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ATTABAD LAKE HYDROPOWER PROJECT

FEASIBILITY STUDY

VOLUME 3

GEOLOGICAL AND GEOTECHNICAL STUDIES

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HYDRO PLANNING ORGANIZATION

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ATTABAD LAKE HYDROPOWER PROJECT
LIST OF VOLUMES

LIST OF ABBREVIATION

A

ADB	Asian Development Bank
AKCSP	Aga Khan Cultural Service Pakistan
AKDN	Aga Khan Development Network
AKF	Aga Khan Foundation
AKHS	Aga Khan Health Service
AKRSP	Aga Khan Rural Support Program
C	
CBM	Confidence-Building Measure
CBOs-	Community-based organizations
CPEC	China Pakistan Economic Corridor
DLP	Defect Liability Period
E	
EIA	Environmental Impact Assessment
EL	Elevation Level
EMMP	Environment Monitoring Management Plan
EOT	Electric Overhead Bridge Type Traveling
EPA	Environment Protection Agency
ESIA	Environmental Impact Assessment
G	
GB	GilgitBaltistan
GEF	Global Environment Facility
GHG	Green House Gases
GLOF	Glacial Lake Outburst Floods
GSP	Geological Survey of Pakistan
H	
ha	Hectare
HPO-	Hydro Planning Organization
HPP	Hydropower Project
I	
ICT-	Information and Communication Technologies
IEE	Initial Environmental Examination
IRS	Indus River System
IUCN	International Union for Conservation of Nature
K	
KKH	Karakoram Highway
KNP-	Khunjerab National Park

LIST OF ABBREVIATION

KPK-	Khyber Pakhtunkhwa
L	
LAA	Land Acquisition Act
LGO	Local Government Ordinance
M	
MASL	Meters Above Sea Level
MBT	Main Boundary Thrust
MKT	Main Karakoram Thrust
MMM	Mitigation Management Matrix
MMT	Main Mantle Thrust
MW	Mega Watt
N	
NA	Northern Areas
NCS	National Conservation Strategy
NEQS	National Environment Quality Standards
NGO	Non- Governmental Organizations
NOC	No Objection Certificate
P	
PAP	Project Implementation and Resettlement of the Affected Persons
PEPA	Pakistan Environmental Protection Act
PEPC	Pakistan Environmental Protection Council
PMAC	Program for Mountain Areas Conservation
PPC	Pakistan Penal Code
R	
RAP	Resettlement Action Plan
RNR	Renewable Natural Resources
S	
SC	Supervisory Consultants
SWHP	Surface Water Hydrology Project
T	
TOR	Terms of Reference
U	
UNDP	United Nations Development Program
V	
VO	Village Organizations
W	
WAPDA	Water and Power Development Authority

LIST OF ABBREVIATION

WCSDO	Wildlife Conservation and Social Development Organizations
WCS	Wildlife Conservation Society
WHO	World Health Organization
WUO	Water Users' Organizations
WWF	World Wide Fund

UNITS: CONVERSION FACTORS: SI TO FPS

Length	**To convert from**	**To**	**Multiply by**
	M	Ft	3.281
	Cm	Ft	0.0328
	Km	Ft	3,280.84
	M	Mi	0.0006214
	Km	Mi	0.6214
Area	m^2	ft^2	10.764
	km^2	mi^2	0.3861
	m^2	acre	0.0002471
	km^2	acre	247.105
	Hectare	acre	2.471
Volume	m^3	ft^3	35.315
	m^3	US gal	264.172
	m^3	UK gal	219.969
	L	ft^3	0.035315
	m^3	Acre Feet	0.000810714
Velocity	m/s	ft/s	3.281
	cm/s	ft/s	0.03281
	m/s	mi/h	2.237
	km/h	mi/h	0.622
Acceleration	m/s^2	ft/s^2	3.281
Mass	Kg	lb_m	2.205
	Kg	ton	0.00110
Pressure and Stress	Pa or N/m^2	psi	0.000145
Discharge	m^3/s	ft^3/s	35.315
	L/s	ft^3/s	0.035315
	m^3/s	US gal/min	15850.3
	m^3/s	UK gal/min	13198.2
	L/s	US gal/min	15.850
	L/s	UK gal/min	13.198

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1 INTRODUCTION

1.1 GENERAL

Attabad Lake Hydro Power Project (ALHPP) is proposed on Hunza River, a left tributary of Gilgit River. A large slide occurred on January 4, 2010 from right side slope of Attabad chocked the Hunza River. The total height of the slide as estimated by GSP (Geological Survey of Pakistan) was about 100 m and the blocked length of river was about 2 km that destroyed 1.3 km of Karakorum Highway (KKH) (ISSMGE Bulletin: Volume 4, Issue 3 Page 21). WAPDA Authority planned to utilize the potential of hydropower due to this lake. Firstly, Govt. of GB carried out Feasibility Study by engaging Local Consultants. The study was deficient in many aspects including geotechnical investigations, laboratory testing, layout planning, pros and cons of sliding, Neo-tectonic study and environmental issues. Therefore Govt. of GB requested WAPDA to carryout Feasibility Study again and Hydro Planning Organization (HPO), WAPDA updated the Feasibility Study.

The HPO, WAPDA entrusted to carry out the Feasibility Study of ALHPP. During the detailed analysis and investigations, it is estimated that Lake potential of 0.1MAF (125 Mm^3) can be utilized to generate about 54 MW of electricity.The coordinates of weir site are 484036.834 m E and 4018143.837 m N with mean bed elevation about 2368 m a s l **(DRW No: AFS- WR - 403)**

The proposed weir site is located about 20 km upstream of Aliabad (Central Hunza), near Attabad village, District Hunza. The site is accessible by metaled road from Gilgit, the capital of GB. From Islamabad, the site is reachable through Karakorum Highway (KKH) by covering about 750 km. It is also accessible through PIA airplane from Islamabad to Gilgit and there on to Hunza via Karakurum Highway **(DRW No: AFS- GN- 102)**. Recently PIA operated direct flights from Lahore and Karachi to Gilgit.

Geologically the site is located in Karakorum Block further north of Main Karakorum Thrust (MKT). The Karakorum Block consists of Sedimentary, Metasedimentary, Igneous as well as Metamorphic rock, throughout its extension from Karakorum Fault in the east, Chaman and Herat Fault in west (Zanchi 1993) ranging in age from Precambrian to Cretaceous. The overburden material, consist mainly of Angular Boulder Gravel with Sand and appreciable amount of fines (ABGM) and Rounded Boulder Gravels with Sand and appreciable amount of fines (RBGM). The talus deposits are main constituents of ABGM and well developed mostly in Shamshal valley and along Hunza River in upstream reaches. There are many evidences (the deposition of clayey silt along both banks of Hunza River) along the road indicate that river might have chocked many times in recent past. Prior to Attabad slide, the slope failure occurred at Salamanabad in 1958 and chocked the Hunza River.

The topography and geological conditions present in this valley indicates that it is glacial originated valley modified later on by river system. There are many glaciers that feed the Hunza River, from south to north i.e. Hassanabad, Gulmit , Gulkin, Passu and Batura Glaciers, from right side and Shamshal Valley Glacier from left side. Morphologically the valley is lithological as well as structurally controlled. Weak lithology i.e. slates as well as fault system attribute for the development of present shape of the Hunza valley in upper reaches and near MKT.

This report is mainly based on the annotations observed during geotechnical investigations carried out at ALHPP. The geological and geotechnical investigations include Surface Geological Mapping, Drilling and Test pits at weir site, sediment flushing channel/under sluice, headrace tunnel and powerhouse area, and identification of borrow area for construction material. Samples collected during geotechnical investigations have been tested to ascertain geotechnical properties at Central Material Testing Laboratory (CMTL), Lahore.

1.2 SCOPE OF WORK

During the Feasibility Study of ALHPP, HPO, WAPDA, has identified the deficiencies of geotechnical investigations in pervious Feasibility Study (FS) and carried out detailed geotechnical investigations for comprehensive FS at present. The layout plan was completely changed during present FS and investigation were conducted according to new layout. One of most important aspect is Neo-tectonic studies, because this area is affected by Attabad Slide in 2010. It is very important for the development of hydropower project in this area to develop the understanding of Neo-tectonic setting operating under regional tectonic forces for the stability and planning of the hydropower project. All the geotechnical data procured during geotechnical investigations have been utilized for foundation evaluation of all the structures of ALHPP.

1.3 OBJECTIVES

Main objectives are:

- Evaluation of the surface condition of rock mass i.e. shearing, fracturing, jointing, faulting, appropriately during surface geological mapping.
- To investigate the subsurface geological conditions by drilling at weir, sediment flushing channel/undersluice, tunnel and powerhouse area.
- Test pits have been carried out to explore the shallow subsurface conditions of different project structures.
- Core samples from different boreholes, selected and sent to CMTL to conduct testing, for design of different structures.
- Identification of borrow area for coarse as well as for fine aggregate. Samples from these areas were collected and sent to laboratory to carry out different tests for their suitability for construction as well as for rip rap material.

1.4 METHODOLOGY

These include:

- Collection of previous research on regional as well as on local geology, geomorphology and tectonics of Project Area.
- In-depth studies on GT sheets of the area after enlargement at scale of 1:10,000.
- Detailed topographical survey at scale of 1:1000 to study all the aspects of slided mass and slope area along both banks of the Hunza River.
- Detailed geological map of the Project Site using plane table , brunton compass, long range Topcon Total Station, used to mark the contacts among different lithological units as well as different soil units at geological map.

- During field visit keen concentration has been given to characterize the kinematics of fault where possible e.g. sense of fault (Strike and Dip), alignment and type of fault, dip direction and other associated characteristics.
- Total 400 m drilling consist of 6 boreholes have been drilled at weir site, sediment flushing channel/undersluice, tunnel and powerhouse area to observe the subsurface conditions. Drilling activity was executed by Drilling and Investigation Division (DID) of Hydro Planning Organization, WAPDA with Longyear as well as Acker Drilling rigs, from September to December 2020.
  - A total 10 test pits were excavated to explore the shallow subsurface conditions. Composite samples have been collected and sent to CMTL for testing.
  - Borrow areas for fine as well as for coarse aggregate has been identified. Samples from these areas have been collected and sent to laboratory for different testing, to check their suitability for construction work.

2 REGIONAL GEOLOGY

2.1 GENERAL

Information and data relating to regional geology of Project Area is taken from already published literature and research papers. The catchment area lies in Karakorum Block (KB) where snow covered peaks are quite common. The geological features in 40 km upstream and 50 km downstream of the Project Area have been studied in detail. In the Project Area many neo-tectonic features have been observed/recorded in the recent deposits which indicate that the regional tectonic forces are operating there.

The Project Area lies in the KB bounded in north by Central Pamir through Rushan Pshart Suture, in east by Karakorum Fault, in the west by Herat Fault and in south by Kohistan Island Arc (KIA) through Main Karakorum Thrust (MKT) (Pashkov & Shvol'man, 1979 & 1981). The KB have classified as a part of Gondwana land in pre-collision history. The rocks of KB have stratigraphic association with rocks of Indian Plate as indicated by Paleozoic to Mesozoic sequence of both plates. It is likely to be considered that Karakorum Micro Plate and Indian Plate were united till Mesozoic Era.

The stratigraphic sequence of the Karakorum Plate is metamorphic equivalent of Sedimentary Rock in Indian Plate shows that both plates have pre-collision similarities. Also the Karakorum Plate consists of sedimentary (well exposed is in Chitral along Mastuj River), Ignoeus rocks (Karakorum Batholith) and Metamorphic rock (slates, schist and marbles).

The rocks of KB include a thick sedimentary cover, which is mainly Paleozoic in the western termination and Permian to Cretaceous in the central and eastern area. In the Hunza valley, the cover consists of a thick pile of Permian-Cretaceous sediments cropping out north of the Karakorum Axial Batholith (KAB). It separates the sedimentary cover to the north, named North Karakorum terrain by Searl (1991), from high to low grade metamorphic present south of the KAB just north of the MKT.

2.2 STRATIGRAPHIC SEQUENCE

The area under study mostly includes part of the Northern Karakorum Terrain, which comprises intensively folded and thrusted sedimentary rocks with a very low metamorphic imprint, locally reaching low grade conditions (Zanchi,1993). The Lower Permian to Upper Cretaceous succession of the North Karakorum represents one of the few terrains which escaped strong metamorphism during the Indian-Eurasian collision, thus permitted a detailed reconstruction of its stratigraphic framework **(DWG No: AFS-GE-291).** Plutonic bodies mainly of mid-Cretaceous age intruded the sedimentary cover forming a discontinuous granitic belt developed about 100 km north of the KAB. Four main tectonic units have recognized in the Project Region (Gaetani et all., 1990). These include;

- Misgar Unit
- Sost Unit

- Gojal Unit
- Karakorum Axial Batholith (KAB)

The brief description of these units are given below;

2.2.1 Misgar Unit

This unit consists mostly of slates, with few intercalations of metacarbonate quartzite and black terrigenous slates, mostly exposed at the Northern part of the Project Area. In some areas, its thickness increases upto thousand meter. It is strongly folded with intensive development of slaty cleavage. The fold axes generally trend E-W upto the Khunjerab Pass, where they turn to NNW-SSE. The unit has low grade metamorphism indicated by chlorite, biotite, and muscovite. This unit is intruded by granitoide pluton in northern and eastern terrain having western extension upto Sost. This unit belongs to different stratigraphic formations of Paleozoic age.

The southern boundary of Misgar Unit is faulted with south vergent thrust plane, the northern fault stacking the Misgar Slate over Jurassic limestone and sandstones of Sost belt (Gaetani et al. 1990). Large recumbent folds present along the northern flank of the Chapursan valley suggest southward movement of Misgar Unit.

2.2.2 Sost Unit

It consists of grey to dark grey slates, meta-limestone, and quartzite. At places, it has dolomitic patches (Gojal Formation). Some sandstone beds with slate intercalations overlain by argillaceous limestone (Gircha Formation). Some sandstone, siltstone limestone and dolomites of Lupghar Formation, Panjshah Formation, Lashkargaz Formation of middle to late Permian age.

It comprises thick pile of folded and thrusted sheets forming in the whole antiformal stack, later disrupted by strike-slip faults. The unit is bounded by two major faults, the Upper Hunza Fault (Desio, 1979) to the south-east and the Northern Fault to the north. Complexity of the tectonic pattern often prevented the reconstruction of continuous stratigraphic successions, as in the Middle Late Jurassic sediments. Fold axes and fault striations along the main thrust surface generally indicate a N-S compression. The well-developed schistosity is defined by sericite, muscovite and fine grained biotite with occasional occurrence of epidote and chloritoid. This suggests that low grade condition of metamorphism with an important increase of temperature with respect to other thrust sheets of the Sost Unit. These shear zones are still poorly understood and may possibly be related to the eastward prosecution of Hunza Fault juxtaposing the Gircha Slates of Gojal Unit to analogues metasediments of Sost Unit. The stratigraphic succession present in the Sost Unit spans from Permian to Late Cretaceous.

2.2.3 Gojal Unit

This tectonostratigraphic unit was defined by Gaetani et al. (1990) and includes the sediments lying between the Karakorum Axial batholith and the Upper Hunza Fault (UHP). It is composed of two units, a terrigenous unit (Passu Slates) below and a calcerous-dolomitic unit above. In the lower Shamshal valley, dolomitic marbles terminate along a subvertical NS trending fault while southward this unit is intruded by KAB. Contact metapelites generally undeformed or poorly deformed intrusive that grades into biotite, muscovite, and andalusite. Folds within the unit trend from NW-SE to NNW-SSE and are generally NE-facing. Thrust planes show the same trends and are NE-vergent, as in case of UHF.

2.2.4 Karakorum Axial Batholith (KAB)

The KAB crops out along the southern part of the study area, where two major plutonic complexes were recognized, the Hunza and Batura Units (Debon et al., 1987). The Hunza Unit consists in a huge plutonic unit extending for more than 250km, made up of medium grained granodioritic in composition, locally recrystallized. They represent a calc-alkaline association. Mafic enclaves of various sizes are abundant and a conspicuous network of Cenozoic leucocratic dykes is locally present.

The Batura Unit intrusive, spanning in age from Paleocene to Eocene, is mostly new, as well as the findings of plutonic bodies belonging to this unit in Upper Chapursan valley. The Batura Unit includes two main intrusives; The Kuk and Sarbzea Plutons.

The Kuk Pluton consists in pinkish, un-deformed and un-foliated granitoides of various grain size, locally with porphyritic, microgranular and rapakivi textures. The Sarbzea Pluton mainly differs from the Kuk Pluton by its very coarse to medium grained rocks, sometimes deformed.

2.2.5 Ganesh Formation

This Formation consists of pelite-psammite turbidite unit and overlying calc-pelite marble unit and are intercalated with each other. These units are metamorphosed up to upper amphibolite facies and therefore have well developed sheets of amphibolite. The Formation has well developed ruby and spinal. Different mines are also established in this unit as can be observed along road near Ganesh Bridge.

2.2.6 Hassanabad Granite

It is well exposed in the Lower Hunza valley and consists mainly of lower s-type granitoid-migmatite complex with metasedimentary enclaves. These garnet-tourmaline bearing two mica granitoids and migmatites are well exposed in Hasanabad Nullah and in Hunza valley along Hunza River.

