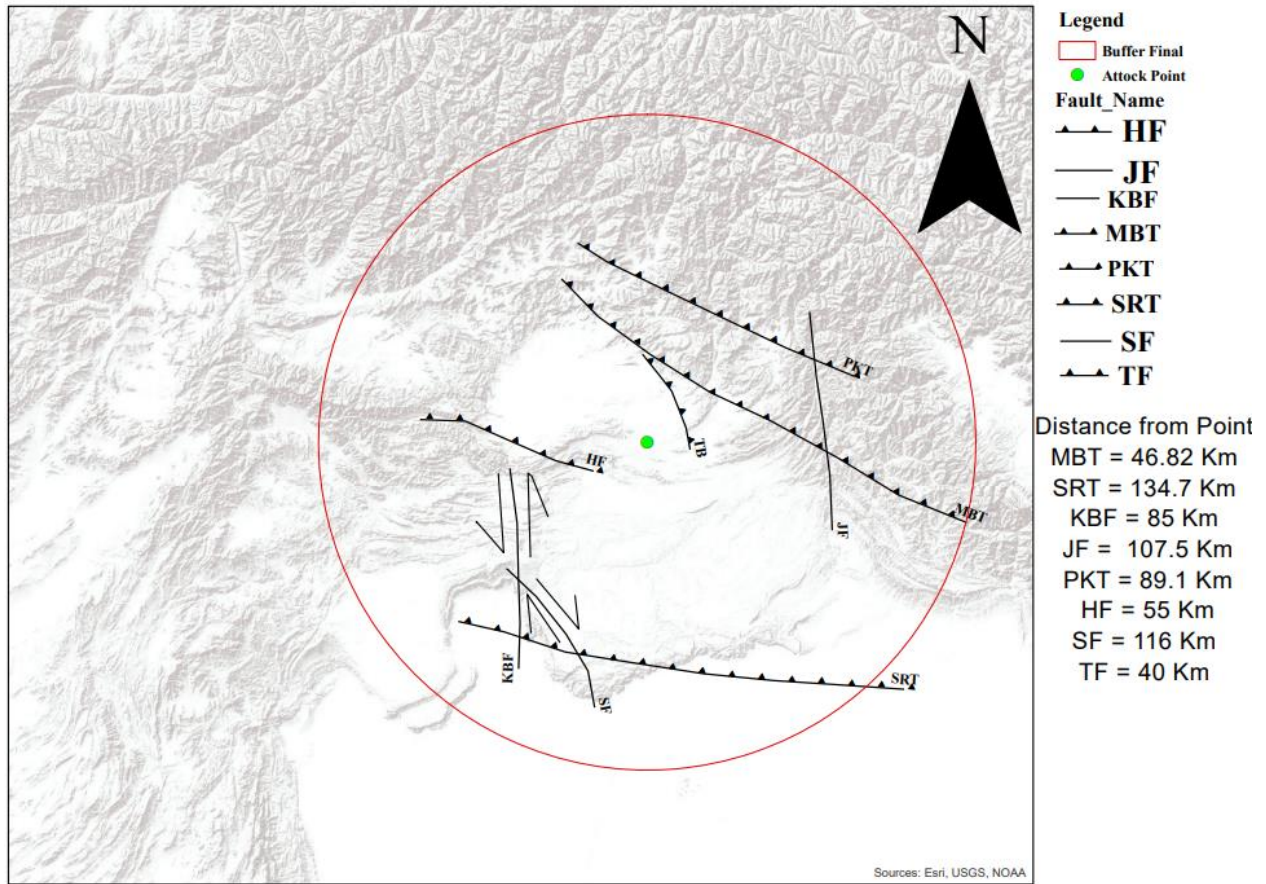


Figure 3 Regional fault map showing active fault systems within a 200 km radius of the project site at Mehria Town, Attock (indicated by the green dot) and measured shortest distances from each fault trace to the project site. Fault data compiled from ESRI, USGS, and NOAA databases.

