6. SEISMICITY

6.1 GENERAL

Basic concepts about the approach followed to assess the seismic risk in a region of interest are presented. Some case studies are presented to illustrate how such works are normally carried out in practice.

The current status of seismic risk assessment is that no generally accepted method exists. However, some techniques have become part of standard practice. Therefore, emphasis has been given in this work to apply standard techniques aiming at a better understanding and acceptability of results.

6.1.1 SEISMIC EVALUATION - CONCEPTUAL FRAMEWORK AND METHODOLOGY

6.1.1.1 SEISMIC HAZARD, SEISMIC VULNERABILITY AND SEISMIC RISK

There seems to be some confusion in defining hazard and risk. Many people even consider the word *hazard* as a synonymous of *risk*, and both are found in the literature with subtle variations which results in confusion.

The Earthquake Engineering Research Institute's Committee on Seismic Risk defines:

- *Seismic risk* as the probability that social or economic consequences of earthquakes will equal or exceed specified values at site, at several sites, or in an area, during a specified exposure time.

- *Seismic hazard* as any physical phenomenon (e.g. ground shaking, ground failure) associated with an earthquake that may produce adverse effects on human activities.

Man-made facilities constructed in seismic regions are subjected to earthquake hazards that are not under human control. If the facilities are seismically vulnerable due to their construction technique, then they are very likely at a risk.

On the other hand, if the facilities are intentionally made less vulnerable or if they are inherently not vulnerable, then they are little affected by earthquakes and the seismic risk is low, even if the earthquake hazard is high. This means that while seismic hazard must be accepted as given by nature, seismic risk can be controlled and reduced by means of a correct application of earthquake engineering technique.

The seismic hazard analysis of a site is intended to identify the existing natural level of exposure in order that correct earthquake engineering measures can be implemented to keep the seismic risk at a reasonably low level in spite of the seismic hazard being moderate or high. The degree of protection of a facility can be relaxed or increased as a function of the actual seismic hazard level. This fact emphasizes the importance of a correct identification.

Seismic hazard assessments yield two types of results: general qualitative statements about the seismic exposure and specific quantitative parameters called seismic design parameters.

6.1.1.2 SEISMIC DESIGN PARAMETERS

The following paragraphs contain description of some of the most relevant seismic design parameters. These parameters have been derived in this study for the sites under consideration.

6.1.1.2.1 PEAK GROUND ACCELERATION (PGA)

This parameter represents the highest pulse of ground acceleration during an earthquake. Although it has some theoretical shortcomings as a statistically representative measurement of the intensity of an earthquake, it has been, and still is, the most widely used numerical assessment of the "punch" of an earthquake. Dozens of statistical relationships describing specific characteristics of an earthquake have been derived on the basis of PGA. These range from structural design parameters to damage statistics.

6.1.1.2.2 PEAK GROUND VELOCITY (PGV)

This parameter is less widely used than PGA; however, it has been gaining importance as a supposedly more stable statistical descriptor of the damaging capabilities or "punch" of an earthquake. Lately it has been used to scale empirical seismic velocity spectra which are then converted to acceleration spectra which, in turn, are used to evaluate seismic stresses in structural analysis.

6.1.1.2.3 DESIGN SPECTRA

These are used to calculate the seismic loading on structures. They can be used for the final structural design of all facilities in hydropower projects. Only very critical facilities (such as large dams) require more comprehensive ground motion descriptors. The response spectra would be sufficient information at the feasibility stage for virtually all aboveground facilities expected to be built on the analyzed sites. Once appropriately reviewed, response spectra would be one of the main tools for a final structural design.

6.1.1.3 DEGREE OF EARTHQUAKE PROTECTION

Due to the nature of the seismic loading, no facility can be made absolutely earthquake-proof. Modern technology offers "earthquake resistance", meaning that the facility is intended to survive a strong earthquake while undergoing a certain degree of damage. In fact, the very process of undergoing controlled damage and post-elastic deformations is one of the main sources of seismic energy dissipation, preventing the need of having to provide oversized members capable of handling the seismic energy in the elastic range of the structural materials.

This means that there is a range of possible solutions to earthquake resistance. There is a trade-off between having to build a larger structure, able to delay the onset of damage and accepting a lower threshold of damage (provided the structure is ductile enough as to dissipate the excess of seismic energy). In the latter case, although a well designed facility does not collapse, the damage incurred may put it out of commission temporarily - or even permanently in case of extreme ground shakings.

Hence, how low to accept the onset of damage is an economic and functional decision. It depends on the importance of the hydroelectric project and also on the importance of individual facilities within the project. This also means that not all facilities need to be designed for the same level of earthquake resistance.

To provide the adequate amount of earthquake protection two levels of seismic loading are often defined for important projects: Operating Basis Earthquake, and Maximum Credible Earthquake. Seismic designs are carried out using this limiting conditions and values in between. For the foregoing reasons, the seismic evaluations described in Section 6 assess a range of seismic loadings rather than specific values.

6.1.1.3.1 OPERATING BASIS EARTHQUAKE (OBE)

This is a seismic loading that a facility must withstand without loss of operating capabilities. It is associated with the onset of damage. The more important a facility is within a functional system, the higher the OBE should be. To decide how high the loading must be, an acceptable risk level must be decided upon. For example, an acceptable risk level associated with the onset of structural damage due to earthquake in an ordinary building is about 15 per cent probability of the load being exceeded in a 30-year period. This implies about 0.005 events per year or equivalently, close to a 200-year return period. A tolerable risk level associated with the suspension of operations of a large and important dam should be much lower, say 5 percent in 100 years i.e. a 2000-year return period.

Of course tolerable risks of incurring significant damage must be even lower, say 1 percent probability in 100 years in the case of a very important facility; this is about 0.0001 events per year or equivalently, a 10000 year return period. But these low levels of probability are better handled with the concept of a maximum credible earthquake discussed in another section of this report.

6.1.1.3.2 RISK LEVELS

As discussed above, earthquakes are an uncertain loading. A significant earthquake may not hit a facility during its lifespan; if it does hit, its "punch" is not readily predictable. One can only attempt to correlate seismic load levels to probabilities of occurrence.

In the present seismic analysis, the earthquake loadings corresponding to a number of hazard levels were evaluated for each site. Earthquakes were assessed for hazard levels of 0.005, 0.002, 0.001, 0.0005, 0.0002, and 0.0001 events per year (which is the same as return periods of 200, 500, 1000, 2000, 5000 and 10000 years. This approximately corresponds to the following probabilities of occurrence: 15% in 30 yrs, 10% in 50 yrs, 10% in 100 yrs, and 5%, 2%, 1% in 100 yrs.

To correlate the above mentioned probabilities of occurrence with a time period and a rate of occurrence, a Poisson random process is usually assumed. In accordance to the exponential distribution, the relationships are of the form:

$$P_{exc} = 1 - e^{\frac{T_e}{RP}} \qquad \textbf{(6.1)}$$

or conversely

$$RP = -\frac{T_e}{\ln(1 - P_{exc})} \qquad \textbf{(6.2)}$$

with:

RP = return period in years or average time between events
T_e =time interval during which facility will be exposed to seismic activity, i.e. lifespan
P_{exc} =probability of the seismic activity being exceeded during the time span Te

As well known in other disciplines of engineering, the return period is the expected period between events and thus is the inverse of the annual probability of occurrence, also known as the rate of occurrence (events/year).

In this regard, following criteria may be considered for the selection of design parameters:

- *Ordinary facilities* can be designed for seismic loading that has the probability of 20% of being exceeded in 50 years. This corresponds to a return period of approximately 225 years or a recurrence of 0.00446 events per year. (Hazard level A)
- *Special facilities* can be designed for seismic loading that has the probability of 10% of being exceeded in 50 years. This corresponds to a return period of approximately 475 years or a recurrence of 0.0021 events per year. (Hazard level B)

- *Essential facilities* such as hospitals, bridges, etc. can be designed for seismic loading that has the probability of 5% of being exceeded in 50 years. This corresponds to a return period of 975 years or a recurrence of 0.001026 events per year. (Hazard level C)

- *Critical facilities* may be designed for seismic events with even lower probability (i.e. 0.0001 or 10000 years return period). (Hazard level D)

6.1.1.3.3 MAXIMUM CREDIBLE EARTHQUAKE (MCE)

Rather than attempting to assess very low probabilities of occurrence, it is more pragmatic to evaluate an upper bound earthquake. This earthquake loading is thus assumed to be the worst possible earthquake intensity that can occur at the site. MCE's are normally evaluated for each site of interest.

6.1.2 GEOTECTONICAL CONSIDERATIONS

In the area of interest, major tectonic features should be identified. This information normally provides the basic framework to understand how the surface of the earth, as seen today, evolved to the present conditions. This assessment gives also important hints about expected future activity.

6.1.2.1 GLOBAL SEISMOTECTONICS

The present knowledge about seismic activity on global basis is summarized in Figure 6.1. Evidently, most of the events follow the borders of the earth crust's segments known as "tectonic plates". Figure 6.2 depicts the main plates and their direction of movement.