2.2.7 Chalt Formation:

It consists of dark grey quartz biotite schist with subordinate quartz, marble and conglomerate. It is exposed along overturned anticline and faulted against Dumordo Formation. Permo-Carboniferous age is assigned to this Formation.

2.3 REGIONAL TECTONICS

Before the northward flight of the Indian Plate, small continental pieces (Cimmerids, i.e. Karakorum, Helmad , Hasha ocks etc) were broken up from the northern edge of Gondwana and welded with the southern edge of Eurasian Plate, consuming the old Tethey and opening the Neo Tethey, (Tapponnier, 1975, 1977; Molnar, 1977a).

In general, due to the subduction of the oceanic part of the Indian Plate beneath the Eurasian Plate, the Island Arc emerged in Middle Cretaceous age. The Arc Complex consists of Calc-Alkaline Plutonic Rocks mainly mafic in nature. The presence of Blue Schist Metamorphism in Swat and Shangla Area indicates the trench environment.

The collision of the Indian and Asian Plates has been described as a “head on” north-south collision (Shackleton and Ries, 1984). This is generally accepted by many workers to have occurred in Eocene times (55-40 Ma) (Powell, 1979; Klootwijk et al, 1979; Dewery et al, 1988; Treloar and Coward, 1991; Serrle et al, 1987, 1988). The terminal collision between Indian and Asian Plates is suggested to have occurred between 45-40 Ma (Molnar and Tapponnier, 1975; Klootwijk et al, 1985). It is generally agreed however, that by 55 Ma, the Kohistan Island Arc was already sutured to the Asian Plate, probably since the Late Cretaceous, forming the MKT Zone. This is confirmed by the presence of 85-80 Ma thermal event at this time (Treloar and Rex, 1990).

The rocks of Shyok Suture Zone are interpreted to represent the tectonised remainder of a marginal basin. The closure of the marginal basin occurred at the Eocene-Oligocene time boundary, and crustal shortening was responsible for generation of Neogene 2-mica granites of the Karakorum Plutonic complex and regional metamorphism of the Pangong Tso Group (V.C Thakur, D.K. Misra, 2007).

The collision between the Indian Plate and Kohistan Island Arc is recognized as when the Tethyan Ocean disappeared and the continental masses docked. Following features recognize the main arguments for the Eocene age of collision: -

- Sediments deposited on the northern margin of the Indian Plate being of Eocene age.
- Subduction of the oceanic crust stopping, as recognized by the end of calc-alkaline magnetism north of the Indus Suture.
- The blue schist facies are not developed along MKT zone showing the collisional belt.
- Slowing down of the Indian Plate motion, as recognized by magnetic anomalies.
- After collision, continued suturing occurred, associated with a 35˚ anticlockwise rotation of the Indian Plate relative to Eurasia. As a result of collision mighty mountain ranges of Himalayas were developed having Island Arc Sequence in the north.

There are some topographic observations about the Himalayas that were immediately noticeable:

- The general curvature of the mountain chain.
- The mass of high land behind the mountain belt (Tibetan Plateau)
- The lineament of the high peaks confined in a rather smaller area.

This seemingly simplified chain becomes very disturbed, with a complete loss of these features in the Northern Himalaya. The general curving of the Higher Himalayan Peaks and the suture around angles of some 180˚, is related to the structural anomalies that are present in Northwestern Himalaya: i.e. the syntaxes (Nanga Parbat Syntaxis, Hazara-Kashmir Syntaxis etc). These are absent in Central Himalaya. This shows that the collision between two Plates is not a simpler phenomenon but there was a much greater extent of deformation to which the collision was accommodated. The accommodation was not constant, but suggested to be partitioned with different mechanisms occurring in different places of the orogenic belt.

Anticlock wise rotation of Mega Lhasa followed the Late Triassic docking of the Iranian Spur, using the later as pivot. The rotation was completed during the Middle Jurassic, when SE Pamir, Shaksgam and Karakorum joined the Qiangtang, more closely assembling Mega Lhasa as it approached the Asian margin (Maurizio Gaetani, 2007). The KB bounded in the east by Karakorum Fault, in the north by Rushan- Pshart Suture, in the west by Herat Fault and in south by Main MKT.

Structurally the KB is characterized by broad asymmetrical to tight, isoclinal folds which are commonly imbricated. A number of large regional scale thrust faults, e, g. the Tirchmir Fault, Reshun Fault, Baltit Fault, UHF, and Chapursan Fault and the MKT extends for a distance upto 100 km or more. The KB has undergone multiple deformation since the Cambrian. Parts of the KB have undergone at least four more deformations since the Kohistan-Karakorum collision from Paleocene to Pliocene.

After the collision, due to further northward subduction of the Indian Plate, still active 45mm/yr, the stresses were accommodated by the imbricate thrust faults from north to south (Treloar et al, 1989). The collisional history along with metamorphic events, trapped many clues between these fault systems. These are very useful to delineate the historic events and to unravel the movement of Indian Plate, collisional environment and modern deformational style.

2.4 REGIONAL FAULTS

The major regional faults of the region include, from north to south, the MKT, Main Mantle Thrust (MMT), Panjal Thrust (PT), Main Central Thrust (MCT), Main Boundary Thrust (MBT), Kashmir Boundary Thrust (KBT) / Himalayan Frontal Thrust (HFT) and Salt Range Thrust (SRT) **(DWG No: AFS-GE-292).**

Along with these regional faults, many local faults were developed to accommodate the regional stresses; these may be thrust fault or strike slip fault in nature. In most of the area many small scale strike slip faults are associated with the thrust faults to accommodate the deformation.

The general trend of these faults excluding MKT is predominantly east-west with change in trend due to syntaxial bends. The general descriptions of these major faults are given as follows: -

2.4.1 Karakorum Fault

Dextral Strike Slip fault of about 800 Km long bounds Western Tibet. The Karakorum Fault (KF) represents a much younger terrane boundary, juxtaposing rocks of the Ladakh and Saltoro Blocks to those of Karakorum terrane. U-Pb zircon age of leuco-granites intrusion shows that it is younger than 15 Ma old. Movement on the fault displaces the sequence approximately 200-250 Km to Southeastern Tibet where the regional rock sequence can be regained (Burtman et al. 1963, Srimal 1983). It merges at the confluence defining a triple point and three blocks; the Ladakh Block to the south, Saltoro Block to the northwest, and the KB to the northeast.

A number of teleseismic events have occurred along the fault. Interpretation of seismic data from 1975 Kinnaur earthquake confirms right-lateral strike slip motion on this fault. Three events were recorded from Karakorum Fault Zone (KFZ) at the head of the Nubra valley, since 1980, recorded by portable seismic stations, established by International Karakorum Project (IKP). It is seismically an active fault.

2.4.2 Upper Hunza Fault

It is east west trending thrust fault that runs along the depression formed by the Chapursan and Upper Yarkhun valleys (Zanchi 1973, Kazmi 1979b, Gaetani ey al. 1995). In this region it runs parallel to the northern margin of the Karakorum Axial Batholith (KAB). Southeast of morkun (Upper Hunza) three teleseismic events of magnitude 5-7 and focal depth of less than 50 km have been recorded. These epicenters form a cluster very close to the mapped trace of the UHF. It means that the northern and western margins of the KAB is characterized by active zone of faulting along Upper Hunza-Reshun Fault zone.

2.4.3 Main Karakorum Thrust

The MKT is a low angle mega-shear with strike slip component, which on eastern side passes through Machlu in Hushe valley, Shigar valley, Zuhri Brook in Shyok valley and Chalt in Hunza valley extends westward through Ishkuman, Yasin and Shishi valleys **(DWG No: AFS-GE-292).**. Its general trend swings between east and - east-northeast at low to medium dips towards the north. It is believed that this Fault is seismically active.

2.4.4 Main Mantle Thrust

The MMT, which is aligned with the Nanga Parbat-Haramosh tectonic line on east, span an area of about 400 km through Diamir, Kohistan, Swat, Dir and Banjaur, before entering Afghanistan **(DWG No: AFS-GE-292).** The general trend of MMT is NE-SW. It is located along the contact of the mafic/calc-alkaline meta igneous rocks and the meta-sediments belonging to the Indo-Pakistan continental mass. Along this Megashear near Jijal village on Indus River (right bank), the igneous rocks have overthrusted the meta-sediments to the south over a 10-15 km wide zone. The thrust also manifests as the broad high topography of Kohistan relative to the Hazara adjacent to the south. In addition, numerous auxiliary fractures are developed and across the thrust frequent brecciation and mylonitization are also present along the contact. It is seismically active fault.

3 SITE GEOLOGY

3.1 GENERAL

The Project Area lies in KB north of MKT. It is V-shape valley, originated by glacier and modified later on by Hunza River. It is stratigraphically as well as structurally controlled. The second highest peak of the World K-2 lies in this Range. The rock units comprise granitoides with pellite and psammite sequence ranging in age from Paleozoic to Cretaceous age.

3.2 SURFACE GEOLOGICAL MAP

The surface geological mapping has been carried out at scale of 1:1000, consists of 16 topo-sheets prepared by Survey Division Peshawar, HPO, WAPDA. During the site visit at left and right side of the Hunza River, different rock units have been studied and marked on the map and presented as drawing **(DWG No: AFS-GE-293 to 312).** Different geological units marked on map are summarized below:

3.2.1 Lithological Units

3.2.1.1 Soil Units

The recent deposits are the most widely spread soil units overlies the bed rocks. The slopes are covered with overburden having variable thickness. Terrace deposits comprise mixtures of clay, sandy silt, boulders and gravel in various proportions. These units are mostly present in Aliabad, Karimabad, Nagar and Gojal **(DWG No: AFS-GE-293 to 312).**

The soil units present in the Project Area are described below: -

3.2.1.1.1 Angular Boulder Gravels with Sand and Appreciable Amount of Fines (ABGM)

Most of the slopes are covered by material comprising of ABGM. This is colluvial material broken from the rock units rolled down slope and settled at the foothill or along the slopes.

These deposits are mainly associated with crushed/brecciated rock units, originated/caused by brittle deformation due to faulting/shearing at both sides. It has modified by erosion/weathering and accumulated as ABGM at foothills, forming active slides, along both side slopes.

3.2.1.1.2 Rounded Boulder Gravels with Sand and Appreciable Amount of Fines (RBGM)

River bed is mainly occupied by RBGM material. Some exposure is also present at power house site near old Chinese Camp and Helipad Area. Due to formation of lake, the bed of the River is mostly covered with silt and sand extends up to Shishkat Bridge.

3.2.1.1.3 Terrace Deposits

Terrace Deposits consist mainly of mixture of clay, silt, sand and gravels with occasional boulders. These are mostly developed in loose material (RBGM, ABGM, Morainic and Breccia) **(DWG No: AFS-GE-302,305 & 309)** in all villages, depending upon the availability of water. Most of the irrigation water channels are coming from glaciers. In Central Hunza (Hyderabad, Aliabad and Karimabad) water coming from Ultar and Hassanabad Glaciers. Similarly, from Gulmit and Passu Glacier. The Terrace Deposits are excavated to fulfil requirement for irrigation water from the melting of these glaciers.

3.2.1.1.4 Morainic Deposits

It consists mainly of material ranging in size from large boulders to clay size particles, angular to sub-angular, elongated and have flat surface **(DWG No: AFS-GE-299 & 302).** The direction of elongation indicates the route of advancement of glacier. These are well exposed throughout the valley.

3.2.1.2 Rock Units

The main rock units exposed in Project Area explored during Neo-tectonic Studies are as follows:

- Granitic gneiss
- Granodiorite
- Passu Slates
- Marbles

It is 70 to 120 km wide and 1400 km long structural zone comprises the Karakorum crustal plate which is one of the fragment of Cimmerian Collage derived from Gondwanaland and accerated to Eurasia. The stratigraphic history of the Karakorum is similar as that of Himalaya up to Cretaceous. The Project Site mostly present in the KAB consist of igneous and metamorphic rocks.

The brief description of the rock units is given below;

3.2.1.2.1 Granitic Gneiss

It is light grey to grey in color on fresh surface and weathers to light brown, coarse to very coarse grained, moderately to highly jointed, highly sheared up to higher elevation due to faulting, sparsely to moderately weathered, moderately hard to hard. It has well developed foliation with trending value N61ºW and plunging value 79ºNE. It is exposed at the right as well as at the left bank of the Hunza River. Some shear zones are also present within the unit **(DWG No: AFS-GE-293 to 312).**

On the basis of petrographic analysis, it is evident that the major constituents' minerals present in Granitic Gneiss are Quartz, oligoclase, biotite while amphibole, chlorite, muscovite, epidote, and tourmaline are present as minor constituent minerals. The high percentage of quartz grains show strong strain extinction, indicating that this unit has Alkali Silica Reaction (ASR) potential.

The rock may therefore not be used as a coarse aggregate with Ordinary Portland Cement (OPC) or High Alkali Cement. It may be used with low alkali cement, fly ash, pozzolan. Some chemical additives like lithium nitrate or silica fume can also be used to control this reaction. The Schmidt Hammer values ranges from **35** to **45 MPa** indicating that rock is moderately strong to very strong. But in some shear zone where rock is tectonized locally; this value reduces upto **18-22 MPa**.

3.2.1.2.2 Granodiorite

It is dark grey to blackish grey in color, weathers to brownish grey, medium to coarse grained, moderately weathered, moderately hard to hard, moderately jointed intruded by pegmatite and granitic gneiss. It is foliated with trend and plunge values of N60ºW/79ºNE. Further downstream it becomes light grey to grey in color, coarse to very coarse grained. It is crushed, mylonized, and sheared at places. It is well exposed at both banks where it is intruded by many pegmatite dykes. Some shear zones are also present in this unit.

On the basis of petrographic analysis, it is evident that granodiorite is quite dominate in the Project Area. The major constituents' minerals present in this unit are plagioclase, quartz, biotite, and amphibole while Iron, muscovite, chlorite, and epidote are minor constituents. The high percentage of Quartz grains show strong strain extinction, indicating that this unit has Alkali Silica Reaction (ASR) potential. The rock may therefore not be used as an aggregate with Ordinary Portland Cement (OPC) or High Alkali Cement or it may be used with low alkali cement, slag, fly ash, pozzolana. Some chemical additives like lithium nitrate or silica fume can also be used to control this reaction.

3.3 GEOLOGICAL STRUCTURES

The Project Area tectonically lies in KB . These units have undergone Karakorum as well as Himalayan Orogeny. The whole area has undergone/modified by two major fault systems MKT and Karakorum Strike Slip Fault (KSSF). The MKT system which accommodated southward thrusting. Karakorum Fault 800 km long dextral strike-slip fault that bounds western Tibet, extending from the Pamirs to Gar Basin. As the Project Area has undergone multiple episodes of tectonics events, many regional as well as local faults and their splays have formed as discussed below.

3.3.1 Faults

Many thrust fault system related to regional faults are present in the Project Area. There are many faults present in the vicinity of proposed ALHPP **(DWG No: AFS-GE-293 to 312).** These faults are splays of MKT and KSSF, and lies in between these two fault systems. These include:

- Batura Glacier- Hussaini Fault
- Borith Lake-Shamshal Nullah Fault
- Shishkat- Gulkin Glacier Fault
- Attabad -Hispar Valley Fault
- Central Hunza/Nagar- Chalt Fault

- Hassanabad Nullah Fault
- Hunza River-Nagar Fault

All these faults have been marked on the GT sheets and presented as **(DWG No: AFS-GE-318 to 320)**. The dip and strike values of major faults have been plotted on the drawings.

Some of these faults have been observed during Surface Geological mapping and marked on geological maps **(DWG No: AFS-GE-293 to 312).** The brief description of these units are: -

3.3.1.1 Attabad-Hispar Valley Fault :

It is thrust fault striking N30°E and dipping 40°SE, and is well exposed at the left side slope near the Project Area **(DWG No: AFS-GE-293 to 312).** This fault crosses the Hunza River and forming a junction point with Hunza River and Attabad Fault in Attabad village. The whole rock mostly granitic gneiss along its alignment is sheared / brecciated, forming fault breccia at many places. Due to high degree of shearing, many active slides have been originated along the whole slope. Rolling down of large boulder is quite common, and can be seen on old KKH. The retaining wall along this slide is fractured/jointed into parts due to operational stresses and downslope load movement. The ABGM along the slope is folded. It is clear indication that this fault has some movement, and is seismically active.

3.3.1.2 Attabad Fault:

This Thrust Fault is striking N60°W and dipping 52°NE, exposed in area rear of Attabad village. It is small scale fault and terminates along junction point of three faults. A large brecciated and sheared rock is present along this Thrust Fault. At the junction point of these faults **(DWG No: AFS-GE-293 to 312)** a large slide originated and destroyed about 2 Km of KKH. Sheared and brecciated rock can be seen on outcrop at right side slope up to higher elevation.

3.3.1.3 Attabad River Fault:

The exposure of this fault is present at right side slope of Hunza River. The breccia is well exposed at right side, just downstream of Sarat Suspension Bridge. The intensity of brecciation increases towards Salamanabad village. In fact, Salamanabad village is established on this breccia. It may be present up to higher elevation **(DWG No: AFS-GE-293 to 312).**

4 GEOLOGICAL & GEOTECHNICAL INVESTIGATIONS

4.1 SURFACE INVESTIGATIONS

The surface investigations / observations are one of the most important tools to reveal the geological conditions prevailing at the site. The natural processes operating on surface left clues to reveal the environments persisting in ancient time. Surface geological mapping is one of the best tool to check the geological conditions existing at site and to explore the deformation for the assessment of rock condition during the Feasibility Study.