The following seismic sources were considered in **Table 1:**

Sr. No	Fault Name
1	MBT – Main Boundary Thrust
2	JF – Jhelum Fault
3	KBF – Kalabagh Fault
4	PKT – Panjal Khairabad Thrust
5	SF – Surghar Fault
6	SRT – Salt Range Thrust
7	HF -Hissartang Fault
8	TF – Tarbela Fault

Each fault was characterized based on:

- Fault type
- Geological activity
- Historical seismicity
- Rupture potential
- Maximum expected magnitude

Based on the above criteria, the major active faults identified within the study region are described below.

#### **Main Boundary Thrust (MBT)**

The Main Boundary Thrust (MBT) is the principal frontal thrust of the Himalayan range, extending nearly 1500 km from Assam in the east to Kashmir in the west. First identified by Wadia (1957) [6], the most external fault was later renamed the Murree Thrust by Seeber and Armbruster (1979) [7], though it remains commonly referred to as the MBT in Pakistan. In the northwestern Himalaya, the MBT served as a floor thrust along which Precambrian and Phanerozoic rocks of the Kala Chitta and Attock-Cherat Ranges were emplaced over Cenozoic strata of the northern Kohat and Potwar Plateaus (McDougall et al., 1993) [8]. Within the Hazara-Kashmir Syntaxis, the MBT is offset by the left-lateral Jhelum Fault, with fault dips ranging between 50° and near-vertical (MonaLisa and Khwaja, 2005)[9]. Focal mechanism solutions further confirm left-lateral strike-slip motion along the MBT splays in the western syntaxis region (MonaLisa and Khwaja, 2005) [9].

#### **Kalabagh Fault (KBF)**

The Kalabagh Fault is an active dextral strike-slip fault forming the tectonic boundary between the Potwar Plateau to the east and the Kohat Plateau to the west (Abbas et al., 2022) [10]. Paleoseismic investigations reveal evidence of late Quaternary surface ruptures and alluvial offsets, indicating events of  $M_w \geq 6$  during the late Pleistocene. A maximum credible earthquake of  $M_w 7.5$  is assigned to this fault in the regional probabilistic seismic hazard assessment of Zaman et al. (2012) [11]. Although seismicity along the KBF remains relatively low, suggesting possible aseismic creep between events, the fault is still considered active and capable of producing damaging earthquakes.

The Kalabagh Fault is located approximately 85 km from the project site at Mehria Town, Attock.

#### **Salt Range Thrust (SRT)**

The Salt Range Thrust (SRT) is an active frontal thrust of the Himalayan fold and thrust belt in Pakistan, that overthrusts Precambrian to Pliocene rocks and overlies Quaternary rocks of the Punjab Plain. Low-temperature Thermochronology suggests the SRT commenced activity, at least since  $\sim 4$  Ma, with a long-term average shortening rate of  $\sim 5-6$  mm/Year, and high exhumation above the thrust ramp (Ghani et al., 2021) [12]. The Salt Range Thrust (Zaman et al., 2012) [11] is the maximum credible earthquake for the region ( $M_w 7.4$ ).

#### **Jhelum Fault (JF)**

The Jhelum Fault is an active sinistral (left-lateral) strike-slip fault that forms the eastern boundary of the Potwar Plateau and marks the abrupt structural curvature of the Hazara-Kashmir Syntaxis in the NW Himalaya (Shah et al., 2022). [13] Widespread evidence for active deformation is evident on the JF from tectonic geomorphological mapping using satellite imagery, such as deflected streams, offset ridge crests, displaced Quaternary deposits and faulted alluvial fans. The fault has a length of more than 120 km and relates both with reverse and thrust faults, which are required to take up the oblique convergence between the Indian and Eurasian plates. According to Zaman et al. (2012)[11] regional probabilistic seismic hazard assessment, Jhelum Fault (JF) has the maximum credible earthquake value of  $M_w 7.5$ . Southern trace is in part (sub)buried by the river sediments, however, the JF is still a potential major seismic generator.