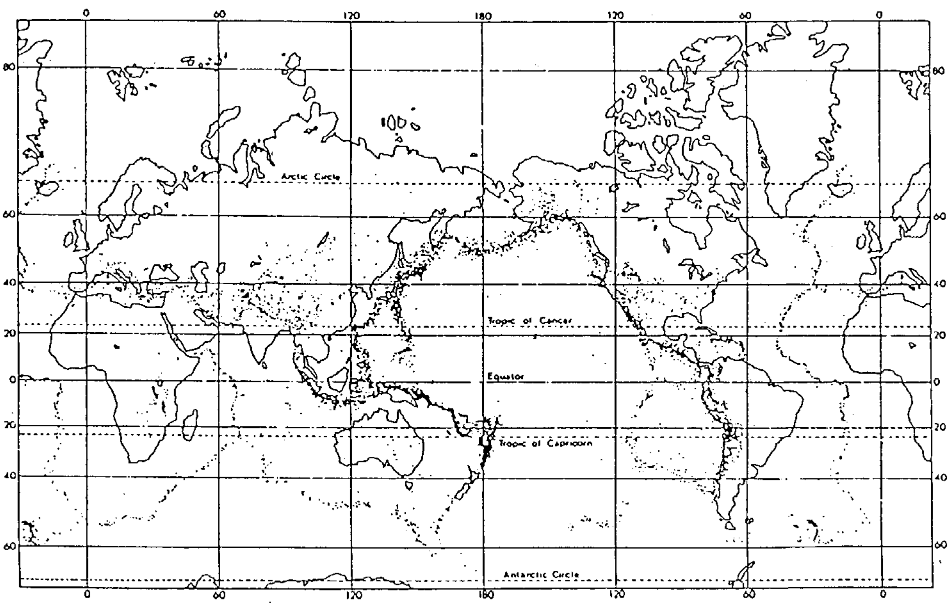


Fig. 6.1: Seismicity map of the world

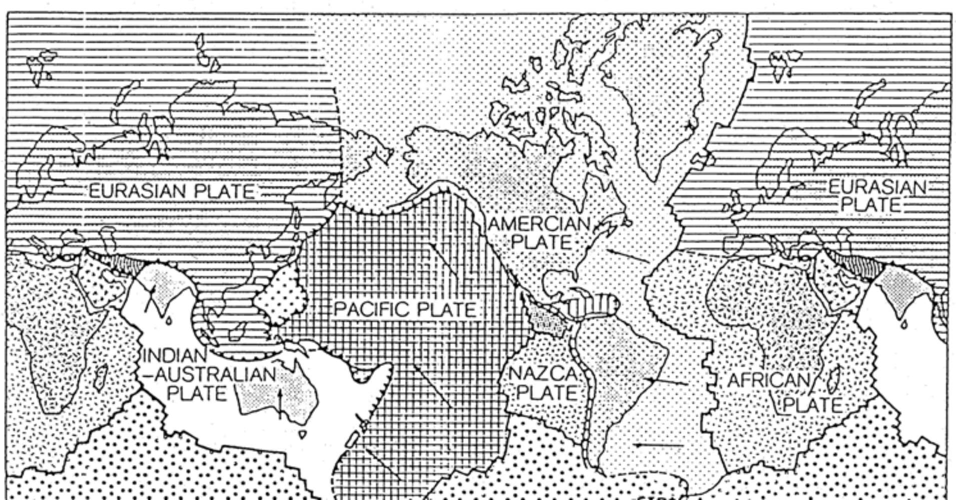


Fig. 6.2: Tectonic plate map of the world

Boundaries of plates are of four main types:

a) *Divergent zones,* where new plate material is added from the interior of the earth. These are found at the oceanic sea floor ridges.

b) *Subduction zones*, where plates converge and the underthrusting one is consumed. A typical example is the west coast of Central and South America.

c) *Collision zones*, former subduction zones where continents riding on plates are colliding. Typical examples are the Himalayas and the Alps.

d) *Transform faults*, where two plates are simply gliding past one another, with no addition or destruction of plate material.

Almost all earthquakes closely follow plate boundaries and are related to relative movements of the plates.

Besides the roughly 15 main plates already identified, smaller sub-plates or buffer plates exist which in some areas tend to ease the relative movement of larger plates. Buffer plates have been identified in Tibet and China, in the western USA and in the junction of African, Arabian, Iranian and Eurasian plates.

On the other hand, plates are not rigid bodies, as could be understood from previous description. Intra-plate earthquakes, not associated with plate boundaries, also occur. These make the analysis of earthquake sources more complex, especially when these are not clearly defined.

6.1.2.2 FAULTING

As indicated by Dowrick (1988), faults are usually the seat of damaging earthquakes and therefore need to be given special attention. In this regard, following aspects need to be taken into consideration:

6.1.2.2.1 LOCATION OF ACTIVE FAULTS

Faults may be easier to identify in competent soils, when shallow earthquakes occur and the fault planes will reach the surface. However, this is not always in case of deep foci earthquakes and/or when the overburden is not stiff enough to allow rupture. In other cases faults may reach the surface but are difficult to recognize.
In general, following factors may complicate identification of faults:

- Low degree of fault activity.
- Erosion and deposition rates that are higher than fault slip rate.

- Dense vegetation covering faults.
- Dispersed fault zones at the surface so that individual features are less pronounced.

The location of active faults is normally shown on geologic and geotectonic maps. However, due to the above given reasons this information tends to be incomplete. One way to partially overcome this problem is to study available published literature for the areas of interest. Therefore, identification of active faults may comprise the study of geologic and geotectonic maps, published literature, technical reports, photogeology, satellite images, etc. These studies may need to be complemented with fieldwork.

6.1.2.2.2 TYPES OF FAULTS

The characteristics of strong ground motions are strongly influenced by the type of faulting. Housner recommends that following four types of faults should be considered:

- *Low angle, compressive underthrust faults*. Result from tectonic seabed plates spreading apart and thrusting under adjacent continental plates. (Fig.6.3, a)

- *Compressive, overthrust faults or reverse faults*. Compressive forces cause shearing failure forcing upper portion upwards. (Fig. 6.3, b)

- *Extensional faults, or normal faults.* Is the inverse of the previous type, extensional strains pulling the upper block down the sloping fault plane. (Fig. 6.3, c)

- *Strike-slip faults*. Relative horizontal displacement of the two sides of the fault takes place along an essentially vertical fault plane (Fig. 6.3, d). These faults can also be subdivided in accordance with at least two criteria, i.e. inclination of fault plane and its constellation to bedding.

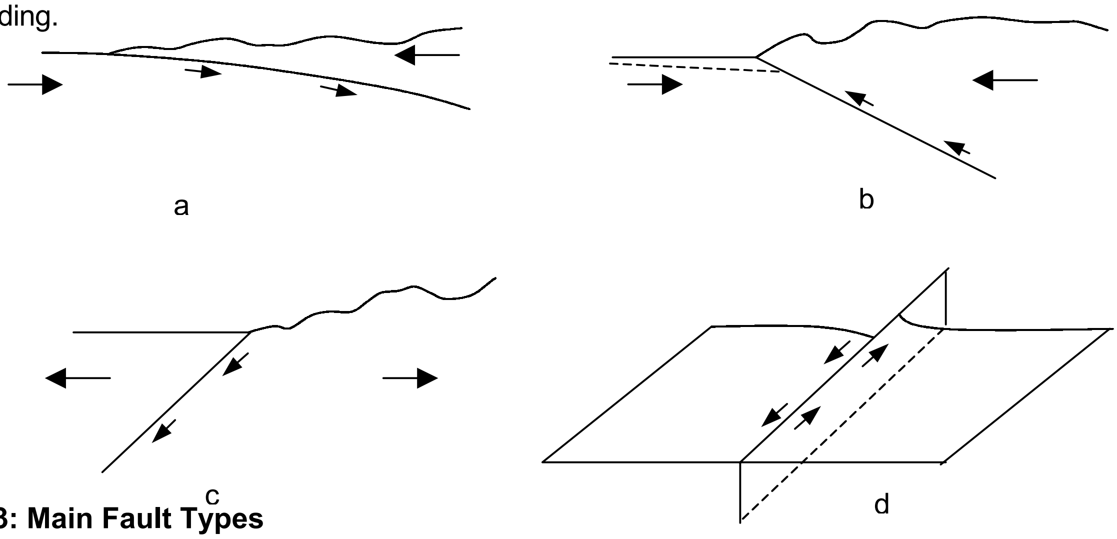


Fig. 6.3: Main Fault Types

Low angle, compressive thrust faults exist in global dimensions only, while other three types can have any size (from micro to continental). Movements along fault planes can have all combinations, ranging from 100% horizontal and 0% vertical to 0% horizontal and 100% vertical.

6.1.2.2.3 DEGREE OF FAULT ACTIVITY

As active faults are denoted every type of faults which are considered capable of moving in the future. Due to the fact that amount and frequency of movements can vary widely, it is important to have an estimate of the degree of likely activity of any fault in the region of interest. Various schemes have been proposed for this purpose, however, certain degree of uncertainty always exists, especially when the faults have not shown any activity in recent time or information about their activity is not available.

6.1.2.2.4 RELATIONSHIP BETWEEN FAULT AND EARTHQUAKE MAGNITUDE

It is always required to know the strength of earthquakes which can be generated by a given fault. However, this is a very difficult task. Therefore, some terms such as 'maximum credible earthquake' or 'safe shutdown earthquake (mostly applicable to nuclear power plants)' have been adopted to get at least an idea of order of magnitude of expected events.

Following methods are frequently used to estimate earthquake magnitude on basis of geological conditions:

a) *Magnitude vs. fault rupture length*. Is currently the most common method. Various relationships for different fault types have been derived, mainly using information on inter-plate zones.
b) *Magnitude vs. fault rupture area*. Used due to a recently recognized complication related to the occurrence of multiple events caused by two or more faults producing overlapping ground shaking. These events may appear superficially as one event, increasing the difficulty of assigning magnitudes.
c) *Magnitude vs. fault displacement*. Some relationships have been derived, however estimates are very rough due to the limited data available on true displacements.

Besides fault characteristics, an important aspect to consider is that the average rupture length of mid-plate events is much shorter than for those events located near the plate boundaries. Therefore, proper care should be taken when assigning magnitudes in these cases.

6.1.2.3 EFFECT OF SITE CONDITIONS

Besides the evaluation of local soil condition on the ground motion, also the influence of seismic activities on the following items should be considered:

a) Landslides
b) Mudflows
c) Liquefaction of non-cohesive soils
d) Failure of sensitive or quick clays
e) Land subsidence
f) Dam failure
g) Water waves, which may be caused by ground motion, landslides, dam failure, etc.