4.1.1 Surface Geological Mapping

The Surface geological mapping of the Project Area has been carried out on 16 topographic sheets prepared by Survey Division Peshawar, HPO, WAPDA on scale 1:1000 with contour interval of 2 m, with the help of Total Station, Plane Table and Brunton compass and presented at scale of 1:2000 **(DWG No: AFS-GE-293 to 312).**The contacts between different rock units e,g granitic gneiss and granodiorite as well as between different soil units have been marked. Structural features like joint sets, faults, foliation and shear zones along with dip and strike values have been marked on these sheets.

Four geological cross sections were prepared along different alignments including, weir site, power tunnel intake area, penstock alignment & powerhouse area.

Photo 4-1 Surface Geological Mapping

4.1.2 Neo-tectonics Study

During the study of ALHPP, HPO, WAPDA, has identified the importance of Neo-tectonic studies, of this area being affected by Attabad slide in 2010. It is very important for the development of hydropower project in this area to develop the understanding of the Neo-tectonic setting operating under regional tectonic forces for the stability and planning of the hydropower project. All the geotechnical data procured during geotechnical investigations were utilized for foundation evaluation of weir, sediment flushing channel/ undersluices and power house.

The area under study has covered by the 2 GT sheets 42 L/15 and 42 L/11 at scale of 1:50,000, covering 40 km upstream and 50 km downstream of slided mass. These GT sheets were enlarged and printed at a scale of 1:15000 and presented at scale of 1:40,000, and used in field for alignment of local as well as regional faults **(DWG No: AFS-GE-318 to 320).**.

4.2 SUBSURFACE INVESTIGATIONS

Sub-surface geological and geotechnical investigation program was prepared to probe the sub-surface foundation conditions at weir, sediment flushing channel/ under sluices and power house including borehole drilling and test pits excavation. Drilling of exploratory bore holes was executed by Drilling Division, Hydroplaning, and supervised by Directorate of Geology, Hydro Planning WAPDA, Lahore.

4.2.1 Drilling

The main objective of drilling was to determine the nature and engineering characteristics of soil and rock units at weir sediment flushing channel/ undersluices and power house. It was performed to observe the subsurface geological conditions at depth in order to find out nature of the different strata in subsurface, to estimate the behavior and nature of overburden material, the depth of water table encountered. The bearing capacity of the soil, “N” values were obtained by performing Standard Penetration Test (SPT) in soil, determine depth to bed rock. To assess the f conductivity, insitu permeability test in overburden and water pressure test (Lugeon) in rock have been carried out.

A total 06 bore holes with total drilling of 401m have been drilled for subsurface exploration at different structures. **(DWG No: AFS-GE-316).** The coordinates, structure, and depths of borehole are given in **Table 4.1 & 4.2**

Table 4-1 Co-ordinates of Boreholes

Sr. No	Borehole	Northing	Easting	Elevation (masl)
1	BH-1	4018100.45	484075.46	2415.79
2	BH-2	4017996.26	484089.59	2452.81
3	BH-3	4018061.58	483541.73	2456.92
4	BH-4	4017721.34	482609.57	2445.37
5	BH-5	4017906.94	481690.72	2318.04
6	BH-6	4017906.55	481605.02	2313.84

Table 4-2 Location of Boreholes

Sr. No.	Borehole	Depth (m)	Location
1	BH-1	90	Weir Site (Left abutment)
2	BH-2	60	Sediment Flushing Channel
3	BH-3	61	Sediment Flushing Channel
4	BH-4	80	Power Tunnel Alignment
5	BH-5	50	Power House Area
6	BH-6	60	Power House Area

Photo 4-2 Drilling Rig at BH-02 Sediment Flushing Channel .

For foundation evaluation of different structures, bore holes of varying depths have been drilled accordingly to estimated geological conditions prevailing in subsurface. Permeability tests have been performed using constant head method in overburden material at 3 m interval whereas water pressure tests (Lugeon tests) in bed rock have been performed at interval of 5 m or at change of strata. Rock cores and soil samples have been collected from all the bore holes at various depths for lab testing. All the tests have been conducted at CMTL, WAPDA Lahore. The logs of bore holes at different structures have been prepared. Permeability values in overburden material and lugeon values in rock have been calculated.

4.2.1.1 Standard Penetration Tests (SPT)

SPT has been carried out in boreholes in overburden which mainly consists of silty sand with clay intercalations. Split spoon samplers have been used to collect the samples. The material encountered in SPT sampler mainly consists of clayey silt. SPT relied upon to provide information about the properties of soils / weak rocks. The principal use of the SPT is to examine, i.e., subsurface investigation profile, soil classification, the determination of geotechnical design parameters estimating liquefaction potential of soils. In foundation designs, SPT in overburden material, blow counts (N Values) are typically used to estimate nature and strength properties of soils used to calculate the bearing capacity for foundation. The results are presented in bore hole logs **Volume 4A**.

4.2.1.2 Cone Penetration Test (CPT)

CPT have been carried out in boreholes in gravelly Silty Sand with Clay intercalations. CPT relied upon to provide information about the properties of soils / weak rocks. The principal use of the CPT is to examine geotechnical design parameters, estimating liquefaction potential of soils. In foundation designs, CPT blow counts are typically used to estimate nature and strength properties of soils, used to calculate the bearing capacity for foundation evaluation.

4.2.2 Test Pits

A total of 10.test pits (3 m×3 m ×3 m) have been excavated in overburden material at weir site, slope along sediment flushing channel and power house area. Composite samples by cone and quarter method have been collected from each test pit. Different tests have been conducted on these samples to estimate the engineering properties of material.

To identify and proven source for coarse as well as fine aggregate, 4 test pits have been excavated. Samples collected from these pits were sent to CMTL, WAPDA, Lahore for testing to check their suitability for fine as well as coarse aggregate. The logs of test pits have been prepared and presented in **Volume 4A.**

4.2.3 Laboratory Testing

To investigate the engineering properties of rock and overburden material different rock cores and soil samples at weir, sediment flushing channel / under sluices and power house site have been sent to CMTL Lahore.

A total of 10 rock core samples from BH-04 (Power tunnel alignment)have been selected for evaluation of geotechnical engineering parameters for design purpose **(Table 4.3)**. The table below shows the testing program proposed in BH-04 at different depths.

A total of 15 samples, i.e. 3 block sample, 3 samples from borrow area, and 9 test pit samples have been selected for investigations. Samples from all tests pits have been selected by cone and quarter method and different test given in **(Table 4.4),** have been proposed to check their engineering properties and confirm their suitability as aggregate material.

All the laboratory tests on rock core samples have been conducted in CMTL WAPDA, Lahore. The detailed results are presented in laboratory testing **Volume 4B.**

Table 4-3 Proposed Laboratory Test on Rock Core Samples

Sr.No	Borehole No.	Location	Sample Name	Depth (m)	Sample length (cm)	Index Properties Test	Point Load Test	Hoek Triaxial Compression Test	Uniaxial Compressive Strength test	Indirect Tensile Strength	Rock Core Modulus	Hoek Direct Shear	Petrographic Analysis
1	BH-04	Head Race Tunnel	ALHPPBH4-01	21.00-21.15	15		√						
2			ALHPPBH4-02	31.21-31.52	31		√						
3			ALHPPBH4-03	38.14-38.43	29	√			√				
4			ALHPPBH4-04	43.25-43.55	30	√	√			√			
5			ALHPPBH4-05	48.00-48.25	25						√		
6			ALHPPBH4-06	52.60-53.00	40	√		√					
7			ALHPPBH4-07	56.00-56.39	39	√			√			√	√
8			ALHPPBH4-08	61.00-61.24	24						√		
9			ALHPPBH4-09	63.00-63.35	35	√		√					
10			ALHPPBH4-10	68.00-68.23	23	√			√				

Table 4-4 Lab Testing On Test Pits Samples and Borrow area

Sr. No	TEST PIT	Depth (m)	Grain Size Analysis	Hydrometer	Unit Weight	NMC	UCS	Alkali Carbonate Reaction	Point Load Test	Rock Core Modulus	Petrographic Analysis	Specific Gravity	Flakiness	Water Absorption	Crushing Value	Los angeles Abrasion Test	Sulphate Soundness	Accelerated Motorbar	Atterberg Limits and Shrinkage Limit	Swelling Potential	Modified Proctor test	Consolidation Test	Organic Contents
1	TP-1	0.0-1.3	√									√		√									√
2	TP-2	0.0-2.0	√									√		√									√
		2.0-3.0	√	√										√					√	√	√		
3	TP-3	0.0-3.0	√	√								√		√					√	√	√		√
4	TP-4	0.0-1.5	√	√								√		√					√		√		√
		1.5-3.0	√	√								√		√					√	√			
5	TP-5	0.0-1.5	√									√		√									√
		1.5-3.0	√	√															√	√			
6	TP-6	0.0-3.0	√									√		√	√								
7	TP-7	0.0-3.0	√				√									√							
8	TP-8	0.0-3.0	√				√		√			√	√	√	√								
9	TP-9	0.0-3.0	√				√						√										
10	Block (TP-3)	1.0	√	√	√	√						√		√					√	√	√	√	
11	Block (A) TP-10	0.5	√	√	√	√						√		√					√	√	√	√	
12	Block (B) TP-10	1.5	√	√	√	√						√		√					√	√		√	
13	Passu						√	√	√	√		√	√	√	√	√	√	√					
14	P/H Area						√		√	√	√	√	√	√	√	√	√	√					
15	Slided Mass						√		√	√	√	√	√	√	√	√	√	√					

5 EVALUATION OF LABORATORY TESTS

5.1 PETROGRAPHIC ANALYSIS

A total of 06 petrographic analyses have carried out to confirm the mineral assemblage in the particular rock unit. Another important feature of petrographic analysis is to determine Alkali Silica Reaction (ASR) by estimating the percentage of deleterious mineral especially quartz grains showing strong extinction to check it suitability in concrete mix design with Ordinary Portland Cement (OPC). For this purpose, 2 samples have been collected through excavation of test pits, 2 samples from different locations have been collected during surface geological mapping, and 01 drilling core sample has been collected from power tunnel alignment. The mineral assemblage more than 5% is considered as major mineral while other with less than 5% is consider as minor minerals. The detail is given in table below: -

Table 5-1 Petrographic Analysis Results

Sr. No.	Borehole No.	Rock Name	Major Minerals					Minor Minerals					Remarks / Description
			Quartz	K-Feldspar	Oligoclase	Biotite	Amphibole	Magnetite	Chlorite	Epidote	Muscovite	Carbonate	
1	Rock Samples	Foliated Granite	24	18	17	21	1	2	2	6	7	1	ASR Potential exists
2		Granite	32	26	14	6	3	2	4	1	3	3	ASR Potential exists
3		Granodiorite	24	11	20	15	16	2	3	5	2	2	ASR Potential exists
4		Granodiorite	26	12	25	14	11	2	3	3	2	2	ASR Potential exists
5	BH-04	Granitic Gneiss	30	13	28	17	4	1	3	1	2	1	ASR Potential exists

The petrographic analysis shows that granodiorite and granitic gneiss are the major rock units exposed at the Project Site. Quartz, plagioclase, K-feldspar, amphibole and biotite are the major mineral constituents. Both rocks units show strong quartz grains extinction and are deleterious in nature. Due to this reason, these rock units cannot be used with ordinary portland cement (OPC) as coarse aggregate. It can be used with low alkali cement, slag cement or cement with additives like fly-ash, pozzoloan, and chemical additives like lithium nitrate or silica fume.

Rock samples (Marble) from Passu village area along KKH have been collected and sent to laboratory to conduct petrographic analysis. Result shows that, marble consists of 91.5% calcite, 5% dolomite, with quartz, magnetite and muscovite as minor minerals. The rock has no alkali carbonate nor alkali silica and therefore can be used as coarse aggregate with OPC.

5.2 DIRECT SHEAR TEST

One sample from BH-04 has been selected for Direct Shear Tests from depth of 56 to 56.35m. Both normal and shear stress have been applied gradually to observe the strain and displacement rate, under applied stress. The result shows that cohesion “C” has 0.595 MPa with angle of shear resistance “ϕ” is 21.8 deg.

The direct shear test results show that both values are in safe limit, indicating that rock is moderately strong to strong.

5.3 ROCK CORE MODULUS

02 core samples from BH-04 and 3 bulk samples from borrow area have been selected to carry out the Rock Core Modulus including Young's Modulus, and Modulus of Deformation, for which the mode of failure has also been observed and presented in table 5-2

Table 5-2 Rock Core Modulus Test Results

Sr. No.	Bore Hole	Location	Depth (m)		Test Results (MPa)		
			From	To	Young's Modulus	Modulus of Deformation	Mode of Failure
1	BH-04	Power Tunnel Alignment	48.0	48.25	$2.29*10^4$	$1.15*10^4$	Axial
2			61.0	61.30	$1.83*10^4$	$9.16*10^3$	Axial
3	Bulk Samples	Passu Area	-	-	$7.52*10^4$	$3.76*10^4$	Diagonal & Axial
4		Powerhouse Area	-	-	$4.16*10^4$	$2.08*10^4$	Diagonal & Axial
5		Slided Mass	-	-	$4.96*10^4$	$1.88*10^4$	Diagonal

Rock samples from BH-04 show "Axial" mode of failure while bulk samples for borrow area of coarse aggregate shows "Diagonal & Axial" mode of failure exists with relative low Poisson's Ratio. The values of Young's Modulus indicate that all the rocks encountered are moderately hard to hard. Result of borrow area shows that the Passu Area rock (Marble) show very high value with diagonal as well as axial mode of failure, this shows that marble is hardest among all samples for borrow area.

5.4 POINT LOAD STRENGTH INDEX (PLSI) TEST

A total of 7 samples, 3 from BH-4 and 4 from borrow area have been selected to carry out (PLSI) Test. The main purpose of the (PLSI) Test is to determine/calculate the strength index of rock mass. For this purpose, ASTM standard D 5731-95 has been used to carry out the (PLSI) Test. The values of these tests are given in table below: -

Table 5-3 Point Load Strength Index Test Results

Sr. No.	Bore Hole No.	Location	Depth (m)		Test Results		
			From	To	Is (Mpa)	Is 50 (Mpa)	Failure
1	BH-04	Power Tunnel Alignment	21.00	21.15	4.04	3.93	Diametrically
2			31.21	31.52	5.39	5.23	Diametrically
3			43.25	43.55	3.14	3.05	Diametrically
4	Bulk Samples	TP-08	-	-	1.81	1.66	Diametrically
5		Passu Area	-	-	4.11	4.30	Diametrically
6		Powerhouse Area	-	-	3.97	4.15	Diametrically
7		Slided Mass	-	-	5.68	5.94	Diametrically

Point Load Index value is an index of strength but not a strength value. The above table shows that all the values except 1.66 MPa (TP-08) is relatively low while all others have reasonably good values which proves that rock strength is moderately high and durable.

5.5 UNIAXIAL COMPRESSIVE STRENGTH (UCS) TEST

A total of 9 samples, 3 samples from BH-04, 3 samples from test pits, and 3 bulk samples from different borrow areas have been selected to carry out the (UCS) Test. The main purpose of the (UCS) Test is to determine the compressive strength under uniaxial load in an unconfined state. The strength is determined by using ASTM standard D-2938. The values are given in table below: -

Table 5-4 Uniaxial Compressive Strength Test Results

Sr. No.	Bore Hole / Test Pits	Location	Depth (m)		Test Results	
			From	To	UCS (MPa)	Failure Mode
1	BH-04	Power Tunnel Alignment	38.14	38.43	49.2	Diagonal
2			56.00	56.39	45.2	Diagonal
3			68.00	68.23	38.5	Diagonal
4	TP-7	Slided Mass (Left side)	-	-	52.40	Diagonal
5	TP-8	Slided Mass (Right side)	-	-	71.91	Diagonal
6	TP-9	Slided Mass (Right side)	-	-	34.63	Diagonal
7	-	Passu Area	-	-	47	Diagonal
8	-	P/H Area	-	-	88	Diagonal & Axial
9	-	Slided Mass	-	-	59	Diagonal & Axial

The rock strength given in table shows that the rock has medium strength and moderately hard.

5.6 INDIRECT TENSILE STRENGTH (ITS) TEST

(ITS) Test has been carried out on core sample collected from BH-04, at depth from 43.25 to 43.55m. A cylindrical specimen is loaded diametrically and tensile deformation perpendicular to the loading direction yields a tensile failure. ASTM standard D-3967 has been used to carry out the indirect tensile strength.

The (ITS) Test is mostly estimated as 10 to 15% of Uniaxial Compressive Strength (UCS). The lab test value is 6.46 MPa which indicates that rock is moderately hard.

5.7 HOEK TRIAXIAL COMPRESSIVE STRENGTH (HTCS) TEST

(HTCS)Test has been carried out on 2 rock core samples collected from different depths from BH-04. (HTCS) Test is used to determine the shear strength of rock samples. The test can determine that how applied stress is related to deformation experienced by rock samples as well as to determine the angle of internal friction and cohesion of the rock samples. ASTM standard D-2664 has been used to carry out the (HTCS) Test. The values are given in table below: -

Table 5-5 Hoek Triaxial Compressive Strength Test Results

Sr. No.	Borehole No.	Depth		Cohesion "C" MPa	Angle (Ø) deg.
		From	To		
1	BH-04	52.60	53.00	2.18	27.749
2		63.00	63.35	0.60	15.543

The values of cohesion "C" and angle of internal friction "ø" calculated by (HTCS)Test, given in table indicates that the shear strength of the rock core samples is low to moderate.