#### **Panjaj khairabad Thrust fault**

The Panjal Thrust is a regional, tectonically important feature which trends northward parallel to the Main Boundary Thrust on western side of the Hazara-Kashmir Syntaxis. Both the Panjal Thrust and the MBT gradually converge and join approximately 5 km north of Balakot.. The fault extends south and can be traced up to Garhi Habibullah and then is buried by the Quaternary

deposits. Further westward it continues along the northern edge of the Attock/Cherat Range, and is known as the Panjal-Khairabad Fault. It lies in a geologic location that places it at an active regional tectonic location with the potential for large earthquakes. [14]

#### Surghar Fault (SF)

The Surghar Fault (SF) is a south-verging frontal thrust fault that marks the active deformational front of the Kohat fold and thrust belt in the outer Himalayas of Pakistan. The fault thrusts Mesozoic-Cenozoic rocks of the Surghar Range southwards over the Punjab foreland. It is interpreted as a fault-bend fold system detached within or at the base of Triassic rocks, with approximately 5.6 km of shortening recorded along the Kutki section. Tectonic uplift along the range front commenced

around 2.3 Ma ago. The fault is located approximately 116 km from the project site at Attock.[15]

#### Tarbela Fault (TF)

The Tarbela Fault (TF) is an active ~N-S trending left-lateral strike-slip fault identified through tectonic geomorphological mapping using satellite imagery in the NW Himalaya of Pakistan. The Indus River flows along its trace for more than 60 km before turning southwest. The fault extends over 100 km in total strike length before transitioning westward into a reverse fault with a minor left-lateral component. It is situated approximately 40 km from the project site, which poses a potential seismic hazard. The maximum credible earthquake magnitude of Mw 7.2 is adopted from (Ansari et al., 2022) (16).

#### 4.2 Source-to-Site Distance Measurement

The shortest horizontal distance from each fault trace to the project site was measured using GIS and Google Earth tools. **Table 2:**

Sr. No	Fault Name	Epicentral Distance to Site (KM)	Maximum magnitude (Mw)
1	Main Boundary Thrust (MBT) fault	46.82	7.6
2	Jhelum fault	107.5	7.5
3	Salt range thrust Fault	134.7	7.6
4	KalaBagh Fault	85	7.5
5	Panjal Khairabad Thrust	89.10	7.5
6	HF -Hissartang Fault	55	7.6
7	Tarbela Fault	40	7.2
8	SF – Surghar Fault	116	7.4

Figure 4 Tahir et al. (2025) [17] presents the regional tectonic map of northern Pakistan, illustrating the major structural boundaries including the Main Mantle Thrust (MMT), Main Central Thrust (MCT), Main Boundary Thrust

(MBT), and Salt Range Thrust (SRT). The project site at Attock, marked by a red box on the map, lies within the External Zone immediately north of the MBT, placing it within a compressional and seismically active tectonic setting.