The assessment of the conditions at site should consider the determination of geological setup, especially with respect to:

a) Soils, including loose sediments transported by wind, water and/or gravity
b) Loose bedrock, chemically or physically weathered and /or totally disintegrated rock with no transport.
c) Bedrock

In this regard, some of most important effects of soil conditions and local geological features are discussed below:

- The greater the horizontal extent of softer soil, the less will be boundary effects (L1 or L2 in Figure 6.4).
- The depth (H1 or H2 in Figure 6.4) of soil overlying bedrock affects the dynamic response, increasing natural period of vibration of soil with increasing depth.
- Slope of soil strata lying on bedrock affects dynamic response.
- Topography of soil strata and bedrock affect incoming seismic waves, creating refraction, reflection, focusing and scattering.
- Local faulting and its characteristics need to be carefully evaluated.

- Soil types and their condition influence the response of the site and structures on it.
- Petrography, stratigraphy and exposure.

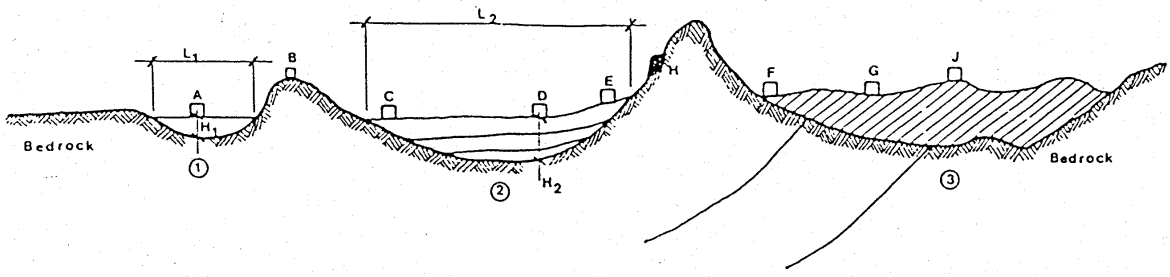


Fig. 6.4: Schematic diagram showing different geological and soil conditions

6.2 CASE STUDY - PLAINS OF INDUS RIVER IN PAKISTAN

6.2.1 FAULTS IN THE REGION

To evaluate the highest possible earthquake intensities at the project site of low head developments in the Indus River Basin, the five main faults and discontinuities have to be taken into consideration, as illustrated in Figure 6.5. The description of these faults is taken from the Kalabagh Dam – Project Report, July, 1984.

Alluvial deposits in the area associated with the known or possible fault zones have to be closely examined to see any evidence of tectonic disturbance in quarternary deposits. The nullah cuts in alignment of the fault zone afford a very good opportunity to look for any disturbance in the Holocene. Several scarps and a few trenches also have to be excavated to observe the evidence of Quarternary deformation. In the following the five main faults in the project area for low head hydropower development in Pakistan will be explained in detail.

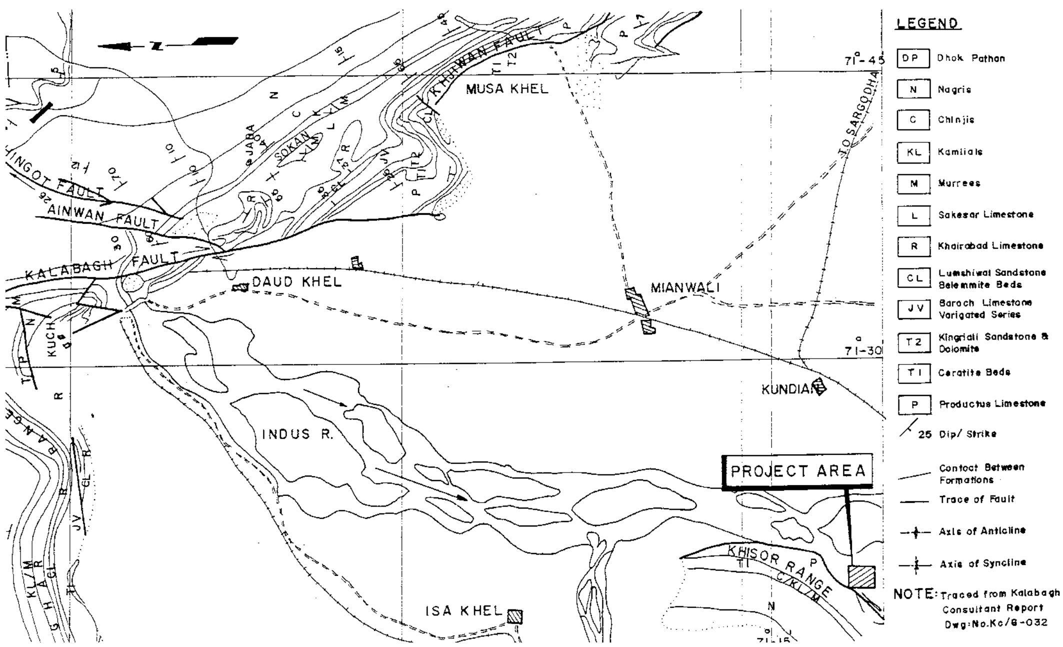


Fig. 6.5: Geotecnic map of Kalabagh Region

6.2.1.1 KALABAGH FAULT

The structural data along the Kalabagh fault, as illustrated in Figure 6.5 from the Chaisal Algad nullah in the north, to the Khairabad area in the south show extensive evidence for recent tectonic activity. Thrust faulting involving bedrock over alluvium as well as thrusting within alluvial gravels is present near Mari Indus, Khairabad and Thatti areas. The direction of thrusting, east to west, as well as the orientation of the fault planes, is consistent in both areas. An erosional origin for the Mari Indus feature is possible, but a thrust fault origin for the Khairabad fault is obvious from the evidence.

As an overview basis, structural data indicates that the main Kalabagh fault is strike-slip in origin with a N-S trend and dipping steeply. Termination of both structures and stratigraphy along the Chaisal Algad nala indicate a major strike-slip fault, as does the orientation of the fault plane and the long linear valley. Evidence in the Khairabad – Thatti area indicates a strike-slip origin for faulting in that area, and strongly suggests that it is related to the continuation of the Kalabagh fault to the south. The horizontal slikensided striae, found throughout the fault zones, are considered to be conclusive evidence for strike-slip faulting. The aerially extensive evidence for displacement of alluvial material along the strike-slip fault, as well as along minor, possibly related, normal and thrust faults strongly indicate that this fault is capable of generating surface displacements with macroseismic events. This fault has a known north-south length of 31 miles extending from the Chaisal Algad nala in the north to Sanwans village in the south. As generally seen elsewhere in the world, some strike faults merge into thrust faults. In case of Kalabagh fault, it is seen that on its north end, it merges into a system of east-west faults which continue up to Karak valley. On the south, the Kalabagh fault merges into the Salt Range Thrust which follows the frontal face.

6.2.1.2 AINWAN FAULT

The Ainwan is a strike-slip fault with a trend of about N 10° E and has a steep dip. This fault broaches of from the main Kalabagh fault in the vicinity of the fertilizer factory, where the geology is extremely complicated. The Ainwan fault follows the nala west of gypsum hill. On the surface the fault is associated with saline series and then cuts across various formations including Ecocene, Kmlials and Chinjis. The Ainwan fault crosses the Indus at a conspicuous bend in the river which may be the cause of relatively recent development in the Indus gorge. The fault continues in the Siwaliks for about 14 km. This feature because of the young geomorphic features and the fact that it is branching off from the Kalabagh fault is being considered active.

6.2.1.3 DHINGOT FAULT

The Dinghot fault has a strong linear signature on the aerial photos and its trace can also be detected on the ERST imagery. The features on aerial photos indicate that this fault branches off from the Kalabagh fault near the Jaba nala. In this area there are wide spread alluvial deposits, which have concealed the trace of the fault south of the village Ainwan.

The southern face of the Salt Range in alignment of the fault does not show any evidence of this feature cutting across the Range. There is an extensive zone of deformation between the Gypsum hills and the Salt Range frontal face behind village Khairabad. It appears that the Dhingot fault branches from the Kalabagh fault in this area.

Between Ainwan village and Chunji village, there is very clear offset seen where the fault has displaced the low level Chinji ridge. The Dhingot fault has a prominent fault controlled valley with springs. Near the river the Nagris are seen to make linear valleys and massive ridges. In this area there is a highly disturbed fault zone about 1400 m wide, incorporating several branch faults. The fault crosses the Indus river near Dhingot village and continues with an N 10° E trend. Its exposures have been studied in detail in the Kharjwan nala, as can be seen in Figure 6.5. The Dhingot fault cannot be traced beyond Vaggi Algad nala. The area south of Ainwan village is occupied by alluvial deposits of Jaba nala. The area was closely examined for any possible evidence of recent activity. Here Quaternary deposits consist of recent gravels and reddish silt, underlain by extensive deposits of alternate beds of gravel and silts. The area between Gypsum quarry and back of the Salt Range behind Khairabad village has been carefully examined. As described in detail above, the late Pleistocene deposits of gravel and silt including the red silts have been found to be deformed. Therefore, it is concluded on the basis of anomalous geomorphic features, deformation of late Pleistocene deposits and possible branching from an active fault that the Dhingot fault is an active fault.

6.2.1.4 BANNU FAULT SYSTEM

The Bannu fault shows a remarkable similarity of tectonic pattern to the Kalabagh fault. It has a N-S trend originating from Bangal Sar northwards and follows northwards an extremely disturbed zone upto Hukni. Here there is a swing in the strike of the beds and the fault follows the system of linear valleys and parallel ridges which continue westwards for about 64 km. The area near Hukni where the fault trend changes is associated with a sag ponds. From Hukni westwards, there are fault controlled linear valleys such as the Karak valley.