5.8 PROPERTY INDEX

A total of 6 rock core samples from BH-04 at different depths have been sent to CMTL, Lahore. Property index tests were conducted under ISRM standard to determine the properties of rock. The table below shows results of test on rock core samples

Table 5-6 Property Index Test (Core) Results

Sr No.	Sample	Depth		NMC (%)	Sp. Gravity	Porosity	Dry Density	Water Abs. (%)
		From	To					
1	BH-04	38.14	38.43	0.12	2.73	1.58	2.69	0.59
2		43.25	43.55	0.21	2.76	1.17	2.72	0.43
3		52.60	53.00	0.04	2.77	0.69	2.75	0.25
4		56.00	56.39	0.27	2.77	1.25	2.73	0.46
5		63.00	63.35	0.07	2.76	0.81	2.73	0.30
6		68.00	68.23	0.09	2.77	0.72	2.75	0.26

Table 5-7 Property Index Test (Test Pits) Results

Sr No.	Sample	Material	Sp. Gravity	Org. Impurities	Water Abs. (%)
1	TP-1	Fine	2.68	NIL	1.11
2	TP-2	Coarse	2.71	-	-
3		Fine	2.65	NIL	1.20
4	TP-3	Fine	2.17	NIL	-
5	TP-4	Fine (0.0-1.5m)	2.30	NIL	-
6		Fine (1.5-3.0m)	2.27	-	-
7	TP-5	Fine	2.36	NIL	-
8	TP-6	Coarse	2.67	-	-
9		Fine	2.70	-	1.04
10	TP-8	Coarse	2.72	-	-
11		Fine	2.69	-	1.12
12	Block (TP-3)	Fine	2.36	-	-
13	Block A (TP-10)	Fine	2.38	-	-
14	Block B (TP-10)	Fine	2.30	-	-
15	Passu	Coarse	2.84	-	0.37
16	P/H Area	Coarse	2.78	-	0.27
17	Slided mass	Coarse	2.75	-	0.33

The values given in table 5.7 (A&B) shows that all the values of fine and coarse aggregate fall in permissible limits besides water absorption test which shows some relative higher values with no organic impurities.

5.9 LOS ANGELES ABRASION (LAA) TEST

A total of 4 samples, from test pits, of different borrow areas have been selected to carry out the (LAA) Test. The main purpose of this test is to indicate aggregate toughness and abrasion characteristics. Aggregate abrasion characteristics are important because the constituent coarse aggregate must resist crushing, degradation and disintegration. ASTM standard C-131 is used to perform this test for 500 revolutions. The values are given in table below

Table 5-8 Los Angeles Abrasion Test Results

Sr. No.	Test Pits	Location	Test Results	
			Percentage (%) Wear	Uniformity of wear
1	TP-7	Slided Mass (Left side)	48	0.41
2	-	Passu Area (marble)	27	0.20
3	-	Power House Area	18	0.21
4	-	Slided Mass	56	0.34

(LAA) Test results indicate that, samples of Passu Area (marble) and powerhouse area show minimum wearing ability and values ranges within the permissible limits while TP-7 and samples from slided mass show high percentage of wearing.

5.10 SULPHATE SOUNDNESS TEST

A total of 03 samples, from different borrow areas have been selected to carry out the Sulphate Soundness Test. The main purpose of this test is to determine the aggregate resistance to change of volume due to change of physical condition and weathering. These physical conditions include freezing and thawing, temperature change, alternative change of drying and wetting in normal condition and alternative change of drying and wetting in salt water for 5 No. of cycles. ASTM standard C-88 is used to perform this test. The values are given in table below: -

Table 5-9 Sulphate Soundness Test Results

Sr. No.	Location	Test Results		
		% Passing Designated Sieve after Test	Weighted Percent Loss	Total
1	Passu Area	0.96	0.89	0.89
2	Power house	0.85	0.81	0.81
3	Slided Mass	1.88 & 1.78	1.69 & 0.18	1.87

Sulphate Soundness Test results indicates that, samples of Passu Area (marble) and powerhouse area show minimum loss while slided mass material shows relatively double values. Therefore, both can be used as an aggregate with concrete.

5.11 CRUSHING VALUE OF AGGREGATE

A total of 5 samples, 2 samples from test pits and 3 samples from different borrow areas have been selected to carry out crushing value of aggregate. The main purpose of this test is to determine the aggregate resistance to wear and tear. BS-812 (1990) Part 110 is used for performing this test with fraction used (3/4”-1/2”). The values are given in table below: -

Table 5-10 Crushing Value of Aggregate Test Results

Sr. No	Location	Depth	Crushing Value
1	TP-6	0.0-3.0	43
2	TP-8	0.0-3.0	NP
3	Passu Area	-	24
4	Powerhouse Area	-	27
5	Slided Mass	-	22

Table 5-10 shows that, samples of Passu area (marble), powerhouse area and slided mass fall in permissible limits while TP-6 shows relatively high value.

5.12 FLAKINESS/ELONGATION INDEX

A total of 5 samples, 2 samples from test pits and 3 samples from different borrow areas have been selected to carry out the particle shape of the aggregate specimen and each particle shape being preferred under specific condition. For cement concrete types and base coarse construction and bituminous-construction, the presentence of flaky and elongated aggregate particles are considered undesirable as they may cause inherent weakness with possibility of breaking down under heavy loads. BS-812 Part 105.1 & 105.2 is used for performing this test. The values are given in table below: -

Table 5-11 Flakiness/Elongation Index Test Results

Sr. No.	Location	Depth	Flakiness Index
1	TP-8	0.0-3.0	13
2	TP-9	0.0-3.0	04
3	Passu Area	-	22
4	Powerhouse Area	-	23
5	Slided Mass	-	21

Table 5-11 shows that, all samples fall in permissible limits.

5.13 CONSOLIDATION TEST

A total of 3 samples undisturbed box samples, from different test pits have been selected to carry out consolidation tests. The main purpose of this test is to determine the magnitude and rate of consolidation of soil when it is restrained laterally and drained axially while subjected to incremental applied controlled stress loading. ASTM Standard D-2435 is used to perform this test. The values are given in table below: -

Table 5-12 Consolidation Test Results

Sr. No	Block Sample	Moisture Contents		Bulk Density mg/cm		Dry Density mg/cm		Void Ratio "e"		Saturation (%)	
		Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
1	TP-10 (A)	9.8	27.0	1.66	1.97	1.51	1.55	0.775	0.725	33.8	99.8
2	TP-10 (B)	4.2	29.0	1.52	1.94	1.46	1.51	0.837	0.778	13.4	99.8
3	TP-3	6.9	27.7	1.54	1.96	1.44	1.54	0.866	0.744	21.5	99.7

Consolidation plays an important role in stability analysis for the embankment, footings or a column constructed on clayey soils. The settlement behavior of these structures and the pore pressure needs to be investigated for construction on these soils. Table 5-12 shows that, the clayey silt fall in permissible limits and therefore may be considered as impervious blanketing material.

5.14 SWELLING POTENTIAL, UNIT WEIGHT AND NMC

A total of 7 soil (clayey silt) samples, i.e. 3 undisturbed block samples, 4 disturbed samples from different test pits have been selected to investigate swelling potential of soil. The main purpose of this test is to determine the swelling potential when come in contact with water. The values are given in table below: -

Table 5-13 Swell Potential, Unit Weight and NMC

Sr. No	Location	Depth	Swell Potential (KPa)	Unit Weight mg/m^3	NMC (%)
1	TP-2	2.0-3.0	39.5	-	-
2	TP-3	0.0-3.0	30.0	-	-
3	TP-4	1.5-3.0	12.5	-	-
4	TP-5	1.5-3.0	31.5	-	-
5	Block (TP-3)	1.0	22.5	1.683	3.88
6	Block (TP-10) A	0.5	23.0	1.688	3.72
7	Block (TP-10) B	1.5	25.0	1.691	3.18

All the samples of clayey silt show high swelling potential irrespective of TP-4, having moderate swelling potential and needs proper attention prior to their use as fine aggregate or for the foundation while unit weight and NMC fall in permissible limits.

5.15 MODIFIED PROCTOR TEST

A total of 5 of samples, from different test pits of borrow areas have been selected to carry out Modified Proctor test. The main purpose of this test is to determine the maximum compaction at corresponding moisture content of different types of soil and the relationship between dry density and moisture content. ASTM standard D-1557 is used to carry out this test. The values are given in table below:

Table 5-14 Modified Proctor Test Results

Sr. No	Location	Depth	Max. Dry Density (mg/m^3)	O.M.C (%)
1	TP-2	2.0-3.0	1.893	13.30
2	TP-3	0.0-3.0	1.887	13.05
3	TP-4	0.0-1.5	1.783	10.54
4	Block TP-3	1.0	1.881	12.87
5	Block TP-10	0.5	1.878	12.80

Table 5-14 shows that, all the values fall in permissible limits.

5.16 ACCELERATED MORTAR BAR TEST

A total of 5 samples; 2 samples from test pits and 3 bulk samples from different borrow areas have been selected to carry out Accelerated Mortar Bar Test. The main purpose of this test is to determine the changes in volume / expansion of material, either fine or coarse when mixed with ordinary Portland Cement (OPC) and reading for 28 days. ASTM Standard C-1260 is used to conduct this test. The values are given in table below: -

Table 5-15 Accelerated Mortar Bar Test Results

Sr. No	Location	Depth	Material	Average Change (28 days)	Average Expansion (28 days)
1	TP-1	0.0-1.3	Fine aggregate	0.099	0.039
2	TP-2	0.0-2.0	Fine aggregate	0.106	0.042
3	Passu Area	-	Coarse aggregate	0.235	0.093
4	P/H Area	-	Coarse aggregate	0.251	0.099
5	Slided mass	-	Coarse aggregate	0.246	0.097

All values of coarse as well as fine aggregate fall under permissible limits and can be used as concrete aggregate with OPC.

5.17 GRAIN SIZE ANALYSIS

A total of 15 of samples, from each test pits at different depth have been selected to carry out Grain Size Analysis. The main purpose of this test is to determine the different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles. ASTM standard D-422 is used to carry out this test. The values are given in table below:

Table 5-16 Grain Size Analysis Results

Sr. No.	Test Pit	Depth (m)	Boulder %	Gravel %	Cobbles %	Sand %	Passing # 200	Silt %	Clay %
1	TP-1	0.0-1.3		0		99	1		
2	TP-2	0.0-2.0		0		76	24		
3		2.0-3.0		0		0		55	45
4	TP-3	0.0-3.0		0		0		58	42
5	TP-4	0.0-1.5		0		51		39	10
6		1.5-3.0		0		24		66	10
7	TP-5	0.0-1.5		0		48	52		
8		1.5-3.0		0		0		65	35
9	TP-6	0.0-3.0	0	56	11	12	21		
10	TP-7	0.0-3.0	0	62	11	22	5		
11	TP-8	0.0-3.0		0		72	28		
12	TP-9	0.0-3.0		0		63	37		
13	Block (TP-3)	1.0		0		1		59	40
14	Block (A) TP-10	0.5		0		0		60	40
15	Block (B) TP-10	1.5		0		0		56	44

5.18 ATTERBERG LIMITS

A total of 8 samples, from different depth of test pits have been selected to carry out Atterberg Limits. The main purpose of this test is to determine the critical water contents of a fine-grained soil, its shrinkage limit, plastic limit, and liquid limit. The Atterberg limits can be used to determine the response of soil to change in moisture content exhibiting the consistency from hard and soft to rigid and pliable, termed as plasticity. ASTM standard D-422 is used to carry out this test. The values are given in table below: -

Table 5-17 Atterberg Limits Results

Sr. No.	Test Pit No.	Depth (m)	L.L %	P.L %	P.I %	Shrinkage. Limit %
1	TP-2	2.0-3.0	43	31	12	25.2
2	TP-3	0.0-3.0	40	29	11	23.8
3	TP-4	0.0-1.5	NP	-	-	-
4		1.5-3.0	NP	-	-	-
5	TP-5	1.5-3.0	39	31	8	26.1
6	Block (TP-3)	1.0	43	33	10	27.8
7	Block (A) TP-10	0.5	45	34	11	29.1
8	Block (B) TP-10	1.5	46	34	12	28.9

6 GEOLOGY AND FOUNDATION EVALUATION

6.1 GENERAL

The rocks exposed in Project Area consists of granodiorite and granitic gneiss (ganitoide) intruded by pegmatite dykes belong to Karakorum Batholith. Most of the structures i.e. weir with overtopping spillway, sediment flushing channel, pedestals of penstock and powerhouse lie on overburden material. About 2.1 km long power tunnel is proposed at left side and will be excavated through granodiorite and granitic gneiss.

On the basis of surface geological mapping, geological x-sections, borehole logs, test pits excavation and laboratory test results, the foundation evaluation of various engineering structures proposed for Attabad Lake Hydropower Project (ALHP) have been made and describe in the following sections: -

6.2 WEIR SITE

6.2.1 Surface Geological Mapping

The surface geological mapping of the main weir area has been carried out at a scale of 1:1000 with the help of Total Station, Plane Table and Brunton Compass and presented at 1:2000 scale. A geological X-section along line AA` has been developed and presented as drawing **(DWG No: AFS-GE-313).** The main purpose to develop geological x-section is to estimate condition prevailing in subsurface i.e. overburden thickness, extension / alignment of faults, extension / trend of rock units in the subsurface.

Photo 6-1 A View of Weir Site.

An overtopping concrete weir founded on slided mass is proposed after foundation treatment. Geological rock units with which weir has to be abut, includes granodiorite, intruded by pegmatite veins at right side. On left side, weir has to be abut with ABGM formed by slided mass **(DWG No: AFS-GE-297 & 298).** Some treatment / engineering solution have to be implemented for stability of the weir **(Photo 6-1)**.

6.2.2 Boreholes Drilling at Weir Site

A borehole BH-01, has been drilled at left side slope to investigate the subsurface geological conditions. The location of the boreholes is presented on drawing **(DWG No: AFS-GE-316).** No rock has been encountered in this borehole up to 90 m. The core recovery CR (%) and permeability test results are given in **Table 6-1**, and graphically presented in **Figure 6-1**. The permeability tests were conducted after every 3 m. In most of tests, head could not be maintained due to cavities/ open works encountered in subsurface. The borehole has been stabilized with cement.

Table 6-1 Summary of BH-01 (Weir Site Left Abutment)

ATTABAD LAKE HPP											
BH-01											
Depth (m)		**CR (%)**	**K-Value (cm/sec)**	**Depth (m)**		**CR (%)**	**K-Value (cm/sec)**	**Depth (m)**		**CR (%)**	**K-Value (cm/sec)**
From	**To**			**From**	**To**			**From**	**To**		
0.5	1	0		31	32	62		61	62	54	
1	2	0		32	33	88		62	63	44	Head Failure
2	3	40		33	34	83	Head Failure	63	64	55	
3	4	39	0.046178	34	35	100		64	65	31	
4	5	78		35	36	70		65	66	32	Head Failure
5	6	60		36	37	78	Head Failure	66	67	44	
6	7	17	Head Failure	37	38	58		67	68	45	
7	8	40		38	39	69		68	69	88	
8	9	29		39	40	45		69	70	61	Head Failure
9	10	31	Head Failure	40	41	46	Head Failure	70	71	56	
10	11	30		41	42	45		71	72	53	
11	12	32		42	43	53		72	73	65	Head Failure
12	13	12	Head Failure	43	44	68	Head Failure	73	74	65	
13	14	42		44	45	81		74	75	77	
14	15	90		45	46	56		75	76	87	Head Failure
15	16	49	0.002858	46	47	89	Head Failure	76	78	87	
16	17	43		47	48	65		78	79	64	Head Failure
17	18	16		48	49	58		79	80	37	
18	19	96	0.012294	49	50	63	Head Failure	80	81	89	
19	20	100		50	51	66		81	82	57	Head Failure
20	22	90		51	52	33		82	83	32	
22	23	65		52	53	28	Head Failure	83	84	45	
23	25	98	Head Failure	53	54	58		84	85	38	Head Failure
25	26	33		54	55	56		85	86	56	
26	27	45		55	56	100		86	87	66	
27	28	35	Head Failure	56	57	47	Head Failure	87	88	59	
28	29	55		57	58	50		88	89	55	Head Failure
29	30	99		58	59	23		89	90	59	
30	31	100	Head Failure	59	60	53	Head Failure	**End of Borehole.**			

PERMEABILITY TEST IN OVERBURDEN	
K (cm/sec) <10^{-6}	Impervious
K (cm/sec) 10^{-6} to 10^{-4}	Semi-pervious
K (cm/sec) >10^{-4}	Pervious

PERMEABILITY TEST (Lugeon) IN ROCK	
0 to 5	Low Permeable
5 to 15	Slightly Permeable
15 to 25	Permeable
>25	High Permeable

On the basis of drilling borehole log, a graph is developed between CR (%) Vs Depth (m), and is presented as **Figure 6-1.**

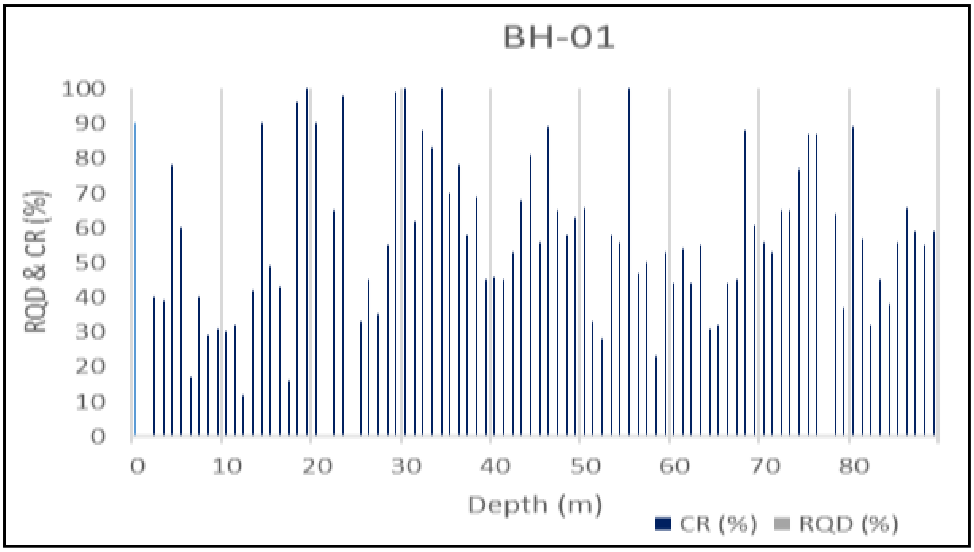

Figure 6-1 Graphical Representation of CR Vs Depth of BH-01.