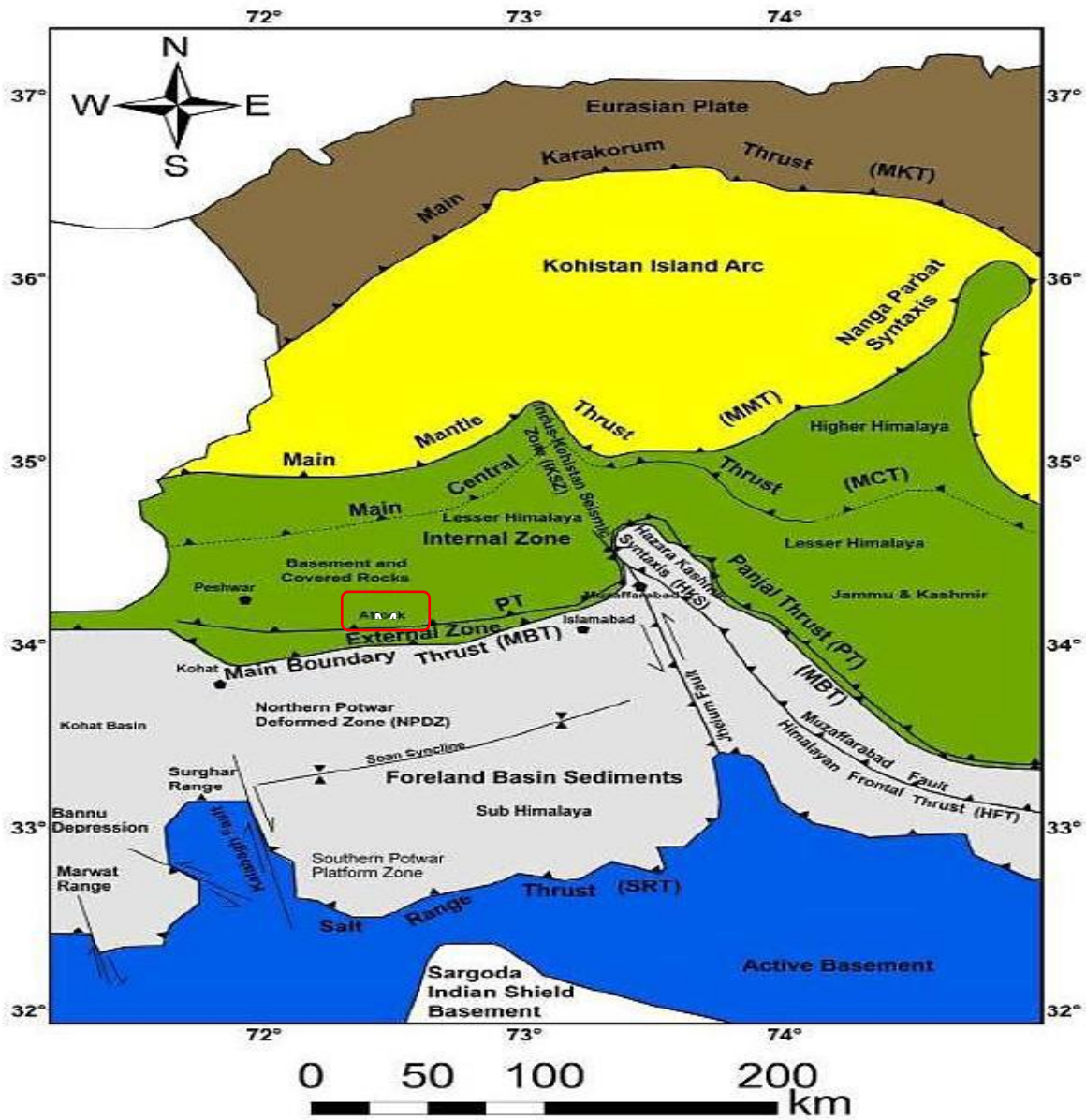


Figure 4 Regional tectonic map of northern Pakistan illustrating the prominent structural features of the Himalayan fold-and-thrust belt and associated plate boundary zones.

Figure 5 illustrates the spatial distribution of earthquakes recorded within and around the Attock region over the past 100 years, color-coded by magnitude ranging from Mw 3.0 to 7.9. The concentration of moderate to large magnitude

events in the northeastern portion of the map corresponds to the activity zones of the MBT and associated Himalayan fault systems, consistent with the seismic sources identified in this study.