These faults within the area of study are all within older formations. Therefore, in order to see evidence of any recent activity the alluvial filled valley has to be studied. The Karak valley offers a good opportunity to study the Pleistocene and Holocene deposits where a number of exposures can be studied. Near Surdag, boulder gravel is been titled at an angle of about 50. Further east of Surdag within the valley, there are several exposures of late Pleistocene deposits which have been deformed. The association of recent deformed material of late Pleistocene age along the fault trace indicates that this may be an active feature. For purpose of assessing rock motions, two different fault segments shall be considered. The N-S trend is 12 km long feature located 19 km from Kalabagh Dam site.

6.2.1.5 SURGHAR FAULT

The Surghar range is a Trans-Indus continuation of the Salt Range. While the Kalabagh fault following the frontal face of the Salt Range, continues along the Chsial Algad nala. Surghar fault is thrust fault following the hill-plain boundary behind Kalabagh town.

This fault forms a branch of the Klabagh fault system. The frontal face in this area is associated with classical features depicting recent tectonics.

Here the saline Series rocks are thrust for more than 50 m over what are probable Holocene gravels. Over 50 m of movement in Holocene or say late Pleistocene times suggest that the last phase of these movements must have been in very recent times. However, the fault movements have also been influenced by some diapirism.

6.3 DATA COLLECTION

The seismic hazard analysis includes the identification of the tectonic and geologic features affecting the project areas, analyses of historical and instrumental seismicity and the study of the seismotectonic set-up of the region. The gathering of seismotectonic information for a project area includes the review of basic geology and tectonics within a 200 km radius of each site with particular attention to the mapped faults; review and evaluation of both, historical and instrumental seismicity to understand the seismic pattern of the region.

The main sources of seismic data are the earthquake catalogs of the US National Oceanic and Atmospheric Administration (NOAA). The NOAA database can now be accessed via Internet. It consists of various catalogs covering different regions of the world. Some have a worldwide coverage, other cover specific sectors of the planet. To study an area of the world, a geographic window has to be defined and the applicable catalogs are scanned to select the seismic records that fall within the window.

Following catalogs are available:

- PDE-EQH-USE Catalog - Worldwide Preliminary Determination of Epicenters, US Geological Survey
- Special International Earthquake Catalog, NOAA
- Soviet Earthquake Catalog
- People's Republic of China
- Multiscoure Global Data File, NOAA

The PDE Catalog contains comprehensive data with worldwide coverage although the main set of data cover since the 1960's. The international Catalog yields useful information about medium to large sized earthquakes since the beginning of the century to circa 1960. Therefore files No.1 and N0.2 are complementary for the region.

The Soviet Catalog provides numerous records but only in a band around the former Soviet Border. Thus they are not homogenous in space and therefore very seldom are used for other regions in the rest of the world.

The Chinese Catalog does not yield any information useful for the study areas outside china.

The Multisource Global Data file only provides information already contained in the International Catalog.

With help of this information, a more specific window can be created covering the nearby area of the project. An example of the data file obtained from NOAA is given in Table 6.1 and Table 6.2. While Table 6.1 a part of the listing of the NOAA data set, Table 6.2 gives the summary of events as a function of the year and the magnitude. The example covers the area of a circle around the Project Jinnah N 32.95 E71.53 with a diameter of the circle of 400 km. The depth ranges from 0 to 50 km. The extreme dates of data set are from 12 September 1924 to 31 October 1994. The number of events in the aforementioned area and time is 596.

Additionally to the analysis and evaluation based on available data banks, specific field studies should also be carried out. It is necessary that detailed seismotectonic studies be carried out for a better understanding of the potential seismic sources governing the expected ground motion of a project area.

Especially in regions with a generally high seismic activity, also active earthquake sources need to be identified in the field. The instrumental assessment of seismic activity by means of local networks of seismographs should be undertaken, where planned high head hydropower developments might be effected. For this purpose the possibility of establishing a seismographic network should be evaluated.

Moreover accelerographs should be installed. These instruments yield complementary information that seismographic networks cannot gather. These instruments are strategically distributed to record detailed information about the strong ground motion during an intense earthquake. They are stand-by instruments that only get activated operation like the seismographs. It is recommended to consider the expansion of a seismic network in project areas with the inclusion of a sufficient number of accelerographs.

Table 6.1: Extract from seismic data set, Jinnah Barrage

Data Source: PDE + International NOAA FILE 1+2
Window is circle around Jinnah Project site N 32.95 E 71.53
Diameter of the circle: 200 Km
Range of depths: 0 to 50 Km
Extremes dates of data set: 12-09-1924 to 31-10-1994
Number of events in window: 596

SOURCE	YEAR	MONTH	DAY	LATITUD	LONGITUD	DEPTH	ASSESSED MAGNITUDE	GEOG.	Ms	Mb
ISS	1924	9	12.007	33.200	71.400	0	6.08L5	710	0	0
PDE	1968	11	18.212	33.091	71.109	41	5.24L4	710	0	0
PDE	1972	5	17.421	33.496	71.541	33	5.24L4	710	0	0
PDE	1976	1	29.290	32.392	71.744	33	3.76L5	710	0	0
PDE	1978	2	24.996	32.776	71.457	33	3.67L5	710	0	0
PDE	1980	2	9.766	32.745	72.531	33	2.90L4	710	0	0
PDE	1981	7	20.595	32.241	71.178	58	3.98L4	710	0	0
PDE	1983	12	31.749	33.221	71.387	33	2.00L4	710	0	0
PDE	1984	2	11.359	33.455	71.566	33	4.52L4	710	0	0
PDE	1984	4	30.929	33.128	72.114	33	3.40L5	710	0	0
PDE	1985	8	8.309	32.630	72.441	33	3.36L5	710	0	0
PDE	1987	6	11.949	32.209	71.978	33	2.36L4	710	0	0
PDE	1989	5	12.028	32.260	71.095	33	4.16L4	710	0	0
PDE	1990	6	29.089	32.729	71.928	33	3.62L4	710	0	0
PDE	1990	8	24.618	33.045	71.783	33	3.08L4	710	0	0
PDE	1991	1	29.043	33.440	72.119	4	4.16L4	4 134	0	F .00
PDE	1991	1	29.101	33.361	72.050	4	4.52L4	3 134	0	F .00
PDE	1991	2	12.214	32.678	72.382	3	3.62L4	710	0	0
PDE	1991	2	17.070	33.465	72.026	3	3.98L4	710	0	0
PDE	1991	3	29.136	32.994	72.089	4	3.80L4	134	0	0
PDE	1991	4	23.152	32.189	72.030	1	3.08L4	134	0	0
PDE	1991	5	13.033	32.223	71.392	8	3.98L4	4 135	0	F .00
PDE	1991	5	13.033	32.179	71.392	8	3.80L4	4 135	0	F .00
PDE	1991	6	24.112	32.447	71.702	7	3.98L4	2 135	0	F .00
PDE	1991	6	29.183	33.735	71.046	8	3.98L4	4 135	0	F .00
PDE	1991	8	13.051	32.407	71.699	3	3.44L4	135	0	0

Table 6.2: Seismic Recurrence (Radius = 200 km; Depth < 50 km), Jinnah Barrage

YEAR	DISTRIBUTION MAGNITUDES											TOTAL
	2 TO 2.4	2.5 TO 2.9	3 TO 3.4	3.5 TO 3.9	4TO 4.4	4.5 TO 4.9	5 TO 5.4	5.5 TO 5.9	6TO6.4	6.5TO6.9	7TO7.4	
1924	0	0	0	0	0	0	0	0	1	0	0	1
1968	0	0	0	0	0	0	1	0	0	0	0	1
1972	0	0	0	0	0	0	1	0	0	0	0	1
1976	0	0	0	1	0	0	0	0	0	0	0	1
1978	0	0	0	1	0	0	0	0	0	0	0	1
1980	0	1	0	0	0	0	0	0	0	0	0	1
1981	0	0	0	1	0	0	0	0	0	0	0	1
1983	1	0	0	0	0	0	0	0	0	0	0	1
1984	0	0	1	0	0	1	0	0	0	0	0	2
1985	0	0	1	0	0	0	0	0	0	0	0	1
1987	1	0	0	0	0	0	0	0	0	0	0	1
1989	0	0	0	0	1	0	0	0	0	0	0	1
1990	0	0	1	1	0	0	0	0	0	0	0	2
1991	0	0	5	28	7	1	0	0	0	0	0	41
1992	0	1	31	98	59	14	3	1	0	0	0	207
1993	0	0	23	84	63	7	1	1	0	0	0	179
1994	0	0	0	0	1	0	0	0	0	0	0	1
1993	0	0	0	1	0	0	0	0	0	0	0	1
1994	0	0	20	69	49	10	4	0	0	0	0	152
TOTALS	2	2	82	284	180	33	10	2	1	0	0	596

6.4 DATA PROCESSING

6.4.1 POTENTIAL SEISMIC SOURCES

To evaluate the worst possible earthquake intensities at the sites of interest the following faults were taken into consideration:

Source No.	*Name*
1	Kalabagh fault
2.	Ainwan fault
3.	Dhingot fault
4.	Bannu fault
5.	Surghar fault

6.4.2 ANALYSIS OF INDIVIDUAL SOURCES

For each of the faults and thrusts listed above, the opinion of geologists was taken into consideration to pinpoint the segments of faults and thrusts appearing to have a higher degree of activity. Much of the information in this respect is even speculative, based on geological judgment. For lack of local seismic networks there is no microseismic evidence that could be used for the purpose of identifying active faulting. The faults of interest are shown in Figure 6.5