It is noticed that head could not be maintained throughout the drilling of borehole. 100 % water loss has been observed. It indicates that slide mass is highly permeable with large cavities and open works which required cementing for stabilization of bore holes during drilling.

6.3 INTAKE AREA

The surface geological mapping of the intake area has been carried out at a scale of 1:1000. and presented at 1:2000 scale. A geological X-section along line BB` has been developed and presented as drawing **(DWG No: AFS-GE-313).** The main purpose to develop geological x-section is to estimate condition prevailing in subsurface i.e. overburden thickness, extension/alignment of faults, extension/trend of rock units in the subsurface.

The intake area is proposed at the left side of the Hunza River. Granodiorite rock is exposed at steep angle where it is hard, massive, strong to moderately strong with Schmidt hammer values ranges from 40 to 58 MPa **(DWG No: AFS-GE-295 & 298).** The rock is foliated where platy minerals are aligned in specific orientation with trending at N42°W and plunging at 52°NE. Different joint sets measured at the outcrop is given below

N20°W/50°NE	**N62°E/64°NW**	**N24°W/49°SW**
N25°W/61°NE	**N85°W/82°SW**	**N06°E/88°SE**
N58°E/88°NW	**N85°W/67°NE**	**N75°E/74°SE**

Photo 6-2 Proposed Intake Area for Power Tunnel

Granodiorite rock is hard, strong to moderately strong, and sparsely to moderately jointed **(Photo 6-2)**. But at higher elevation, the rock is highly jointed and sheared, having vertical open joints which must be treated for stability and safety.

6.4 POWER TUNNEL

6.4.1 Surface Geological Mapping

The surface geological mapping of the power tunnel alignment has been carried out at a scale of 1:1000. and presented at 1:2000.

Photo 6-3 Rolling down of Scree along Active Slide

It is observed during surface geological mapping that a fault is running obliquely across the alignment of power tunnel alignment **(DWG No: AFS-GE-296,297,300,303,304 & 307).** A geological X-Section CC` has been developed to estimate the subsurface conditions and presented as **(DWG No: AFS-GE-303).** The power tunnel has to be excavated mostly through the granodiorite with subordinate granitic gneiss at the left side slope of Hunza River. The strength of rock reduces downstream and near the termination point of slided mass, brecciated/ gaugic rock is present/exposed **(DWG No: AFS-GE-303).** Rolling down of large boulders are quite common at this point **(Photo 6-3).** The rock units are quite crushed, sheared and brecciated forming active slides throughout its alignment.

A borehole BH-04 has been drilled to estimate the rock conditions in the subsurface. The brief description of CR and RQD is given in table 6-2 below.

Table 6-2 Summary of Borehole BH-04

Depth (m)		CR(%)	RQD(%)	Lugeon	Depth (m)		CR(%)	RQD(%)	Lugeon
From	To				From	To			
0	1				35	38	94	91	
1	2	14			38	40	97	94	2.60
2	3	12			40	43	98	98	
3	4	12			43	45	98	97	3.77
4	5	18			45	47.6	98	97	
5	6	15			47.6	50	98	98	0.42
6	8	91	41		50	52	100	100	
8	10	85	70		52	53	100	100	
10	13	97	97		53	54	100	100	
13	15	97	92	2.48	54	55	100	100	0.12
15	16	92	58		55	56	99	99	
16	17	93	63		56	57	98	96	
17	19	98	95		57	60	99	99	0.00
19	20	91	90	1.22	60	63	99	99	
20	23	97	89		63	65	99	99	
23	24	92	60		65	68	100	100	
24	25	98	98	1.45	68	70	100	100	
25	27	96	94		70	73	99	99	
27	30	96	91	1.68	73	75	100	100	
30	32.5	95	76		75	78	100	100	
32.5	35	96	83	0.64	78	80	100	100	

Lugeon test has been conducted in the field to check the permeability condition of the rock mass at every 5 m interval.

On the basis of data collected during borehole logging, a graph has been developed between depth Vs RQD and CR and presented as Figure 6.2.

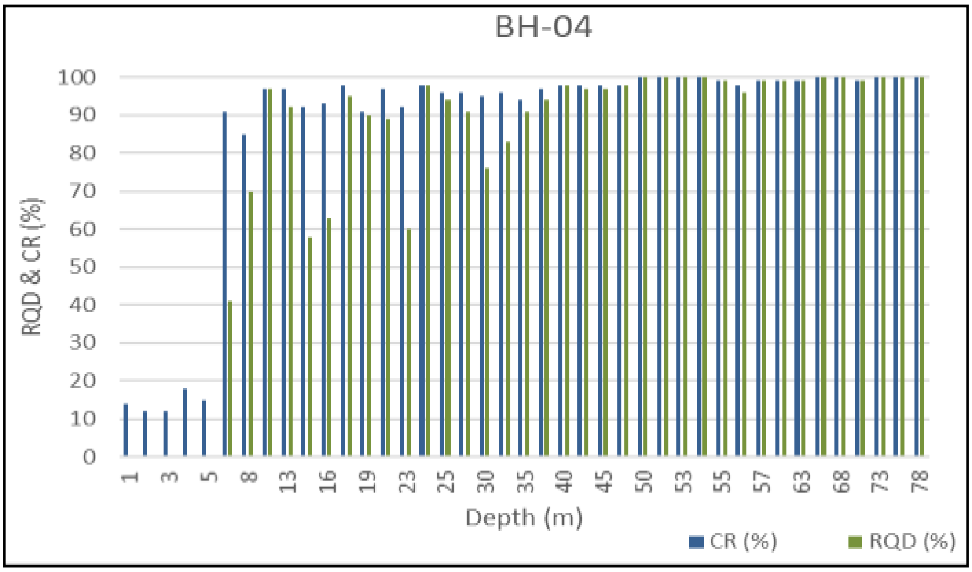

Figure 6-2 Graphical Representation of RQD&CR Vs. Depth of BH-04

During drilling works, it is estimated that the RQD values in upper 23 m is fair after that the value tends to excellent to good and good. The lugeon values calculated after every 5 m interval indicate that rock is low permeable. It shows that rock in sparsely jointed in subsurface. The lab test results indicate that in spite of the fact that RQD is quite high in lower portion but the strength index is moderate. The value of all tests indicate that the rock in BH-04 is moderately hard and moderately strong with low cohesion “C” and low angle of internal friction “Ø”. While excavating through this portion, some treatment is required to enhance for stability of structure.

6.5 SEDIMENT FLUSHING CHANNEL

6.5.1 Surface Geological Mapping

The surface geological mapping of the power tunnel alignment has been prepared at a scale of 1:1000 in field and presented at 1:2000 scale. It is proposed on the left side of Hunza River **(Photo 6.4)**. It is observed during surface geological mapping that the sediment flushing channel has to be excavated through ABGM of slided mass **(DWG No: AFS-GE-297 & 298).**.

Slided mass covers an area of about 1 km and consist of huge volume of ABGM. One of the difficult and critical task is to stabilize the both side slopes along the sediment flushing channel. The large boulders of more than 25 m in length are present in slided mass. Benching is one of the best solution for such type of slope to stabilize. At some place, mashing or gabion may be helpful for slope stabilization.

Photo 6-4 Intake Area of Sediment Flushing Channel.

6.5.2 Borehole Drilling

To investigate the nature of material exposed at left side slope, two borehole BH-02 and BH-03 have been drilled at outlet and intake of sediment flushing channel respectively. The summary of these boreholes is given in table 6.3 and 6.4.

Table 6-3 Summary of Borehole BH-02

ATTABAD LAKE HPP											
BH-02											
Depth (m)		CR (%)	K-Value cm/s	Depth (m)		CR (%)	K-Value cm/s	Depth (m)		CR (%)	K-Value cm/s
From	To			From	To			From	To		
0	1	0	Head could not be maintained	21	22	42	Head could not be maintained	41	42	30	Head could not be maintained
1	2	10		22	23	60		42	43	28	
2	3	13		23	24	23		43	44	37	
3	4	16		24	25	9		44	45	27	
4	5	18		25	26	16		45	46	25	
5	6	16		26	27	15		46	47	41	
6	7	19		27	28	32		47	48	27	
7	8	21		28	29	22		48	49	24	
8	9	29		29	30	22		49	50	25	
9	10	55		30	31	34		50	51	29	
10	11	47		31	32	28		51	52	36	
11	12	29		32	33	33		52	53	21	
12	13	24		33	34	23		53	54	25	
13	14	42		34	35	27		54	55	36	
14	15	29		35	36	21		55	56	22	
15	16	39		36	37	24		56	57	27	
16	17	25		37	38	25		57	58	27	
17	19	65		38	39	12		58	59	39	
19	20	27		39	40	15		59	60	24	
20	21	36		40	41	44		**End of Borehole.**			

On the basis of data collected during borehole logging, a graph has been developed between depth Vs CR and presented as **Figure 6.3**. Permeability tests were performed at every 3 m interval. It is noticed that throughout the borehole drilling, head could not be maintained and 100% water loss is observed during drilling.

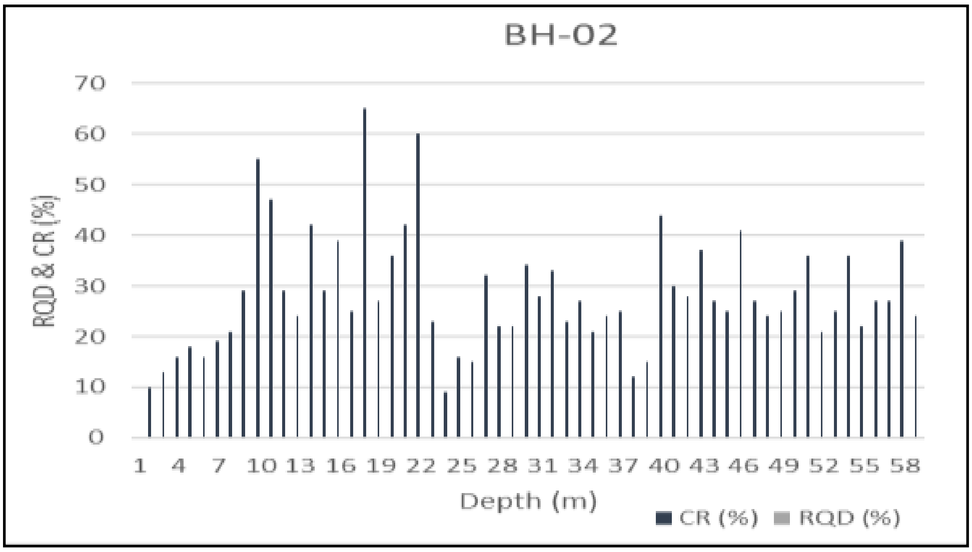

Figure 6-3 Graphical Representation of CR Vs Depth .

Table 6-4 Summary of Borehole BH-03

ATTABAD LAKE HPP											
BH-03											
Depth (m)		CR (%)	K-Value cm/s	Depth (m)		CR (%)	K-Value cm/s	Depth (m)		CR (%)	K-Value cm/s
From	To			From	To			From	To		
0	1	33		20	21	77	Head Failure	40	41	66	
1	2	70		21	22	41		41	42	31	0.00281
2	3	32		22	23	48	Head Failure	42	43	27	
3	4	24		23	24	29		43	44	34	
4	5	34		24	25	60	Head Failure	44	45	30	
5	6	83		25	26	73		45	46	25	0.00183
6	7	51		26	27	36		46	47	27	
7	8	25		27	28	34	0.001226	47	48	41	
8	9	23		28	29	75		48	49	37	0.00262
9	10	27		29	30	30		49	50	23	
10	11	20		30	31	20		50	51	24	
11	12	62		31	32	30	0.00704	51	52	66	0.00108
12	13	59		32	33	12		52	53	75	
13	14	46		33	34	40		53	54	45	
14	15	37		34	35	54		54	55	78	
15	16	35		35	36	29		55	56	56	0.00144
16	17	15		36	37	20	0.003243	56	57	49	
17	18	37		37	38	45		57	58	68	
18	19	96		38	39	100		58	59	68	0.00072
19	20	79		39	40	98		59	60	59	
								60	61	23	

On the basis of data collected during borehole logging, a graph has been developed between depth Vs CR and presented as **Figure 6.4**.

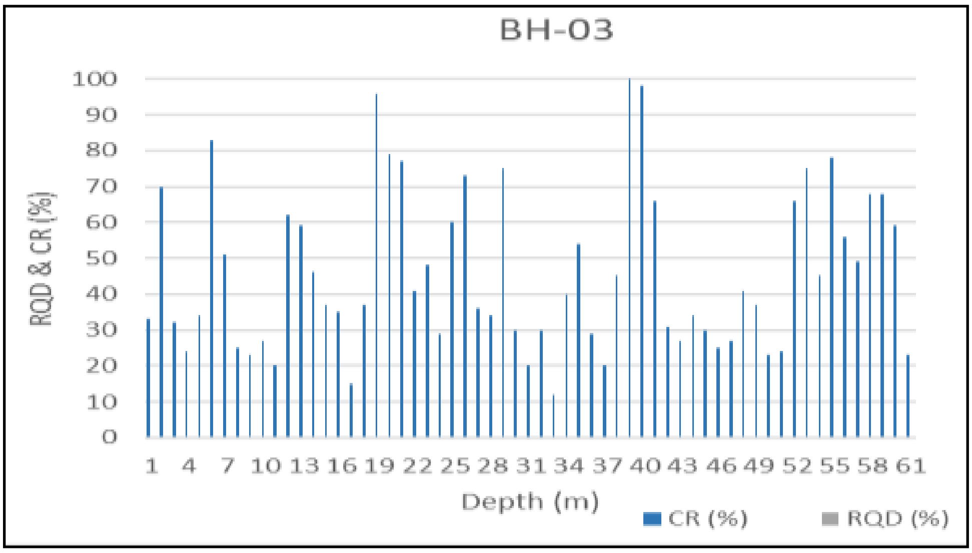

Figure 6-4 Graphical Representation of CR Vs Depth of BH-03.

Permeability tests have been performed at every 3 m interval. These values indicate that the material is pervious.

It is clear from the drilling logs that rock is not encountered upto 60 m in both boreholes. The drilling data and lab test results show that the boulders of overburden material (ABGM) are hard and moderatly strong. The slope can be stablized by benching. The permeability values in BH-02 are quite high as head cannot be maintained throughout drilling while in BH-03 the permeability values show that strata is pervious.

6.5.3 TEST PITS

Two test pits TP-5 and TP-6 have been excavated along sediment flushing channel at inlet and outlet area. In TP-5, it is observed that from 0-1.5 m, ABGM and RBGM is embedded into clayey silt while further from 3 m, fine to very fine grained, moist clayey silt is present. In TP-06 and 07, large boulders with subordinate fine material is present, which was originated from slided mass. During excavation of these test pits, large gaps have been found between these boulders.

6.6 SURGE TANK AND PENSTOCK ALIGNMENT

The surface geological mapping of the surge tank and penstock alignment have been carried out at a scale of 1:1000 in the field and presented at 1:2000 scale. It is proposed on the left side of Hunza River **(Photo 6-5)**. It is observed during surface geological mapping that the granodiorite rock with granitic gneiss is exposed in surge tank area. It is moderately hard, sheared and highly jointed **(DWG No: AFS-GE-307).**

Photo 6-5 Proposed Area for Surge Tank.

From surge tank 450 m long penstock with diameter of 3.6 m is proposed up to powerhouse. Piers will support penstock alignment. The foundation of piers will be laid on overburden material **(DWG No: AFS-GE-306 & 309).** The presence of clayey silt may create problem and might be excavated prior to establish foundation for piers **(Photo 6-6)**.

Photo 6-6 Proposed Alignment of Penstock.

6.7 POWER HOUSE

The surface geological mapping of the power tunnel alignment has been carried out at a scale of 1:1000 in the field and presented at 1:2000 scale. It is proposed on the left side of Hunza River on a flat area **(Photo 6-7)**.

Photo 6-7 Proposed Power House Area.