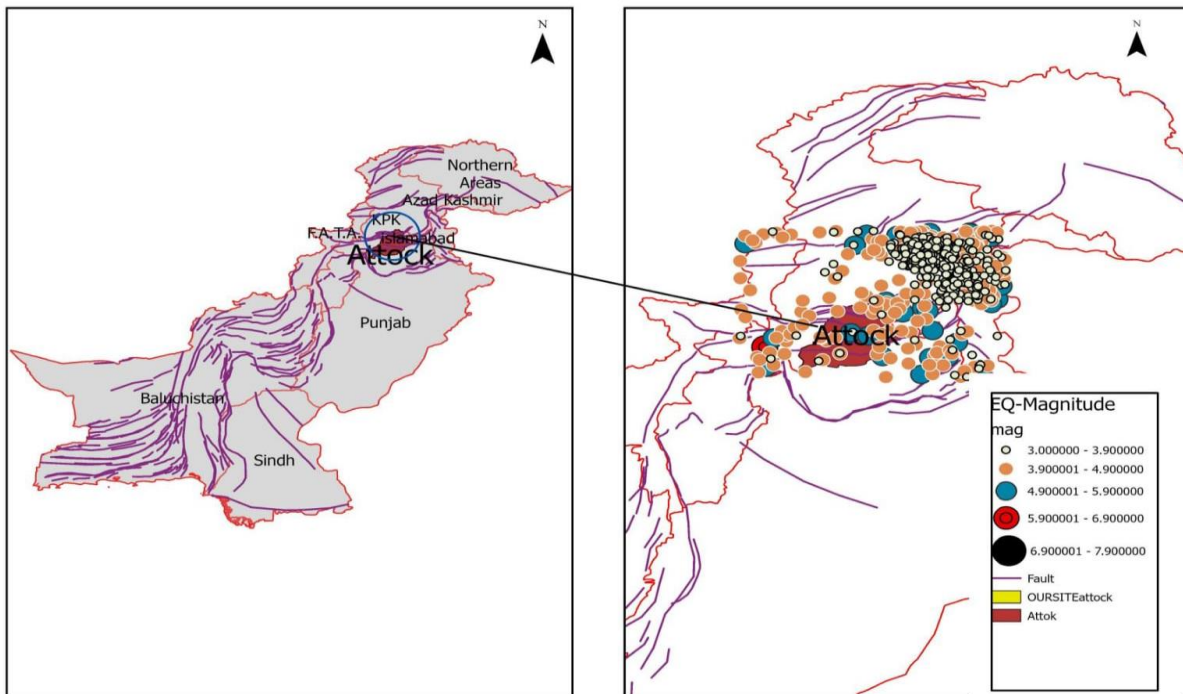


Figure 5 graphical representation of location and size of earthquakes during last 100 years

#### 4.3 Ground Motion Prediction Equations (GMPEs)

To estimate the Peak Ground Acceleration (PGA), two attenuation relationships employed to improve reliability.

(Cornell, Banon et al. 1977) has given the relationship for the PGA values as:

$$\ln PGA (\text{gal}) = 6.74 + 0.859M - 1.80 \ln(R + 25)$$

$PGA$  = Peak Ground Acceleration (gal)

$M$  = Earthquake magnitude

$R$  = Source-to-site distance (km)

(Boore and Atkinson 2008) developed the attenuation relationship for the prediction of the PGA values as:

$$\ln (PGA) = -1.715 + 0.5M - \ln (R + 0.0055e^{0.4M}) + 0.3 \ln \left( \frac{V_{S30}}{760} \right)$$

Where:

$PGA$  = Peak Ground Acceleration

$M$  = Earthquake magnitude

$R$  = Epicentral distance (km)

$V_{S30}$  = Average shear wave velocity in the upper 30 m of soil profile

For this study, a representative value of  $V_{S30} = 760 \text{ m/s}$  was assumed due to the absence of detailed geotechnical investigation data. This value corresponds to Site Class B very dense & rock conditions as defined in the NEHRP site classification scheme and is consistent with the reference rock condition adopted in the Boore

and Atkinson (2008) GMPE formulation. The same reference rock condition has been widely adopted in regional seismic hazard studies for Pakistan in the absence of site-specific shear wave velocity measurements, including the updated probabilistic seismic hazard assessment of Waseem et al. (2023) [3].

The Cornell, Banon et al. (1977) relationship is a widely referenced early attenuation model that provides a conservative upper-bound estimate of PGA for shallow crustal earthquakes. Despite its age, it remains applicable in engineering practice for preliminary hazard assessment and for

comparison purposes. The Boore and Atkinson (2008) model is a modern and well-validated Ground Motion Prediction Equation developed from a global database of shallow crustal earthquake records and is among the recommended models for active tectonic regions.

Both models are applied together in this study to assess the range of expected PGA values and to provide a conservative basis for structural design. PGA values were estimated for each fault source using both attenuation relationships, and the results are presented in Table 3.