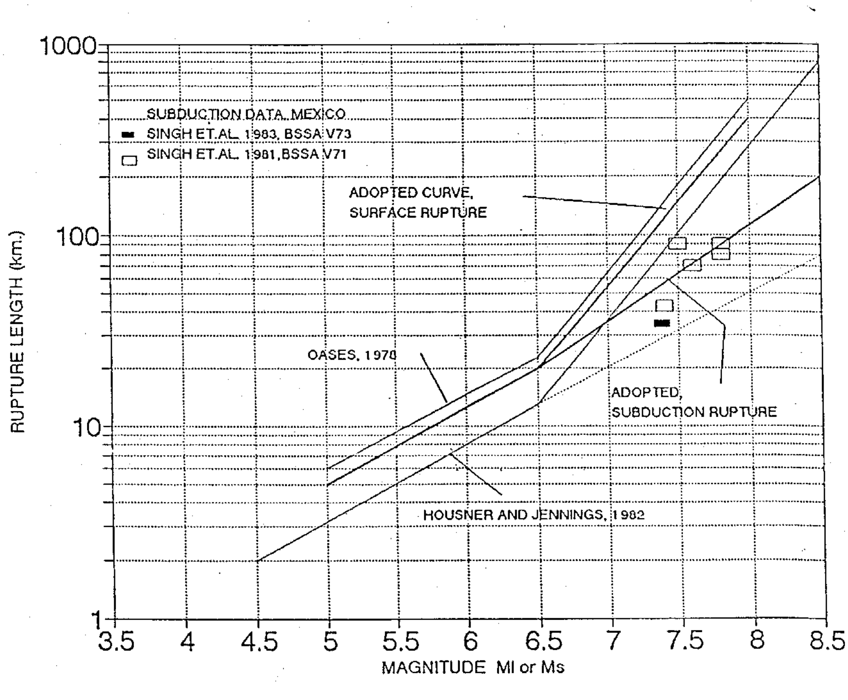
6.4.2.1 MAXIMUM RUPTURE LENGTH

To assess the maximum credible event two possibilities were considered:

- The maximum earthquake corresponds to a fault rupturing its full length.
- The maximum earthquake corresponds to a fault rupturing half its length.

6.4.2.2 MAGNITUDE ASSUMPTION

To assign the magnitude that would correspond to the assumed maximum rupture, a set of magnitude-rupture empirical relationships was used. The relationships are shown in Figure 6.6. Because of the difficulty to assess rupture lengths for thrust fault-ruptures as a class, general relationships were used. Below magnitude 6.5, an average between the Housner and Jennings, 1982 curve and the Oases, 1978 curve originally developed for Alaskan subduction earthquakes was used. For larger magnitude earthquakes the Oases relationship appears to be biased in the upper ranges, probably by data of long strike-slip ruptures; thus, some Mexican subduction data were plotted and a curve fitted; this yields a range of possibilities in the upper magnitude reaches. The reason for resorting to the subduction data is that one may expect



more parallelism between major thrust ruptures and subduction than between thrust and strike slip faulting. In any case, values for the ruptures of the specific region were drawn from the middle of the field between curves in Figure 6.6. The magnitude values resulting from these assumptions were deemed reasonable.

Fig. 6.6: Earthquake magnitude vs. rupture length

From the rupture length assumptions and the rupture-magnitude assumptions two magnitudes were inferred. In other words, the maximum credible magnitude for each source was assessed as a bracket, underscoring the uncertainty associated with the value of this parameter.

6.4.3 SEISMIC INTENSITY PARAMETERS

6.4.3.1 PGA, PGV, PSRV AND PSA SPECTRUM

The earthquake intensity parameters used for this kind of hazard assessment are peak ground acceleration (PGA), peak ground velocity (PGV), and Pseudo-relative velocity spectral ordinates (PSRV) and are calculated using attenuation relationships by Joyner and Boore, 1988.

A fourth parameter of importance is the pseudo-acceleration response spectrum (PSA). The ordinates of this spectrum are derived from the ordinates of the PSRV by multiplying them by 2xPIxFreq (Hz); if the velocity is in cm/sec the results are in gals, i.e. cm/sec^2. The PSA is of great importance for structural analysis.

6.4.3.2 ATTENUATION RELATIONSHIP

Dozens of attenuation relationships have been derived in the past decades. The attenuation relationships usable in hazard assessments are statistically based. A general discussion on attenuation relationships can be found in Campbell, 1986. For the resent evaluation the attenuation relationships by Joyner and Boore, 1988, were used. Examples of the format of the J&B attenuations is given in Table 6.3.

Table 6.3: Spectra Attenuation Relationships (Joyner and Boore, 1988)

T [sec]	a	b	c	d	h	k	s	sigma
	Pseudo-velocity [cm/sec] 5% damping							
0.10	2.16	0.25	-0.06	-1.0	11.3	-0.0073	-0.02	0.28
0.15	2.40	0.3	-0.08	-1.0	10.8	-0.0067	-0.02	0.28
0.20	2.46	0.35	-0.09	-1.0	9.6	-0.0063	-0.01	0.28
0.30	2.47	0.42	-0.11	-1.0	6.9	-0.0058	-0.04	0.28
0.40	2.44	0.47	-0.13	-1.0	5.7	-0.0054	-0.10	0.31
0.50	2.41	0.52	-0.14	-1.0	5.1	-0.0051	-0.14	0.33
0.75	2.34	0.60	-0.16	-1.0	4.8	-0.0045	-0.23	0.33
1.00	2.28	0.67	-0.17	-1.0	4.7	-0.0039	-0.27	0.33
1.50	2.19	0.74	-0.19	-1.0	4.7	-0.0026	-0.31	0.33
2.00	1.12	0.79	-0.20	-1.0	4.7	-0.0015	-0.32	0.33
3.00	2.02	0.85	-0.22	-0.98	4.7	-0.0	-0.32	0.33
4.00	1.96	0.88	-0.24	-0.95	4.7	-0.0	-0.29	0.33
	Peak acceleration [g]							

	0.43	0.23	0.00	-1.00	8.00	-0.0027	0.00	0.28
	Peak velocity [cm/sec]							
	2.09	0.49	0.00	-1.00	4.00	-0.0026	0.17	0.33

$$\log y = a + b(M - 6) + c(M - 6)2 + d \log R + kR + s \pm \varepsilon$$

with:
y – randomly oriented horizontal component
s<>0 soil site] 5m thickness; s=0 rock site
5 ∗ M ∗ 7.7; M moment magnitude R = (r2 + h2) 0.5
r - distance to the vertical projection on the earth's surface of the nearest point of rupture

6.4.3.3 HORIZONTAL DISTANCE (RO)

To calculate the intensity parameters it is necessary to select the horizontal distance from the rapture plane to the site. This distance is assessed from the map. The mapped surface trace of faults might be taken, although this may not be strictly correct for plane dipping at an angle. If no other data are available, this approach can be considered as accurate enough.

6.4.3.4 FOCAL DEPTH (H)

With regard to the depth of the earthquake, the Joyner and Boore relationships incorporate a fixed depth parameter. Since the depth value is for shallow earthquakes, it is applicable for the maximum credible earthquake assumptions which call for an earthquake as shallow as possible.
The calculation is performed using local depths of 8 and 4 km, for acceleration and velocity respectively. The values of PGA and PGV at Jinnah HPP are listed in Table 6.4 for soil and rock site. Figures 6.7 and 6.8 show the resulting Pseudo Relative Velocity Spectra. Figures 6.9 and 6.10 show the corresponding Pseudo Acceleration Spectra for soil and rock site.

6.4.3.5 MAXIMUM CREDIBLE SEISMIC INTENSITIES

Tables 6.4 and 6.5 summarize the conclusions of trial maximum credible intensities and comments. Figures 6.7 and 6.8 contain the resulting Pseudo Relative Velocity Spectra. Figures 6.9 and 6.10 contain the resulting Pseudo Acceleration Spectra. Observe that the spectra as well as the other parameters are given as ranges, not as point assessments.

Table 6.4: MCE Analysis, PGA and PGV Intensity Parameters, Kotli

Source		Maximum Credible Earthquake Magnitude		R_0 Horiz. Dist. [km]	Rupture Length [km]		Parameters					
							PGA [g]		PGV [cm/s] Soil		PGV [cm/s] Rock	
n	Name	L	H		Fu	Ha	L	H	L	H	H	H
A	Kalabagh Fault (N-S)	6.3	6.7	2	26	13	0.33	0.4	43.8	68.9	29.7	46.6
B	Ainwan Fault	5.8	6.3	6	11	5.5	0.25	0.27	24.1	26.6	16.3	18.1
C	Dhingot Fault	6	6.5	7	16	8	0.24	0.27	21.5	28.5	14.5	19.3
D	Surghar Fault	5.2	5.7	0	5	2.5	0.32	0.32	30.0	44.4	30.0	30.0
E	Kalabagh Fault (E-W)	6.7	7.2	21	50	25	0.14	0.22	13.0	38.0	8.8	25.7

F	Bannu Fault (N-S)	5.8	6.3	19	12	6	0.11	0.12	8.3	9.24	5.6	6.2
G	Jabbi Dhok Fault	6.7	7.2	37	40	20	0.07	0.12	6.8	19.9	4.6	13.4

L = Low
H = High
Fu = Full
Ha = Half

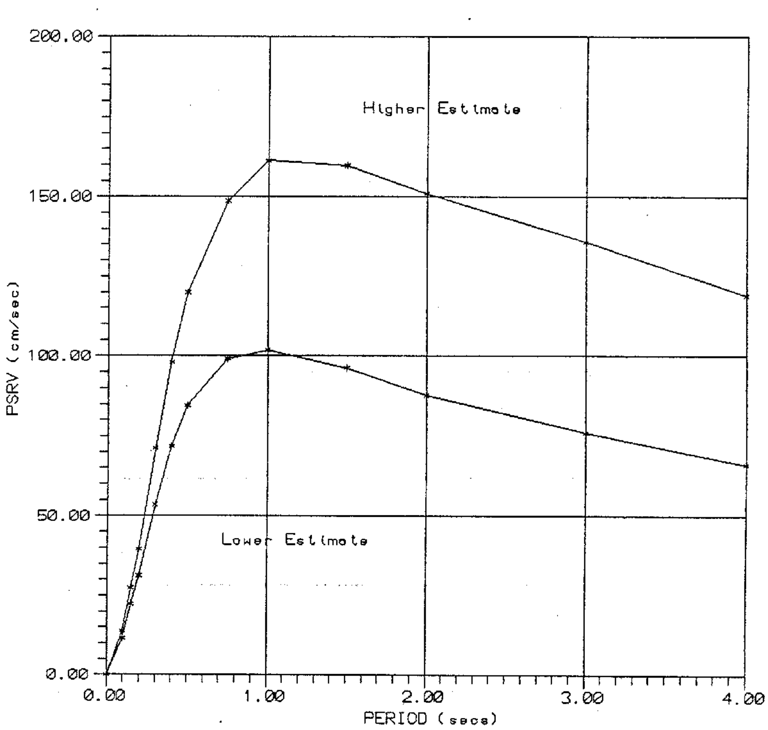


Fig. 6.7: Maximum credible pseudo relative velocity spectra, soil site, Jinnah HPP