It is observed during surface geological mapping that thick clayey silt has been deposited having depth of about 30 m as confirmed by drilling (**BH-5 & BH-6**). It is interbedded in upper layers by RBGM while pure clayey silt found in depth. It is deposited due to choking of Hunza River when Salmanabad slide occurred **(DWG No: AFS-GE-309)..** A geological X-section DD` has been established to estimate the sub surface conditions and presented as **(DWG No: AFS-GE-315).**

6.7.1 Borehole Drilling

To explore the nature of foundation of power house material two boreholes, BH-05 and BH-06 with drilled depth of 50 m and 60 m respectively, have been drilled at powerhouse area. The summary of these boreholes is given in table 6-5 and 6-6 respectively.

Table 6-5 Summary of Borehole BH-05

ATTABAD LAKE HPP											
BH-05											
Depth (m)		CR (%)	K-Value cm/s	Depth		CR (%)	K-Value cm/s	Depth		CR (%)	K-Value cm/s
From	To			From	To			From	To		
1	2	10		17	18	0		34	35	40	
2	3	9		18	19	0		35	36	49	
3	4	9		19	20	0	0.00945	36	37	47	
4	5	0		20	21	0		37	38	41	
5	6	0		21	22	0		38	39	90	
6	7	0		22	23	0	0.00685	39	40	94	
7	8	0		23	24	0		40	41	94	
8	9	0		24	25	0		41	42	92	
9	10	0		25	26	0	0.00635	42	43	83	
10	11	0		26	27	0		43	44	50	
11	12	0		27	28	0		44	45	11	
12	13	0		28	29	0	0.00496	45	46	0	
13	14	0		29	30	0		46	47	0	
14	15	0	0.0277	30	31	44		47	48	80	
15	16	0		31	32	93		48	49	13	
16	17	0		32	33	36		49	50	7	
17	18	0		33	34	43		End of Borehole			

On the basis of data collected during borehole logging, a graph has been developed between depth Vs CR and presented as **Figure 6-5**. Permeability tests have been performed at every 3m interval.

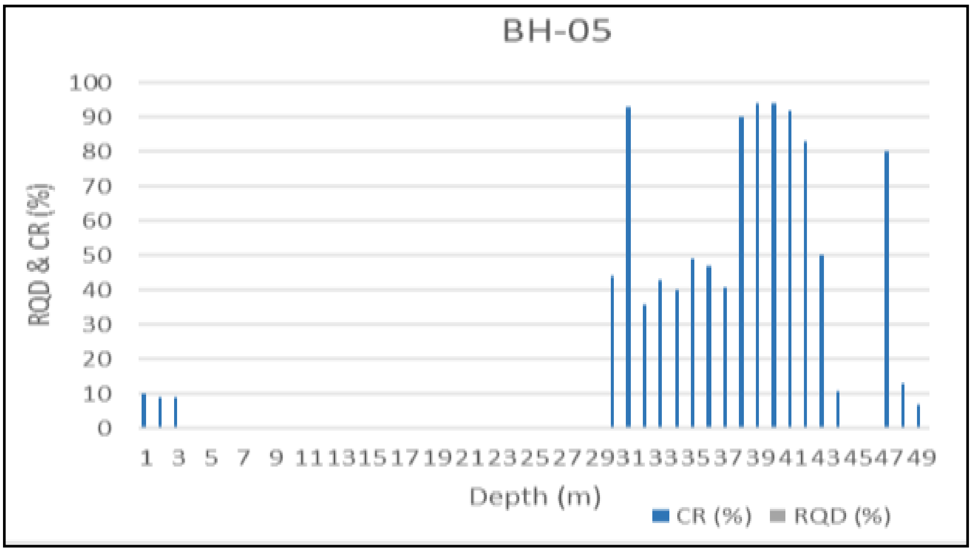

Figure 6-5 Graphical Representation of CR Vs Depth.

Table 6-6 Summary of Borehole BH-06

ATTABAD LAKE HPP											
BH-06											
Depth (m)		CR	K-Value	Depth (m)		CR	K-Value	Depth (m)		CR	K-Value
From	To	(%)	cm/s	From	To	(%)	(cm/s)	From	To	(%)	(cm/s)
0	1	0		21	22	67		41	42	61	
1	2	0		22	23	41		42	43	29	
2	3	0		23	24	81	0.00392	43	44	68	
3	4	0		24	25	62		44	45	43	
4	5	0		25	26	37		45	46	47	
5	6	0		26	27	68	0.00286	46	47	39	
6	7	0		27	28	77		47	48	42	
7	8	0		28	29	77		48	49	92	
8	9	0		29	30	94	Head Failure	49	50	93	
9	10	0		30	31	19		50	51	6	
10	11	0		31	32	13	0.00338	51	52	19	
11	12	0		32	33	23		52	53	22	0.000781
12	13	0		33	34	24		53	54	0	
13	14	0		34	35	69	Head Failure	54	55	17	
14	15	0		35	36	40		55	56	80	0.00298
15	16	27		36	37	34		56	57	52	
16	17	77	0.00241	37	38	86		57	58	59	
17	18	71		38	39	83	0.00279	58	59	100	
18.4	20	74		39	40	68		59	60	100	
20	21	60	0.00289	40	41	16		**End of Borehole.**			

On the basis of data collected during borehole logging, a graph has been developed between depth Vs CR and presented as **Figure 6-6**. Permeability tests were performed at every 3 m interval.

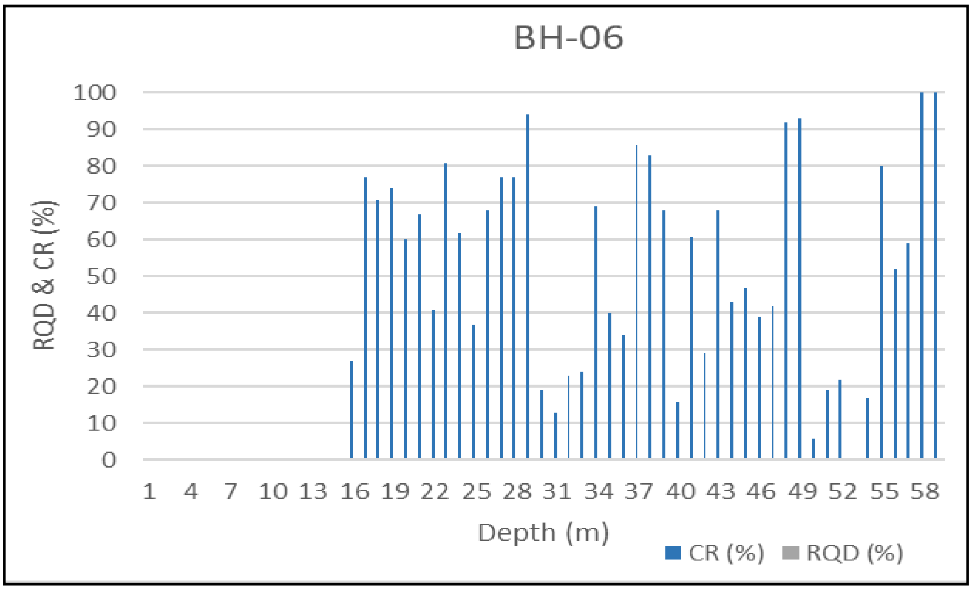

Figure 6-6 Graphical Representation of CR Vs Depth

It is clear from the drilling data that about 15 m clayey silt in BH-06 and about 30 m in BH-05 has been encountered during drilling. SPT has been conducted in the clayey silt for 18 inches penetration in these boreholes. It is estimated from this data that firm to stiff clayey silt is present. The permeability tests conducted in this strata show that they have relatively high hydraulic conductivity. The lab test results indicate that the clayey silt has swelling potential.

Foundation of the powerhouse will be lying on overburden material. The whole thickness of clayey silt layer has to be removed/excavated prior to establish the foundation of powerhouse.

6.8 TAILRACE CHANNEL

The surface geological mapping of tailrace channel has been carried out at a scale of 1:2000. It is proposed on the left side of Hunza River. It is observed during surface geological mapping that the whole channel has to be excavated through the overburden material **(DWG No: AFS-GE-309).**. Water after generating electricity will again join Hunza River near Sarat village suspension bridge.

7 CONSTRUCTION MATERIAL

7.1 GENERAL

Construction material required for various structures of ALHPP is available in ample quantity within/near the Project Area in economic haulage.

The rocks granodiorite and granitic gneiss are exposed in/near the Project Area. Both are acidic rocks and cannot be used as coarse aggregate with Ordinary Portland Cement (OPC) due to alkali silica reaction (ASR). Both rocks show deleterious quartz more than 5%. More over 10 test pits have been excavated for the study of aggregate material and foundation condition. These have been excavated in river bed, slided mass and fine deposits near old Chinese camp in power house area. Samples of marble have been collected from Passu area to conduct laboratory testing in CMTL WAPDA, Lahore.

7.2 FINE AGGREGATE

Two types of fine aggregate sand and clayey silt have been selected for testing and proven source for fine aggregate. Samples have been collected from 0 to 3 m depth (by coning and quartering method) for laboratory testing and sent to CMTL, WAPDA, Lahore.

7.2.1 Sand Quarry

To fulfil the quantity of sand material during construction of ALHPP, ample quantity of this material is deposited in the tail area of Attabad Lake near Shishkat Bridge **(Photo 7-1)**. A test pit TP-1 has been excavated, and samples have been collected for lab testing. Log of test pit is given in **(Volume 4A)**. Gradation test, indicates that 99% sand with only 1% silt and clay is present **(Table 5-15 & 5-16)**. The results of Accelerated Mortar Bar indicate minimum average expansion (0.039) for 28 days. Specific gravity and water absorption values also fall in permissible limits. The results of lab testing are provided in **Volume 4B.**

Photo 7-1 Quarry Area Selected for Sand near Shishkat Bridge.

The lab. test results show that it can favorably be used as sand quarry site for construction of ALHPP.

7.2.2 Silt and Clay Quarry

For fine aggregate (Clayey silt) 3 test pits 3x3x3m have been excavated to analyze the nature of material present in river bed. Two test pits TP-2 & TP-3 in helipad/powerhouse area and TP-10 near Klin area, near Ganesh Bridge, have been excavated to explore the subsurface geological conditions prevailing in the area **(Photo 7-2)**. Both composite as well as block samples from each test pit have been collected for lab testing.

Photo 7-2 TP-3, Excavated for Clayey Silt in P/H Area.

Lab test results indicate that the material consists of clayey silt with clay index ranges from (40-45%). Atterberg Limits and Swell Potential show that some treatment may be needed prior to their use. Results of Modified Proctor test on block and composite samples indicate that max dry density 1.7 to 1.8 mg/m^3 for clayey silt can be attained in range of 10 to 13% optimum moisture contents (ch. 5, Table 5-14). The laboratory test results can be seen in **Volume 4B**.

Another huge source of borrow area for silt and clay is present at brick kiln area near Ganesh Bridge along KKH. It lies in economic haulage. A test pit TP-10 has been excavated in clayey silt and two block samples were collected from this pit and sent to CMTL to conduct different tests. The log of test pit is presented in volume 4A. The Lab test results have been collected and interpreted in chapter 5.

It indicates from lab test results that, clayey silt is present and can be used ase blanket material to minimize the seepage. The ratio of silt and clay naturally present in 60 and 40% respectively (Table 5-16). It is present in adequate quantity in P/H area and near Ganesh Bridge.

Photo 7-3 View of Clayey Silt in P/H Area.

7.3 COARSE AGGREGATE

The rock units exposed in the Project Area are acidic in nature on the basis of silica contents i.e. granodiorite and granitic gneiss. Due to sliding of huge mass downslope, large material is deposited in foothills chocking the Hunza River. For coarse aggregate, three sites have been selected. Samples from slided mass, powerhouse area/river bed and Passu area have been collected and sent to CMTL WAPDA, Lahore to conduct different tests.

7.3.1 Passu Area

It is located about 35 km upstream of Attabad Lake along KKH near Passu village **(Photo 7-4)**. Bulk sample have been collected and sent to laboratory for testing. Petrographic analysis shows that marble is exposed. It consists of 97% of calcite, with specific gravity 2.84 and 0.37 water absorption, Los Angeles abrasion has uniformity of wear 0.20, crushing value 24, with flakiness index of 22. Sulphate soundness test result has weight percent loss 0.89.

The laboratory test results indicate that the rock mostly consists of calcite with no alkali silica reaction and no alkali carbonate reaction. This material has no deleterious quartz and tests results fall in permissible limit; therefore, it can be used as coarse aggregate for concrete with Ordinary Portland Cement.

Photo 7-4 Exposure of Marble in Passu Village Area.

7.3.2 Power House Area

Large quantity of RBGM is deposited near old Chinese camp along old KKh route. Bulk sample from TP-2 has been collected and sent to lab for different tests **(Photo 7-5)**.

Photo 7-5 View of RBGM in TP-2 at P/H Area.

It consists of marble, granite, granitic gneiss, with some slate pieces. As per lab. test results, the material have specific gravity 2.78 with 0.33% water absorption. Los Angeles abrasion value with uniformity of wear is 0.20, crushing value is 27, and flakiness index is 21. Sulphate soundness value is 0.81 and average expansion for 28 days in accelerated mortar bar is 0.099, and point load index is 4.15 MPa (ch-5).

Petrographic analysis indicates that the rock is mostly granitic in composition and has more than 20% deleterious quartz, therefore, it cannot be used with OPC. To minimize the ASR, low alkali cement, slag cement or fly ash, pozzoloan can be used. Some chemical additives like lithium nitrate or silica fume can also be used. The finalization of the additive material depends upon the other strength and expansion tests during concrete mix design. Moreover, all the values of other tests fall in permissible limit, therefore, it can be used as coarse aggregate material for concrete but not with OPC.

7.3.3 Slided Mass

Sample from TP-7 have been collected to conduct different lab tests. Lab testing program has been framed to check the suitability of this material. The description is given below: -

Petrographic analysis shows that rock is granodiorite and has more than 20% deleterious quartz and cannot be used with OPC. Point load strength is 5.94 with diametrically failure, specific gravity 2.72 and water absorption 1.04%. Los Angeles abrasion test show 0.41 uniformity of wear, crushing value 22 with flakiness index of 21. The value of Sulphate soundness test for this material is 1.87.

Photo 7-6 View of Slided Mass in TP-6 at Left Side Slope of Hunza River.

Higher Los Angeles abrasion, Sulphate soundness and presence of deleterious quartz values, show that this rock cannot be favorable for coarse aggregate material as in comparison with other two quarry site. Thus this material is not recommended as coarse aggregate for concrete works with OPC. This material can be used as coarse aggregate with slag cement, low alkali cement and by adding pozzoloan material to counter ASR.

7.4 BUILDING STONE

The granodiorite and granitic gneiss rocks are exposed in the project periphery, available for masonry works in sufficient quantities. More over, the large boulders, present in slided material can be used as rip rap material, to control the erosion/ wave action of water. This material has high strength UCS value ranges upto 72 MPa in TP-8. Similarly, the values of property index test, Los Angeles abrasion test fall in permissible limits. The slided mass may, therefore, be used as rip rap material.

7.5 FILL MATERIAL

For protection works along slopes and structures, shoulder fill, construction of coffer dams, fill material of heterogeneous nature e.g. silty sand, sandy silt, gravelly sand etc. are available in river bed as well as in slided mass. These materials are present in ample quantities in the economic haulage of the Project Area.

Photo 7-7 Fill Material (Boulder and Gravels) in Slided Mass.

The test pits excavated in the powerhouse area / river beds show that large quantities of gravels and cobbles with subordinate sands are present. This materials satisfy the lab test program, therefore it might be used as fill material.

7.6 CEMENT AND STEEL

Cement and steel are required in adequate quantity for the construction of ALHPP. The cement should be supplied from nearby cement factory. The most nearer unit of cement is situated in Haripur/WAH areas includes Askari Cement, Wah cantt unit with capacity of 3500 ton/day and Fauji cement near Fateh Jang has two units; one with 3500 ton/day and other with 6700 ton/day.

These options can be considered for the supply of cement. The steel has to be transported from Rawalpindi to fulfill the requirement of the project. It is suggested that laboratory tests on representative samples should be carried out to determine the engineering characteristic of cement and steel prior to their use / procurement.

8 NEOTECTONICS AND SEISMIC HAZARD ANALYSIS

8.1 GENERAL

A large slided mass moved down and chocked the Hunza River and KKH for more than 2 km in January 2010 from right side near Attabad village. This large slide causes a 25 km long lake to develop upto Khyber village in Gojal. Due to excavation and development of channel through this slided mass, the level of lake decreases down and extension reduces up to Shishkat Bridge. This large mass slided down due to some regional stress operating in this region. To understand these regional forces and their effect and vulnerability of expected slope material to slide, a Neo-tectonic study has been conducted.

During the Feasibility Study, the colossal slide and as a result damping of Hunza River in 2010 has made the Neo-tectonic studies as core point. It is therefore, very important for the development of hydropower project in this area that understanding of Neo-tectonic setting should be explored to know the regional tectonic forces. Regional tectonic forces responsible for the massive slide are affecting Project Area severely as indicated by diverse features.

8.2 OBJECTIVES

Main objectives are:

- Evaluation of the regional tectonic setting of the area and recognition of fault (regional or local) which may act as a seismic source.
- Detailed investigation of the fault geometry, alignment, and structural deformations associated with these fault. These may include shear zones, fault bend folds, active slides and fault breccia.
- Recognition of active fault zones and their distinction from older, dormant fault zones.
- Assessment of the vulnerability of Neo-tectonic activity along the fault/slides around the Project Area so that the movement along the affected area may be predicted.
- Identification of deformation/displacement in recent deposits to evaluate the activity of area.