**Table 3:** Estimated Peak ground acceleration (PGA).

Fault	PGA (g)	
	Cornell, Banon et al.	Boore and Atkinson
MBT	0.268	0.171
JF	0.081	0.071
SRT	0.063	0.059
KBF	0.1145	0.089
HF	0.221	0.146
TF	0.228	0.164
SF	0.067	0.062
PKT	0.1072	0.085

PGA values were computed for all eight fault sources under both attenuation models. The MBT, at an epicentral distance of 46.82 km with Mw 7.6, produced the highest PGA of 0.268g under the Cornell, Banon et al. (1977) model and 0.171g under the Boore and Atkinson (2008) model, identifying it as the controlling seismic source for the project site.

## 5. RESULTS AND DISCUSSION

The DSHA results indicate that the project site is influenced by nearby active tectonic structures. Among the identified seismic sources, the Main Boundary Thrust (MBT) was found to be the controlling fault source due to its relatively shorter epicentral distance (46.82 km) and larger earthquake magnitude potential (Mw 7.6).

Using the Cornell, Banon et al. (1977) attenuation relationship, the estimated PGA at the site is 0.268g, while the Boore and Atkinson (2008) model yields a lower value of 0.171g for the same fault. The higher, more conservative value of 0.268g is adopted as the design PGA following deterministic worst-case selection principles. The Tarbela Fault (TF), at 40 km with Mw 7.2, produced the second-highest PGA of 0.228g (Cornell) and 0.164g (Boore), highlighting it as a secondary hazard contributor. Its lower magnitude assignment relative to the MBT accounts for its strike-slip mechanism and historical rupture record, and confirms that the MBT governs the design ground motion.

This adopted PGA value exceeds the Building Code of Pakistan (Seismic Provisions 2007) Zone

2B coefficient of 0.20g, confirming that the study area falls within a moderate seismic hazard zone and that site-specific analysis is necessary. Although the estimated ground shaking is not in the high hazard category, appropriate earthquake-resistant design measures – including proper detailing, ductility, and lateral force-resisting systems – are essential to minimize structural damage and ensure safety and serviceability of the proposed commercial building.

The findings of this study emphasize the importance of conducting site-specific seismic hazard analyses for structure projects located in tectonically active regions of Pakistan.

## 6. CONCLUSIONS

From this study the following conclusions can be drawn:

1. The Attock region lies within moderately active seismic zone and is affected by active regional tectonic structures.
2. The Main Boundary Thrust (MBT) is the controlling seismic source for the project site.
3. The Maximum Estimated Peak Ground Acceleration (PGA) at the site is 0.268g from the attenuation relationship given by Cornell, Banon et al. (1977) and 0.171g from the attenuation relationship provided by Boore and Atkinson (2008) with the same controlling source. This value of 0.268g will be used as the governing design PGA according to the deterministic worst-case selection principle and this compares to the BCP 2007 Seismic Zone 2B value of 0.20g, confirming the necessity of site-specific analysis.
4. The study demonstrates the importance of site-specific deterministic seismic hazard analysis for improving structural safety and resilience.

## 7. LIMITATIONS OF STUDY

In the present study, regional tectonic and geological information, and the empirical attenuation relationships are used. The detailed geotechnical investigations, local soil amplification studies and probabilistic seismic hazard analysis (PSHA) were not conducted as part of this study. Therefore, the results should be

considered preliminary estimates for engineering design purposes.

## 8. RECOMMENDATIONS

1. Detailed geotechnical investigation should be carried out to determine accurate site soil properties and VS30 values.
2. Local soil amplification effects should be investigated using site response analysis.
3. Probabilistic Seismic Hazard Analysis (PSHA) may also be conducted for comparison and comprehensive seismic risk assessment.
4. Structural design shall be based on Building Code of Pakistan (Seismic Provisions 2007) with due consideration.