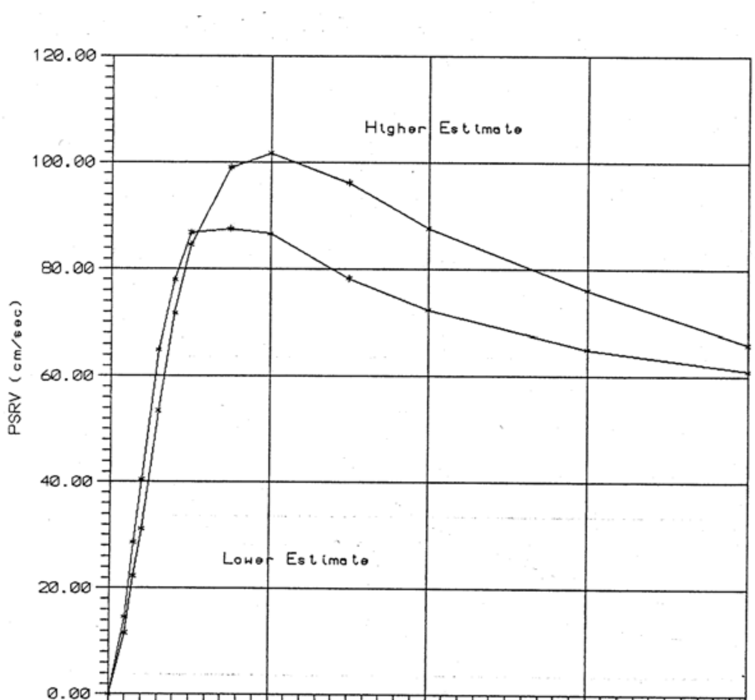


Fig. 6.8: Maximum credible pseudo relative velocity spectra, rock site, Jinnah HPP

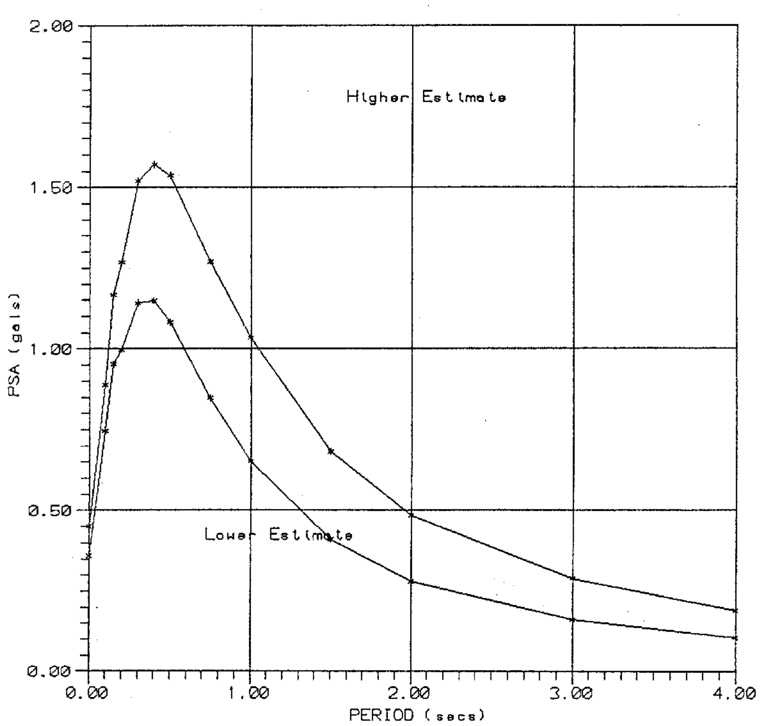


Fig. 6.9: Maximum credible pseudo acceleration spectra, soil site, Jinnah HPP

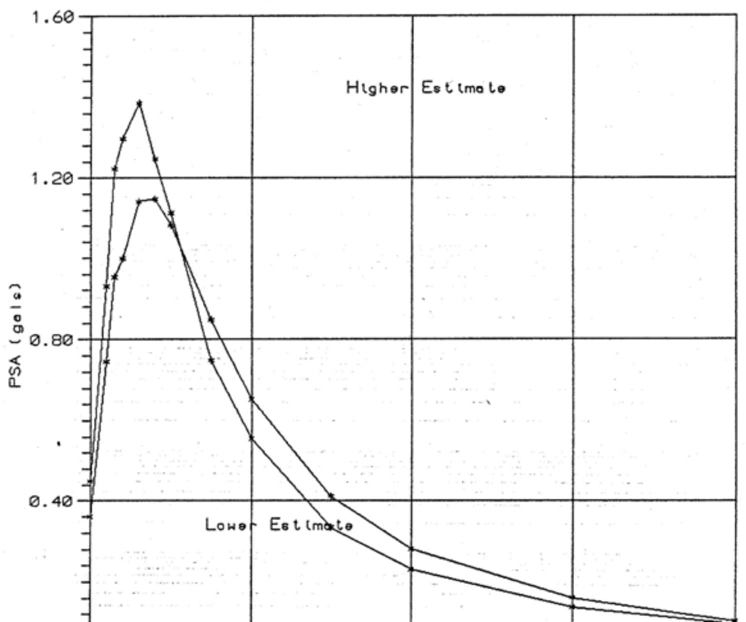


Fig. 6.10: Maximum credible pseudo acceleration spectra, rock site, Jinnah HPP

6.5 SEISMIC HAZARD EVALUATION - DESIGN EARTHQUAKE AT SEVERAL HAZARD LEVELS

The assessment of design earthquakes at various hazard levels requires the estimation of the recurrence of seismic intensities at the sites of interest. The recurrence of seismic intensities is inferred using the method originally devised by Cornell in 1968. It requires data on the location and magnitude of seismicity (i.e. an earthquake catalog); from these data the recurrence of earthquake magnitudes is inferred. The intensities that each magnitude can cause at the sites of interest is calculated knowing the distance between source and target and having a suitable attenuation relationship. The results reported here were numerically evaluated with the program EQRISK (MacGuire, 1977) using the assumptions and performing the tasks described below.

6.5.1 CONVERSION OF MAGNITUDES

Seismic catalogs record particular definitions of earthquake magnitudes. Surface wave magnitude, Ms, is generally considered a good representative measurement of earthquake magnitude in the range 5.5 < M < 7.5, particularly for shallow earthquakes. When surface wave magnitude Ms recordings were not available, magnitudes were converted into Ms scale. Frequently found readings of magnitude in the catalogs scanned are mb (body wave magnitude), Ms (surface wave magnitudes) calculated by the U.S.Geological Survey, and Ms calculated by another authority, for instance a European, Soviet or Chinese seismological agency. Sometimes there are Ms assessments from Cal Tech of Pasadena, California. This diversity of measurements needs to be converted into a single one.

Magnitudes were converted to a common basis using the following conversion rules:

- if Ms (USGS definition) is given, adopt it as magnitude M.
- else, if an alternate Ms value is available, adopt it as M.
- if only mb readings are available convert them to Ms using the method by Wyss and Habermann, 1982:

If year of event < 1963 then

Adopted $$Ms = 1.8 \times mb - 5.2 \qquad \textbf{(6.3)}$$

Otherwise $$Ms = 1.8 \times mb - 4.3 \qquad \textbf{(6.4)}$$

Unknown Magnitudes

Many records in the catalogs, especially older ones, do include geographical position but do not include a magnitude assessment. This is because the sensitivity of the seismic networks used to detect the events was not good enough to pinpoint certain magnitudes somewhat under the threshold of the network. Such thresholds are not specifically reported by the catalog compilers; the increase in sensitivity with the years has to be guessed at.

In the seismic analysis of Ghazi Gariala, Ambrasseys assigns "lower bound" magnitudes to events with no record of magnitude. He used the following relationship attributed to Middle East events:

$$Ms = 7.14 - 0.04253 \times (Year - 1900) \qquad \textbf{(6.5)}$$

For this project, frequency distributions by magnitude and by year were made for the full data window centered on Pakistan. The window is about 4 million square kilometers and is thus large enough for the intended statistics. For increasingly smaller magnitudes, their years of first reading were plotted against the magnitudes to investigate the magnitude-detecting capability of the PDE and the International catalogs. A linear regression was fitted over the data points. The graphs are shown in Figure 6.6. The resulting statistic for the Pakistan-centered region is

$$Ms = 7.15 - 0.0446 \times (Year - 1900) \qquad \textbf{(6.6)}$$

Year < 1963

Hence, earthquake events for which no magnitude value was available were assigned a lower bound magnitude using the above expression in which "Year" is the year of occurrence of the event.