8.3 METHODOLOGY

An array of activities including literature review,image analysis,field studies and datacompilation are involved in Neo tectonic evaluation as per standard practices in Industry. These include:

- Collection of previous research on regional as well as on local geology, geomorphology and tectonics of Project Area.
- In-depth studies on satellite image analysis using GIS techniques by applying various image-enhancing techniques e.g. Digital Elevation Model (DEM) have been studied, the lineaments and faults on regional as well as on local scale have been recognized.

- Detailed geological map of the Project Site, regional and local faults within the vicinity covering the upstream and downstream of the Project Area have been marked on GT sheets at scale of 1:50000 in the field area to understand the trend of regional tectonic forces.
- During field visit keen concentration has been given to characterize the kinematics of fault where possible e.g. sense of fault (Strike and Dip), alignment and type of fault, throw and heave, dip direction and other associated characteristics.
- Development of fault-source map indicating various regional scale faults that may contribute seismic affect in the Project Area.
- The relationship of older tectonic features to the recent ones.
- Field evidences of Neo-tectonic features have been captured in photographs including active slides, tiltness in recent deposits, folding, faulting, step fault, fault associated folding in recent deposits, topographic features including drainage pattern at slopes and abrupt shifting of river/stream course.

8.4 FIELD OBSERVATIONS

This study covers the 40 km upstream and 50 km downstream of the Project Site along both banks of the Hunza River. Different features related to Neo-tectonics activity have been observed during site visit. In this study the focus has been given to the recent deposits, at the both bank of river.

The main objective of the Neo-tectonic study has been to identify/observe the feature of active tectonic events occurred in recent past about 0.1 Million years ago. There are many field observations regarding the Neo-tectonic activity. Some of the Neo-tectonics features/observations are as under: -

- The tiltness in recent deposition, i.e. to study the slopes of gravels, clays, and sand layers w.r.t slope of the stream beds.
- Intersection of faults in recent deposits i.e. lacustrine deposits, terraces/ alluvial deposits or in any cultural features (houses, roads). The amount of displacement, Heave as well as Throw measurement, dip and strike of the fault.
- The presence of active slide zones.
- The displacement /uplift in fluvial as well as lacustrine deposits on each side of the lake/stream and magnitude of its displacement.
- Identify the zones of brittle as well as ductile deformation.
- To observe the movements along slicken sides / fault / joints blocks.
- The presence of hanging valley along the main streams.
- The presence of escarpment slope along the plain area.
- The presence of hanging valleys /cirques along main stream, in series and presence of waterfalls along it.

- Folding/bending in the recent deposits (alluvium, morainic, lacustrine).

The Neo-tectonic features at the right as well as left bank of Hunza River in different villages from upstream to downstream **(DRW No: AFS-GE-318 to 320)** are described below: -

8.4.1 Passu Village:

Passu is one of the largest village in Gojal valley situated at the right bank of Hunza River along KKH about 35 km from Attabad Site. The great Passu Glacier, 56 km in length is present near the village. Many deformational evidences have been observed in recent deposits along the road.

- 2-3 km upstream of Passu village

N	4038610.325 m
E	489292.583 m
El.	2470.03 m.a.s.l

The coordinates measured by mobile topographer application.

A large deposit of RBGM material is present along the right side slope of the river along KKH. This material consists mostly of gravel, cobble, and pebbles with subordinate sandy material. Some inclinations in these deposits have been observed along roof and sole beds. This inclination varies from 15° to 35° layer-by-layer **(Photo 8-1).**

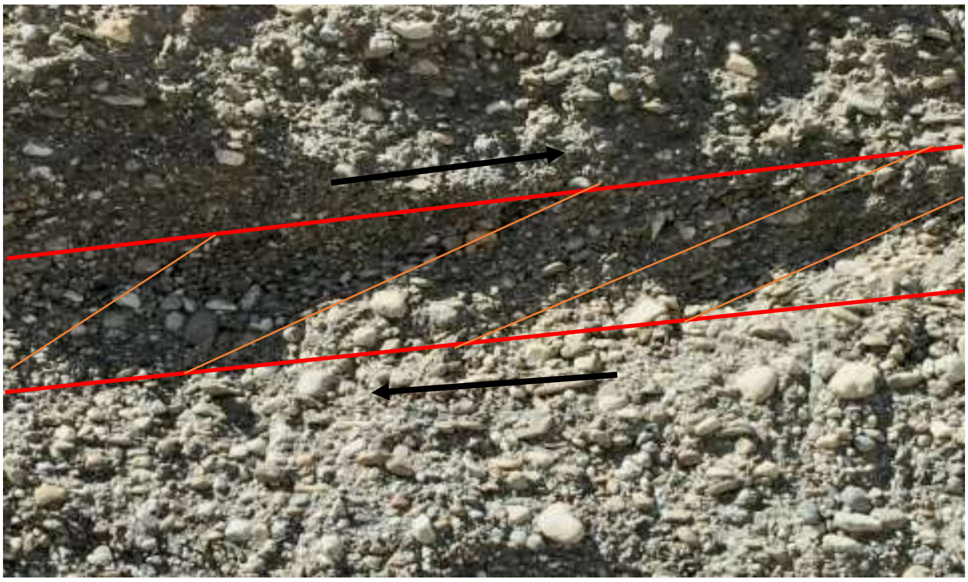

Photo 8-1 Inclined Gravel Layers under Effect of Shearing

Some shearing effects have been chronicled along these planes in numeral layers. This shows that the area is tectonically active.

The clay deposits are overlain by morainic material of Batura Glacier. The clay deposits are tilted upward at an angle ranging from 10° - 15°. The area has undergone compressional regime, which uplifted the clay beds **(Photo 8-2)**.

Photo 8-2 Recumbent Fold Strata with Crenulation in Limbs in Clay Strata.

The clayey strata is folded with straight horizontal limbs and horizontal hingline. This shows that the horizontal compressional stress is applied on this material that turned this unit into folded strata **(Photo 8-3).** Many micro folds (crenulations) in both limbs of fold are present. The Hinge area toward outer layers point out, that intense compressional stress is applied to the strata.

Photo 8-3 Stylolite/Pressure Solutions in Clay Strata.

The strata shows some stylolite structures that are formed by expulsion of water through pressure solutioning. Alignment of wavelength and geometry of hinge area indicates that the compressional stress is applied horizontally **(Photo 8-4)**. This shows that the recent stresses are functioning in this area.

Many joints are developed in the clay beds showing that there are relative movement in blocks along the plane, which might be acted as micro faults **(Photo 8-5)**.

The relative movement of hanging wall block moves down relative to the footwall block, signposted the development of normal fault.

Photo 8-4 Micro Fault in Clay Beds.

At the same location there are cross cutting faults, dipping towards each other in clay beds. The block between two micro faults moves downward forming Graben structure while the block, that cannot move forming Horst structure **(Photo 8-5)**.

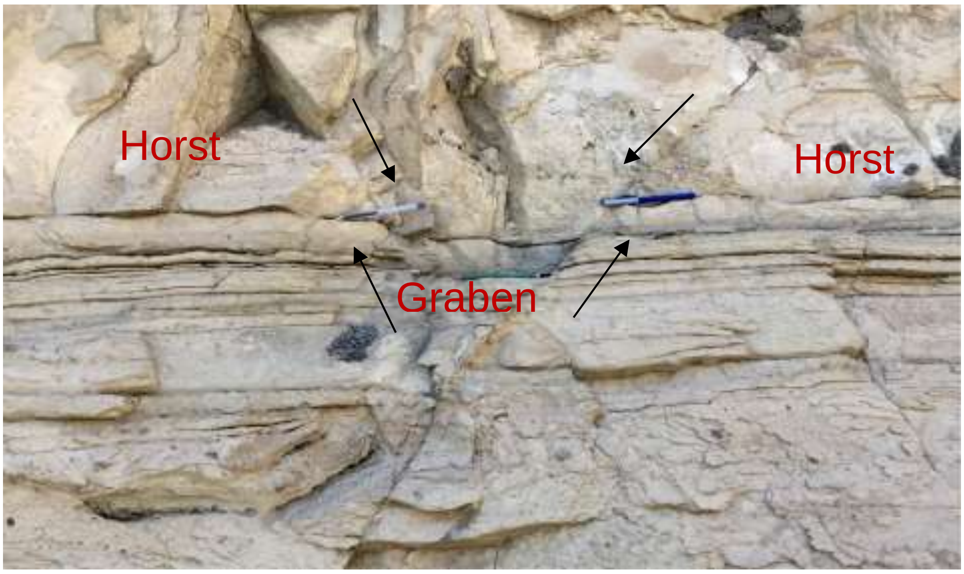

Photo 8-5 Horst and Graben Structure along Micro Fault in Clay Beds.

The formation of these structures in clay beds show that there is relative movement along the micro faults in recent deposits.

The development of these normal fault systems in such compressional regime indicates that these deposits are under such environment where two thrust faults dipping toward each other.

The up thrown block between these two faults undergone extensional regime where normal faults are developed. This indicates that this area is under active tectonics regime.

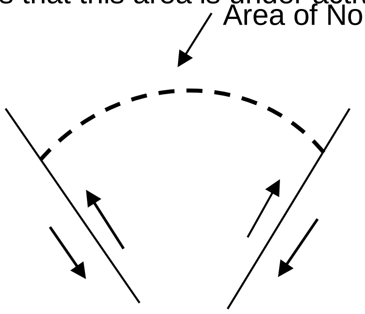

Figure 8-1 Development of Normal Faults under Compressional Regime.

8.4.2 Road Section from Murradabad to Hussani Village:

Coordinate

N	4033080.557 m
E	489417.275 m
El.	2656.69 m.a.s.l

Just upstream of Hussaini village a large mass of ABGM and brecciated rock is exposed along the road. It is present in the alignment of thrust fault where crushed marble is in contact with Passu Slates. The faulted contact between slate and marble is well exposed along road **(Photo 8-6)**.

Photo 8-6 View of Brecciated Rock Upstream of Passu Village.

In this area two faults are intersecting each other; one is striking N60°E and dipping 40°NW while other is striking NW and dipping NE **(DWG No: AFP-GE-3180)**. Due to these faults discrete hillocks have formed with thin overburden overlain by fault breccia. At few feet away from breccia, a slided material consists of ABGM is present along road. Apparently this material seems to be stable but in excavated portion, it is folded. Compressional forces are responsible for this deformation exposed at slope **(Photo 8-7)**.

Photo 8-7 View of Folded ABGM just Upstream of Passu Village.

Rock (Passu Slates) is locally folded, some shear joints along which the cleavage plane (originally bedding planes) across shear joint has different dip values. The overall strike of slates is NW and dipping in NE but along this shear joint some movement took place and the value of dip changes from SW to NE **(Photo 8-8)**. Change of sense of dip along the shear joint shows that some shear forces are active in the area. The developments of such joints indicate the brittle deformational style.

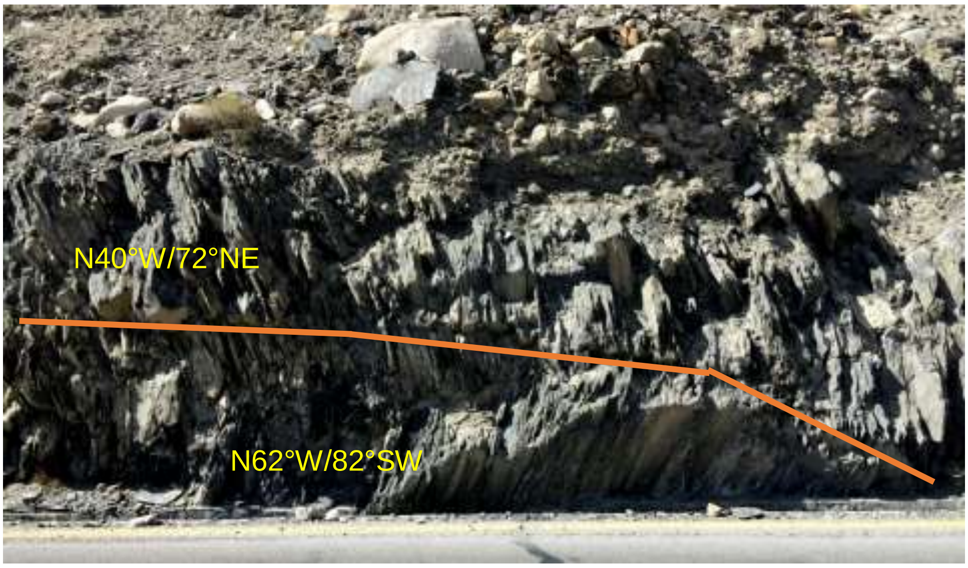

Photo 8-8 Change of Dip along Shear joint.

8.4.3 At Sarat Village:

Coordinates:

N 4018254.850 m

E 481549.816 m

El. 2371.35 m.a.s.l

Due to Salmanabad slide in 1858, a large lake developed in upstream reaches. The depositional clayey silt can be seen on both bank of Hunza River. Due to operational neo-tectonic forces, deformation including folding, jointing, micro faulting have been developed in these deposits.

Both vertical and oblique joints can be seen in clayey silt at right side near Sarat Suspension Bridge. The strike and dip values of vertical and oblique joints are N38°W/87°NE and N32°E/63°SE respectively **(Photo 8-9)**.

Photo 8-9 View of Vertical and Oblique Joints in Clayey Silt at Sarat Village.

Clayey silt beds are striking N 80°E and dipping 18°NW at the left side of road to Sarat Village while at the right side of the road these beds have strike N 32°E and dipping 9°SE **(Photo 8-10 & 8-11)**.

Photo 8-10 Tiltness in Clayey Silt Beds, Left Side of Road at Sarat Village.

The strike of the beds is NE while the dip is in opposite direction, indicating that it forms some sort of antiform. Formation of antiform in recent deposits clearly indicates that lateral shear compressional force are operational in this area.

Photo 8-11 Tiltness in Clayey Silt Beds, Right Side of Road at Sarat Village.

Just downstream of Sarat village near the Suspension Bridge, fault breccia is exposed along the river showing the alignment of fault.

Photo 8-12 Folded and Sheared Clayey Silt at Sarat Village.

Photo 8-13 Sheared and Smeared Clayey Silt at Sarat Village.

Photo 8-14 Fault Breccia just D/S of Suspension Bridge at Sarat Village.

Folding, jointing, smearing and shearing of clayey silt **(Photo 8-12, 8-13, 8-14)** deposits show some lateral stresses are actively operating in this area. The active slides and rolling down of brecciated material from this slope indicate that it is tectonically active area.

8.4.4 Inside Tunnel 2

Many cracks/joints are going to develop in the concrete especially in crown area in tunnel-2. The pattern of the cracks indicates stress release and shear oblique joints **(Photo 8-15)**.

Photo 8-15 View of Recently Generated Joints Tunnel-2.

As far as geological condition is concerned, this portion of tunnel in is under influence of two faults **(DWG No: AFP- GE- 319)**. Rock is highly crushed, rolling down of boulders is quite common along these active faults. The active tectonic forces are responsible for the development of fractures in this terrain. The same features can also be noted in concrete area in between tunnel 2 and 3 **(Photo 8-16)**.

Photo 8-16 View of Recently Generated Joints between Tunnel-2 & 3.

The concrete slab fractured between tunnel 2 and 3. It is evident that some tectonic forces are recently operative in this area.

8.4.5 Power House Area

In powerhouse area near helipad along old KKH, clayey silt is present where Chinese Camp was established. The clayey silt has been deposited after river choking due to Salmanabad slide. Due to operational compressional stresses, some deformations including faulting, shearing, folding, and tiltness in clayey silt have been observed.

Photo 8-17 Micro Thrust Fault in Clayey Silt Beds near Helipad.

The relative movement of both blocks against fault plane indicates compressional environment, moved the hanging wall block upward **(Photo 8-17)**.

Photo 8-18 Inclination of Clayey Silt near Helipad.

The clayey silt beds are well exposed at the left side of Hunza River near Sarat Bridge. The clayey silt beds are well jointed and tilted upward at an angle ranging from 10° to 15° **(Photo 8-18)**. The inclinations of the beds in recent soil are active tectonic features.

Near old Chinese Camp, at powerhouse area, the clayey silt is folded **(Photo 8-19)**. Folding in recently deposited clayey silt may be the result of slipping along fault plane under regional compressional shear forces.

Photo 8-19 Folding in Clayey Silt near Helipad/Powerhouse Area.

Near the SCO building, along old KKH, near tunnel-1, some cracks are going to develop in recently deposited material. The development of joints is mostly parallel in nature but occasional cross cutting joints also present **(Photo 8-20)**.

Photo 8-20 Development of Parallel Joints near SCO Building.

8.4.6 At Murtazabad- Shahyar Road:

Coordinates:

N	4016299.113 m
E	465418.47 m
El.	2095 m.a.s.l

Just crossing the Murtazabad to Shahyar Bridge, a thick alluvial deposit consists of gravels, cobbles, pebbles interbedded with silty sand is exposed. This material moved upward against fault plane and formed fault bend fold **(Photo 8-21)**.

Photo 8-21 Inclination in Clay Silt and Gravels.