## REFERENCES

- Cornell, C. A., Banon, H., & Shakal, A. (1977). Seismic motion and response prediction alternatives. *Earthquake Engineering & Structural Dynamics*, 5(4), 295–315.
- Boore, D. M., & Atkinson, G. M. (2008). Ground-motion prediction equations for the average horizontal component of PGA, PGV, and 5%-damped PSA. *Earthquake Spectra*, 24(1), 99–138.
- Waseem, M., Farooq, M., Ali, Q., et al. (2023). Updated probabilistic seismic hazard assessment of Pakistan. *Natural Hazards*, 117, 2187–2218. <https://doi.org/10.1007/s11069-023-05920-3>
- Building Code of Pakistan – Seismic Provisions (2007). Ministry of Housing and Works, Government of Pakistan, Islamabad.
- Qadri, S. M. T., Mirza, M. Q., Raja, A., Yaghmaei-Sabegh, S., Hakimi, M. H., Ali, S. H., & Khan, M. Y. (2023). Application of probabilistic seismic hazard assessment to understand the earthquake hazard in Attock city, Pakistan. *Sustainability*, 15(2), 1023. <https://doi.org/10.3390/su15021023>
- Wadia, D. N. (1957). *Geology of India* (3rd ed.). Macmillan and Company, London.

- Seeber, L., & Armbruster, J. G. (1979). Seismicity of the Hazara Arc in northern Pakistan: Decollement versus basement faulting. In A. Farah & K. A. DeJong (Eds.), *Geodynamics of Pakistan* (pp. 131-142). Geological Survey of Pakistan, Quetta.
- McDougall, J. W., Hussain, A., & Yeats, R. S. (1993). The Main Boundary Thrust and propagation of deformation into the foreland fold-and-thrust belt in northern Pakistan. In P. J. Treloar & M. P. Searle (Eds.), *Himalayan Tectonics*, Geological Society Special Publication No. 74 (pp. 191-208). London.
- MonaLisa, & Khwaja, A. A. (2005). Seismic activity along the Main Boundary Thrust (MBT), Pakistan. *Geological Bulletin, University of Peshawar*, 38, 23-30.
- Abbas, W., Ali, S., & Reicherter, K. (2022). Seismicity and landform development of the dextral Kalabagh Fault Zone, Pakistan: Implications from morphotectonics and paleoseismology. *Tectonophysics*, 822, 229182.
- Zaman, S., Ornthammarath, T., & Warnitchai, P. (2012). Probabilistic seismic hazard maps for Pakistan. *Proceedings of the 15th World Conference on Earthquake Engineering*, Lisbon, Portugal.
- Ghani, H., Sobel, E. R., Zeilinger, G., Glodny, J., Zapata, S., & Irum, I. (2021). Palaeozoic and Pliocene tectonic evolution of the Salt Range constrained by low-temperature thermochronology. *Terra Nova*, 33(3), 293-305.
- Shah, A. A., Sahari, S., Navakanesh, B., Nurhafizah, A. M., Ashwini, F. F., & Talha, Q. (2022). Tectonic geomorphology of the Jhelum Fault Zone and its contiguous regions in the western Himalaya. *Bulletin of the Geological Society of Malaysia*, 73.
- Asian Development Bank (ADB). (2019). *Khyber Pakhtunkhwa Water Resources Development Project – Tectonic and Seismic Hazard Assessment Report* (Project No. 51249-003). Asian Development Bank.
- Ahmad, S., Ali, F., Sayab, M., Ahmad, I., & Hamidullah, S. (1999). Structural geometry of the Himalayan Frontal Thrust Zone: Surghar Range, Pakistan. *Geological Bulletin, University of Peshawar*, 32, 13-23.
- Ansari, A., Rao, K. S., & Jain, A. K. (2022). *Site characterisation based seismic microzonation of the Himalayan region: Implication towards seismic risk assessment for sustainable tunnelling projects* [Preprint]. Research Square. <https://doi.org/10.21203/rs.3.rs-2397403/v1>
- Tahir, H., Tahir, M. F., Muhammad, S., Numan, M., & Zulqarnain, M. (2025). Site-Specific Deterministic Seismic Hazard Evaluation of a Critical Bridge in Rawalpindi City. Research preprint.