6.5.2 MAGNITUDE-RECURRENCE RELATIONSHIPS

A recurrence relationship describes the frequency distribution of magnitudes for a seismic source. A simple form of recurrence relationship which is used in most engineering applications is log-linear:

$$Log\, N(M,t) = a(t) - b \times M \qquad \textbf{(6.7)}$$

where N(M,t) is the number of earthquakes of magnitude "M" or greater expected on the average to occur within a time-period "t". The coefficients "a(t)" and "b" are derived from the statistical analysis of an earthquake data set specifically assembled for the seismic source of interest. The value of a(t) depends upon the source seismic activity and the time period "t" considered. When the period "t" is 1 year, the recurrence is said to be time-normalized and the inverse of N(M,1) is the return period of events of magnitude M or larger. The time-normalized variable is denoted as N'(M).

Area sources

In many regions it is not possible to reasonably assign seismic events to specific seismogenic sources. This was the case for the Northern Pakistan area. In such cases a standard technique to overcome the modeling limitations is to define as the seismic source an area centered at the analyzed site. A seismic data set for the adopted circle is assembled and all earthquakes located within the circle are counted, classified by magnitude and a recurrence relationship is obtained. When performing the seismic hazard analysis, earthquakes are supposed to randomly occur at any place within the defined circle, while their magnitudes are assumed to follow the magnitude-recurrence distribution.

For the sites of interest, circles 200 Km in radius were defined around each site. The PDE Catalog and the International Catalog were scanned out. A separate data set was assembled for the Chashma HPP and Jinnah HPP, a data set assembled scanning the catalogues. Both catalogues are merged and checked to prevent duplicate events.

Aftershocks of major events need to be removed from the database to prevent bias in the count of number of events and magnitudes, especially if there are main events and numerous trailing smaller events that are only secondary shocks.

However, the database shows numerous instances of multiple events, in which it is difficult to single out a "main event" because they are series of earthquakes of nearly the same magnitude. Multiple events were not removed and they were counted as separated events in the recurrence statistics.

Pairs of shocks were also found. In these cases the shocks are geographically separated more than the rupture length corresponding to their magnitudes. Pairs when identified were not removed and were counted as separated events for the recurrence statistics.

Similarly foreshocks were not removed from the statistics. Foreshocks are defined as smaller magnitude events close in space and preceding a larger event.

The database assembled and filtered as described above was then "magnitude converted". All magnitudes were "transformed" into equivalent Ms magnitudes.

Earthquakes of unknown magnitude were assigned lower bound estimates of magnitude.
Deeper events were removed from the statistical recurrence count for each site. According to the literature there is likely to exist a "decollement" or "shaving-off" of the crust at depths of 30 to 40 Km. Sometimes even less. From the surface expressions of the thrusts seismicity dips at a very low angle, nearly horizontal. In order not to exclude this decollement seismicity a depth of 50 Km was selected to separate deeper from shallower events. Only events less than 50 Km in depth were considered for the recurrence statistics. This approach is deemed conservative and could even be relaxed in future seismic hazard assessments.

The earthquake data set for each site was classified into 0.5 magnitude intervals and the absolute counting of events was performed. However such counts are time-biased because the data set was drawn from catalogs whose magnitude detection capabilities have been improving with time. Therefore the absolute count of each magnitude was divided by an appropriate time span. The appropriate time span was obtained as follows:

$$Yr = 1900 + (7.15 - Ms)/0.0446 \qquad \textbf{(6.8)}$$

Yr is the statistical assessment of the year in which magnitude Ms started to be detected. The time span of the available is:

$$T = 1990 - Yr \qquad \textbf{(6.9)}$$

where 1990 or another year is the date of the last event in the database.

Based on the time normalized count N'= N/T a regression was run on the data obtaining magnitude-recurrence relationships shown in Figure 6.11 for the site of interest. The corresponding best fit equation is:

Jinnah Barrage $$Log(N) = 5.6449 - 1.1605Ms \qquad \textbf{(6.10)}$$

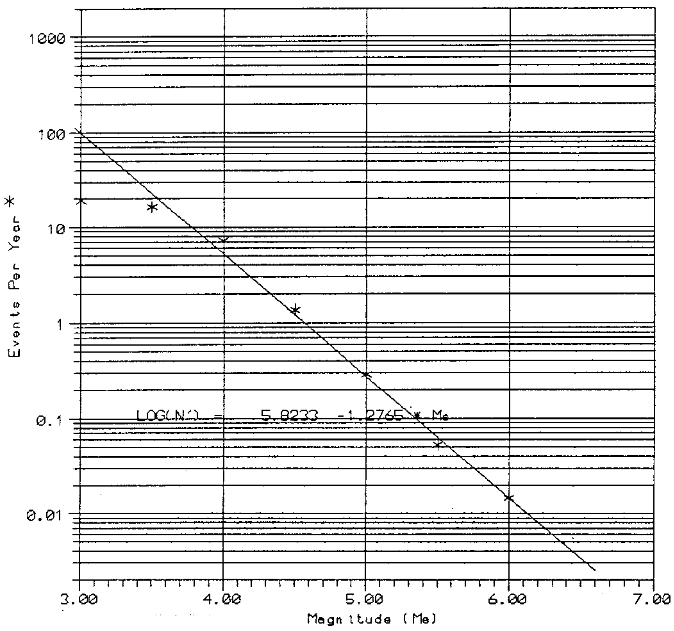


Fig. 6.11: Seismic Recurrence, Jinnah HPP

6.5.3 EVALUATION OF INTENSITY PARAMETERS

For the determination of intensity parameters at various hazard levels a straightforward tool was selected: the program EQRISK (McGuire, 1977 / PC version 1985). This program is very easy to operate and runs in PC personal computers without large demands of capacity. Its limitations, which to some extent reside in the seismic source geometrical model (e.g. it only accepts constant depth sources) were not severe in the Pakistan assessment because of the simplicity of the analytical model of the seismic environment that was used in the current evaluation.

The program EQRISK has many advantages. It has interchangeable formats for attenuation laws; the computer code is relatively transparent and can be easily modified. It has a good User's Guide. The advantages outnumber the shortcomings. As WAPDA engineers become proficient in hazard analysis, other computer codes can be installed in Lahore.

No attenuation law has been developed in Pakistan or in the south Asian region because of unavailability of strong motion data. For the present evaluation, the Joyner and Boore (1988) attenuation was selected as already mentioned in previous sections. The attenuation relationship format and coefficients are given in Table 6.3. The Joyner and Boore attenuation is nominally devised for a Magnitude, Mo, scale. In this assessment all magnitudes were converted to Ms magnitudes. However, the Ms magnitudes did not exceed 7.0. Hence, no further conversion is needed since Mo is supposed to match Ms for magnitudes below 7.5.

6.5.4 PSA AND PSRV - DESIGN SPECTRA

All of seismic design parameters that can be evaluated on basis of the Joyner and Boore attenuation relationship were computed using seismic recurrences described below. Based on the results of the maximum credible events, two runs of EQRISK were made for each, the lower and the higher estimates of maximum magnitude.

Since there was no direct assignment of seismicity to specific seismic sources, the entire circle defined around each site was used as a constant depth seismic source. The depth assigned in each case corresponds to the depths prescribed in the Joyner and Boore attenuation formula. In case of Allai Khwar this rule was modified since the main seismic source, the MMT, is about 30 km away. Hence the lower estimate run was made with the closest distance of 30 km and the higher estimate with a closest estimate of 15 km.

For each site, several runs of EQRISK were made: for PGA, PGV and for relative velocity spectral ordinates at various frequencies. The corresponding acceleration spectral ordinates were derived from velocity ordinates using the appropriate conversions. Each of the 8 parameters were evaluated at 200, 500 1000 and 2000 year return periods. In fact, the computations were actually carried out for longer return periods but these already begin to overlap with the maximum credible events. In these cases it is preferable to rely on the more straightforward concept of MCE. Hence, only the first four hazard levels were incorporated into the results and these were bounded with the MCE results.

6.5.4.1 SEISMIC HAZARD GRAPHS

The decision of when to use PGA and when PGV is a choice of the structural and earthquake engineers that use the design parameters. Since the technique of reading either graph is the same, only the PGA graph will be described.

Peak Ground Acceleration Seismic Hazard Graphs
Results are given in Figures 6.24 and 6.25. The graphs are read selecting a hazard level on the abscissas and reading the corresponding PGA on the ordinates. The hazard level can be selected in either of three ways:
a) by return period at the bottom of the graph
b) by annual probability at the top of the graph
c) choosing one of the letter keys displayed along the abscissas

For the project site of Jinnah HPP, for instance, according to FIGURE 6-12 the ordinary building can be designed on the bases of PGA of 140 Gals (cm/s^2).

As another example, a diverting dam or a barrage whose failure has only economic consequences could be checked say, for a return period of about 1000 years (hazard level C in graph), meaning a PGA of about 300 Gals (cm/s^2).

On the other hand, a very important facility whose failure could imperil the lives of thousands of persons, should be designed at least at a 650-Gal PGA level (hazard level E in the graph). This variation of loading from site to site at a fixed hazard level is the basis of a "uniform risk" structural design. However, for very important facilities, the MCE assessment should be taken into consideration.

The hazard graphs are also useful when seismic designs are required at two or three seismic loading conditions. Very important facilities are structurally verified not to collapse if the maximum credible earthquake were to occur, although severe damage is acceptable under this condition. Additionally, for these important structures an Operating Basis Earthquake (OBE) is defined, at which only minor damage is acceptable. The structures of the project and their contents and equipment should remain functional. Any damage should be easily repairable after the occurrence of an earthquake with ground motion not exceeding the OBE design parameters. The acceptable risk of having the facility out of operation is decided by the agency managing the facility.

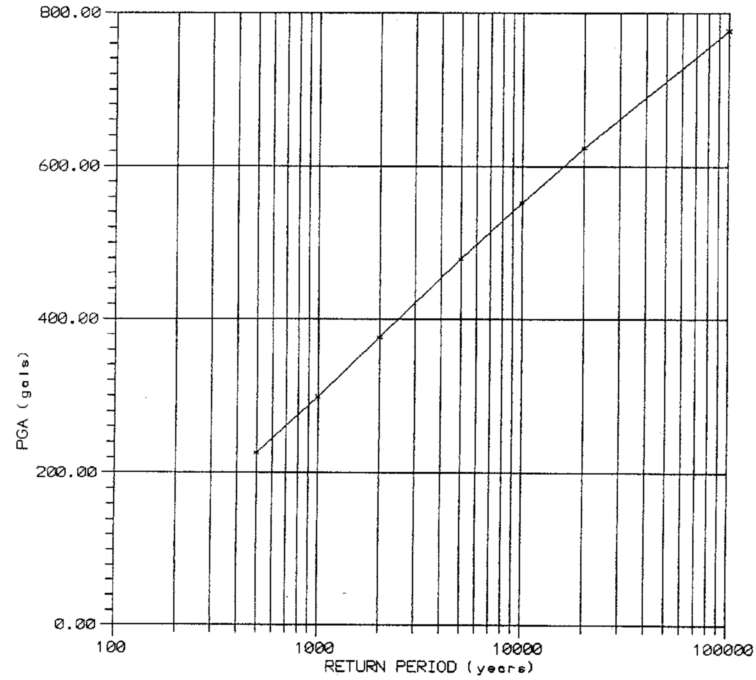


Fig. 6.12: Peak ground acceleration, Jinnah HPP

Peak Ground Velocity Seismic Hazard Graphs
These have the same pattern as PGA graphs. Average values are given in Figures 6.13 and 6.14.

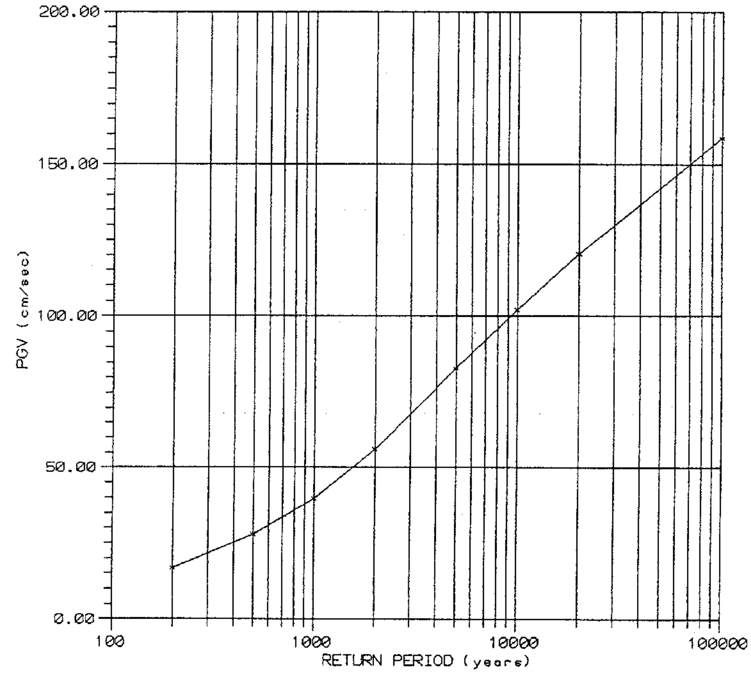


Fig. 6.13: Peak ground velocity, soil site, Jinnah HPP

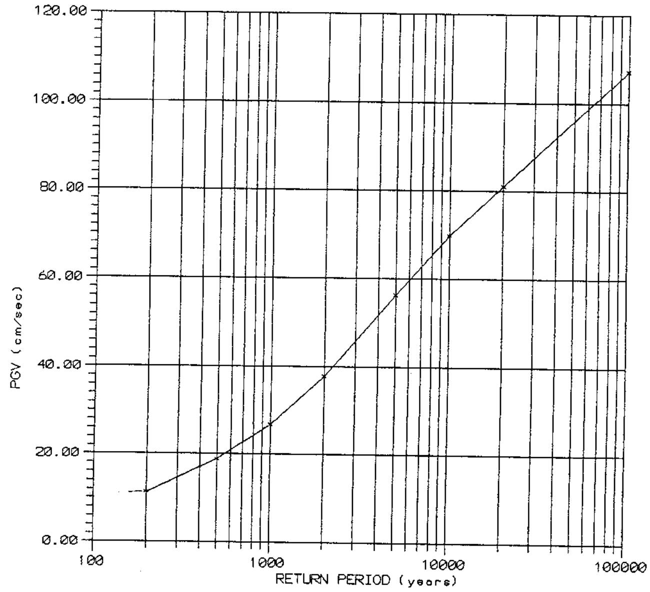


Fig. 6.14: Peak ground velocity, rock site, Jinnah HPP

6.5.4.2 PSA AND PSRV - DESIGN SPECTRA

On account of probabilistic analysis of operational basis earthquakes, design spectra are plotted for PSA and PSRV at different levels of hazards i.e. 0.005, 0.002, 0.001. 0.005 for standardization and better applicability of intensity parameters at various levels of risk and safety of structures of different importance PSA design spectra for soil and rock site are placed at Figures 6.15 and 6.16 for Jinnah HPP as example for low head developments.

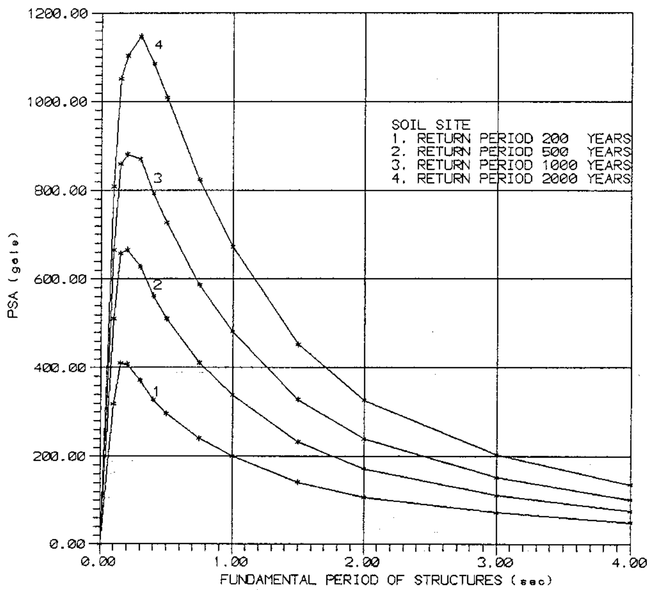


Fig. 6.15: Design spectra (PSA), soil site, Jinnah HPP

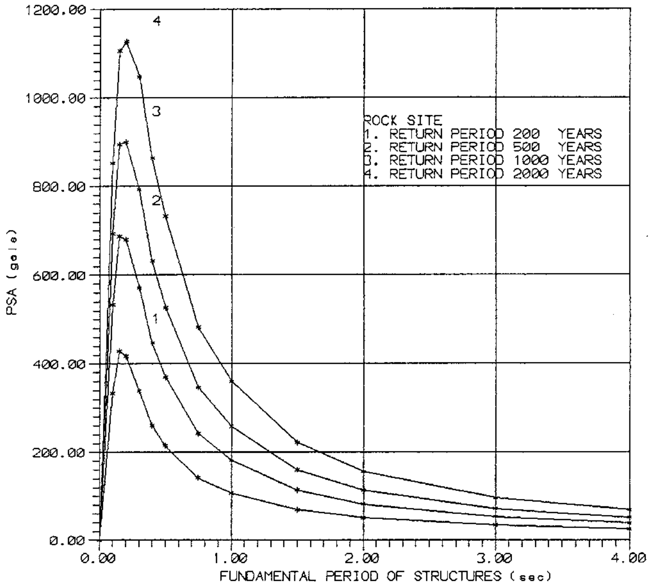


Fig. 6.16: Design spectra (PSA), rock site, Jinnah HPP

To make use of the spectra, a design hazard level is selected and the corresponding spectrum is used directly or else the level of interest is interpolated between two graphs. For a dual loading design, an Operating Basis hazard level is chosen along with another hazard level, say a MCE. The structural design is checked, at the corresponding frequency of vibration, under the two conditions: one at working stress and the other at strength condition or at ultimate condition. It is the structural engineer who decides the details.

The reader is reminded that all spectra in this report are to be considered preliminary until further work is performed in assessing the seismicity of the region.

6.5.5 DISCUSSION OF THE RESULTS

The seismic risk evaluation should be carried out and be based on the available seismic data and the geotectonic setting of the region.

As explained above in the previous paragraphs, the seismic hazard analysis uses the methodology of applying the deterministic and probabilistic approach.

The results of the deterministic approach are used to select the maximum credible earthquake (MCE) for the project. In the absence of a detailed seismotectonic study, several assumptions about the length and movement of the faults existing in the area have to be made. In case of the Jinnah HPP in the Indus River Basin, it suggests the MCE peak ground acceleration (PGA) and peak ground velocity (PGV) as below:

Table 6.5: Results of deterministic approach for Jinnah HPP

Assoc. Source	PGA (g)	PGV (cm/s)

Generating		
Kalabagh Fault	0.40	46.55 (rock site)
Kalabagh Fault	0.40	68.86 (soil site)

The seismic parameters suggested above are based on analysis and evaluation of available data without any comprehensive field study and should be considered as a conservative approach. It is, therefore, recommended that during detailed design stage, always detailed seismotectonic studies should be carried out for a better understanding of the causes which govern the expected ground motion of the project area.

The results of the probabilistic approach are used to define the operating basis earthquakes (OBE) for the proposed project. The expected acceleration for various probabilities of exceedance as shown in Figure 6.12 and the expected peak ground velocity for various probabilities of exceedance are given in Figures 6.13 and 6.14. These results are summarized as follows:

Table 6.6: Results of probabilistic approach for Jinnah HPP

Return Period	PGV	PGV	PGA
	Soil	Rock	[Gals]
200	17	11	140
500	28	19	225
1000	38	27	300
2000	57	37	370