The beds are tilted at an angle of 22° to 30°. Many micro fault in sand beds have been observed in hinge area of the fold. The ramp and flat geometry have NE striking and dip SE **(Photo 8-22)**.

Photo 8-22 Ramp and Flat Geometry along Fault.

Some micro faults have been observed in this alluvium. Step faulting on micro level is well preserved in sandy material **(Photo 8-23)**. This alluvium is overlain by morainic material. Same joint pattern is going to be develop in it. Some open joints ranging from 10 cm to 150 cm have been observed there. All these features indicate that the tectonic forces are active in this area.

Photo 8-23 Development of Micro Faults in Sand.

8.4.7 In Tashot Village:

Coordinates:	N	4012830.531m
	E	462157.244m
	El.	2111.0 m a s l

After crossing suspension bridge near Tishot Bridge, a thick deposit of RBGM and clayey silt are exposed along the road toward Phakhar village. Due to some recent activity, clayey silt has displaced and smeared along micro fault.

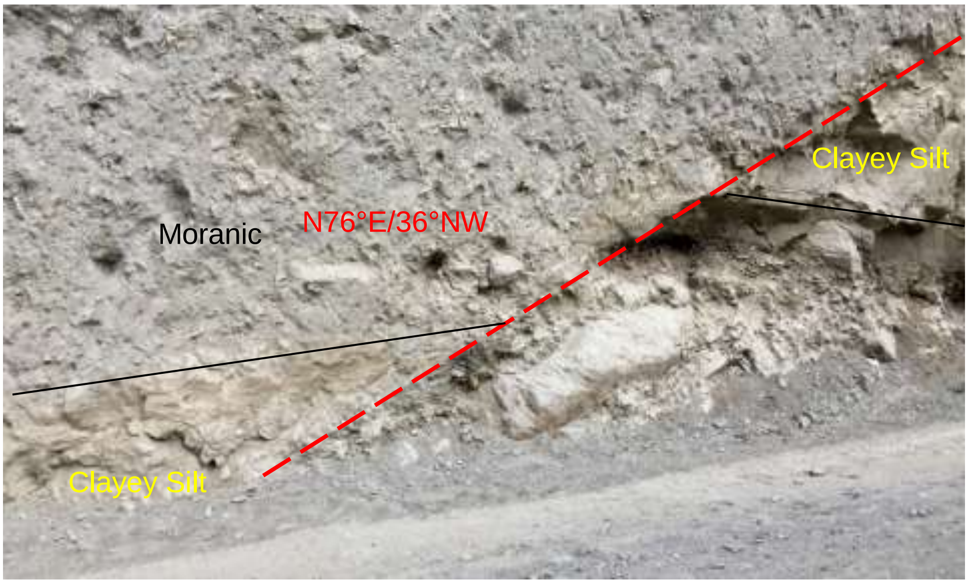

Photo 8-24 Development of Micro Faults in Clayey Silt.

Upward inclination of 6°in recent RBGM in measured along the road **(Photo 8-24, 8-25)**.

Photo 8-25 Inclination in RBGM in Tashot Village along Road.

8.5 SEISMIC HAZARD ANALYSIS

The quantitative and qualitative seismic hazard analyses presented in this study preceded by a detailed appraisal of the structure, geodynamics and neotectonics, to characterize the on-site and regional tectonic scenario to assist in proposing a suitable earthquake resistant design. This study has used the seismic source characterization deduced in the accompanying Neo-tectonic studies and calculated the earthquake potential hazard and related ground motions as presented in this report.

8.5.1 PROBABILISTIC HAZARD ANALYSIS

Both PSHA and DSHA were carried out using EZ-FRISK software Version 7.65 developed by Risk Engineering Inc. USA. The latest version of R-CRISIS Software version 21.1.1 developed by PEER, USA has also been used during the current study. The purpose of using both software has to cross check the validation comparing the quality of the seismic hazard analysis of the two software for the project. During the study it has been found that Ez-Frisk software is more standardized as compared to R-CRISIS software in quality of analysis as well as the smart outputs of the analyzed results. Therefore, Ez-Frisk software has been preferred and used in the in the final analysis.

Important input parameters for different seismic zones used in probabilistic approach are presented in **Table 8-1**. It is assumed that weir foundation will be placed on gravelly soil (alluvium), therefore, the site condition has taken as gravelly soil with average shear wave velocity at 30 meters depth (V_{s30}) of 450 m/sec for soil site (alluvium) and 760 m/s for rock sites. The mean total hazard curve obtained by giving equal weighting to all the Five NGA W2 Ground Motion Prediction Equations.

The total hazard curve obtained for the Project Area is shown as **Figure 8-2** and the total mean Hazard Spectra showing combination of all used Ground Motion Prediction Equations for ALHPP is presented as **Figure 8-3**.

Table 8-1 Seismic Source Parameters for Probabilistic Analysis

Source Zone	Seismic Source Zone	Min. Magnitude Mw	Activity Rate / Year	β	Max. Magnitude Mw
1	Karakorum	4.0	1.929	1.120	7.3
2	Nanga Parbat	4.2	1.112	1.101	7.0
3	Western Himayan	4.1	5.339	1.44	7.0
4	Hindukush	4.2	59.107	1.20	8.0
5	Kashmir Himalaya	4.2	7.143	1.13	7.8
6	Kohistan	4.1	10.500	1.07	7.5

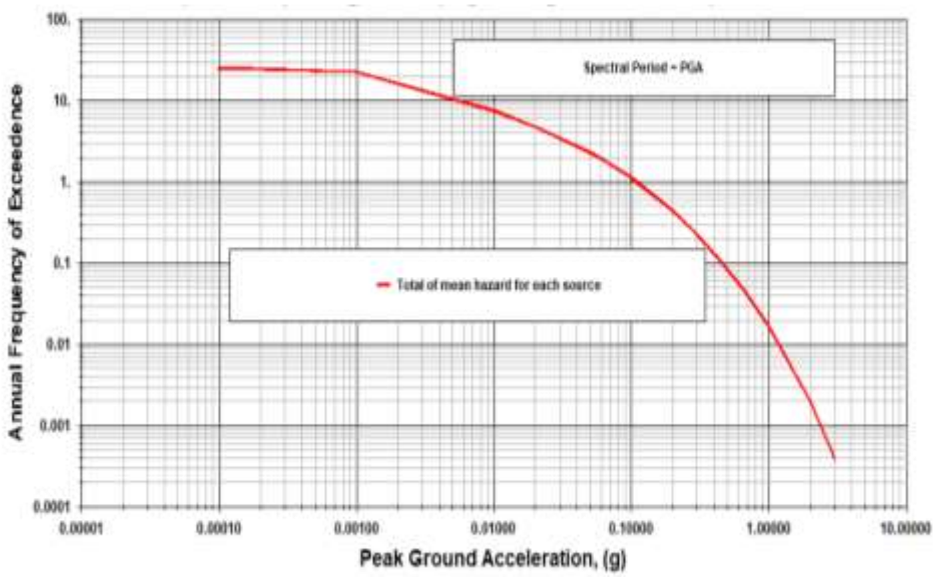

Figure 8-2 Total Hazard Curve for ALHPP.

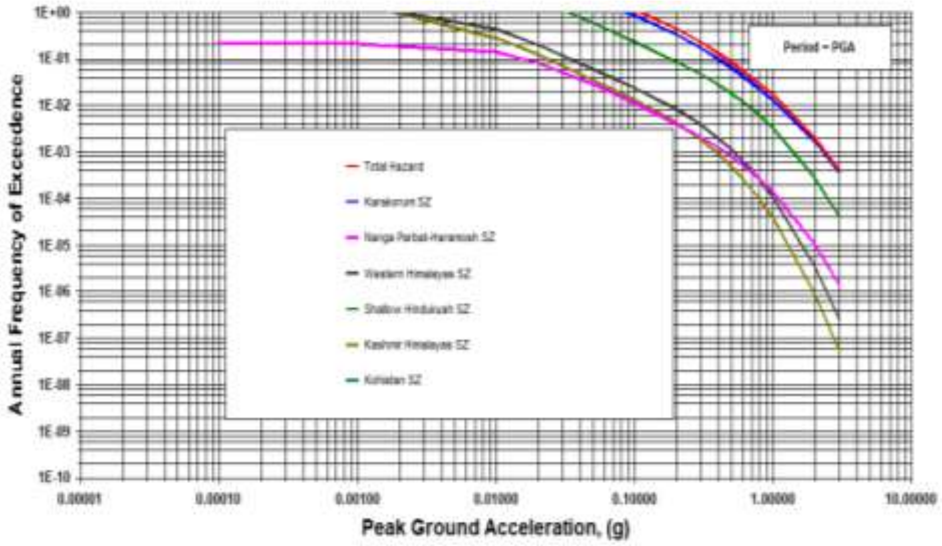

Figure 8-3 Earthquake Hazard by Seismic Sources, Showing Spectral Response.

8.6 DETERMINISTIC SEISMIC HAZARD ANALYSIS (DSHA)

The capability of the faults to generate earthquakes is ascertained by means of analysis of historical and instrumental seismic data and geological criteria such as rupture length – magnitude relationship or fault movement – magnitude relationship.

The main tectonic features around the Project Site within a radius of 200 km which could be controlling the maximum earthquake hazard are as follows:

- Hunza Fault
- Main Karakoram Thrust (MKT)
- Main Mantle Thrust (MMT)

Empirical correlations have been developed between maximum potential of a fault and key fault parameters like rupture length, fault area, fault displacement and slip rate. Out of these fault parameters, only fault lengths are known with sufficient accuracy. For the faults around the ALHPP site, the half rupture length of the faults has been taken for determination of maximum potential magnitude. The maximum earthquake magnitude (in moment magnitude M_W) of each of the fault calculated using Wells & Coppersmith (1994) relationship between fault rupture length and magnitude and the input data given in **Table 8-2** has been used for deterministic approach.

Table 8-2 The Controlling Faults with Quantitative Features (input values of DSHA)

Controlling Faults	Fault Type	Fault Rupture Length (km)	Distance (km)	Maximum magnitude potential	
				Catalogue data	Conservatively Assigned
Hunza Fault	Thrust	5 inferred	1.4	6.1	6.7
MKT	Thrust	200	32	7.0	7.6
MMT	Thrust	260	71.69	6.9	7.6

Ground motion prediction equations developed under the Next Generation Attenuation (NGA) West 2 Project of PEER (Pacific Earthquake Engineering Research Center, University of California at Berkeley, USA) are used to obtain the median and median plus-one percentile levels of Peak Horizontal Ground Acceleration (PGA) in deterministic approach.

The NGA equations are developed using a large worldwide database of strong motion recording of earthquakes of magnitude 4-8 and distances ranging from 0-200 km in accordance with ICOLD Guidelines. The NGA equations are preferable over the older equations for the evaluation of seismic hazard particularly in the near field as these are based on a broad spectrum of data recorded in the near field. The same attenuation equations were used for the PSHA approach too.

For all the seismic sources, thrust rupture mechanism has been considered. It is assumed that dam foundation will mainly be placed on gravelly soil therefore the site condition for weir has been taken as gravelly soil with average shear wave velocity for top 30 meters (V_{s30}) of 760 m/sec. The depth to basement rocks (Z_{25}) is taken as 5 km. The PGA g values have been calculated using the latest 5 sets of NGA West 2 Ground Motion Prediction Equations (GMPEs).

Input values in Deterministic Seismic Hazard Analysis (DSHA) are given in **Table 8-2**. The analyzed results obtained through DSHA are presented in figures.

8.7 DETERMINISTIC RESPONSE SPECTRA

Deterministic Response Spectra for Safety Evaluation Earthquake (SEE) at 50th percentile and 84th percentile levels over the Five NGA West 2 equations are shown in **Figure 8-4 & 8-5** respectively.

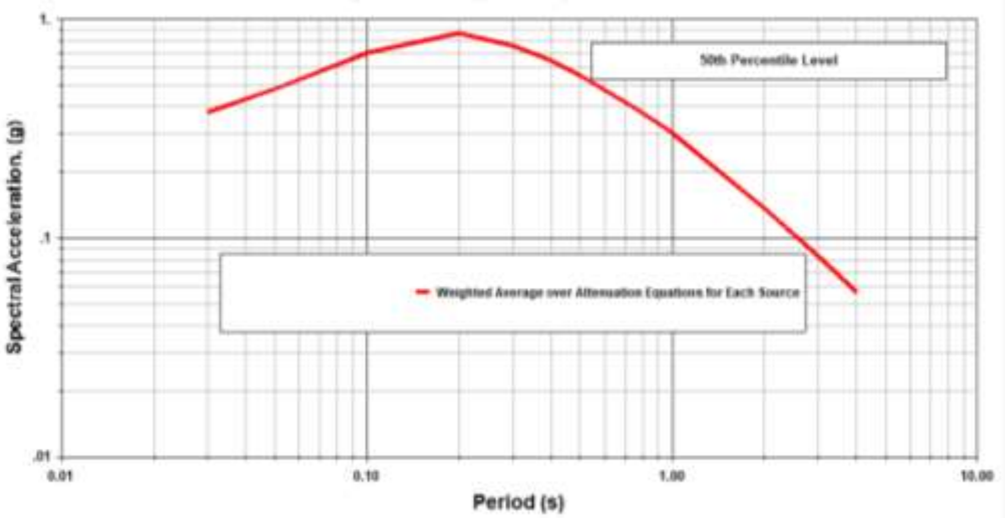

Figure 8-4 Deterministic Spectra at 50th Percentile Level Weighted Average

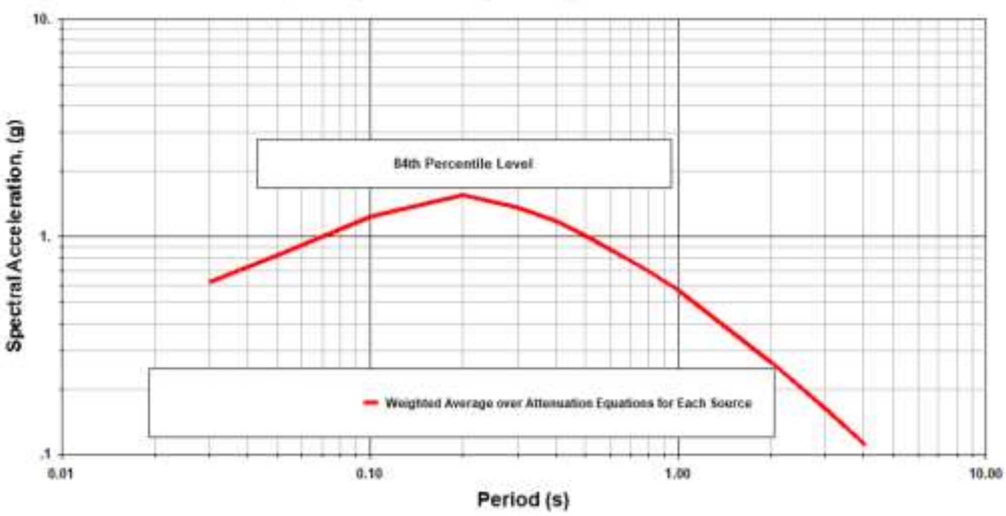

Figure 8-5 Deterministic Spectra at 84th Percentile

8.7.1 Deterministic Pseudo Spectral Acceleration (PSA)

Pseudo spectral acceleration has been worked out using the latest version of R-CRISIS software. Pseudo spectral acceleration Vs time is given in **Figure 8-6**.

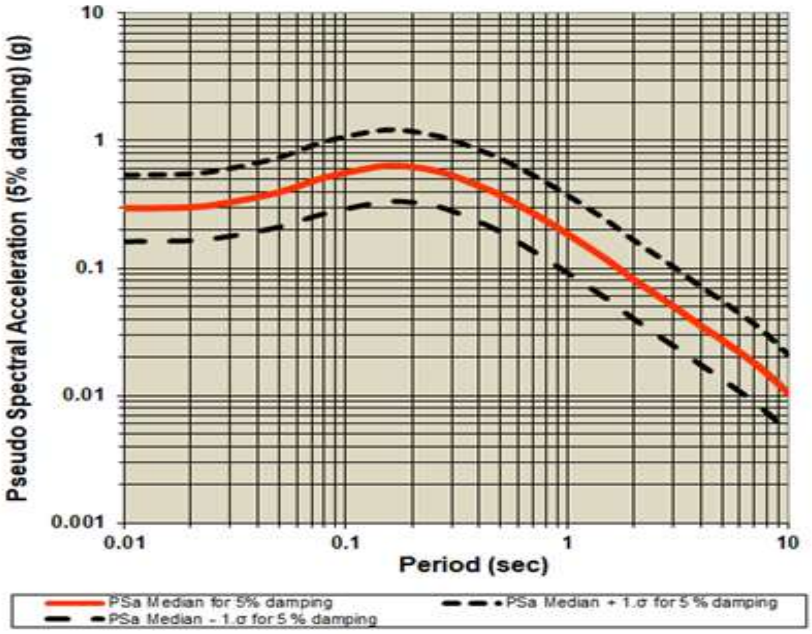

Figure 8-6 Deterministic pseudo Spectral Acceleration (g) at 5% Damping.

8.8 SELECTION OF SEISMIC DESIGN PARAMETERS

8.8.1 Safety Evaluation Earthquake (SEE)

As per ICOLD guidelines (2016) the Safety Evaluation Earthquake (SEE) will produce the maximum level of ground motion for which the dam should be designed or analyzed. For dams whose failure would present a great social hazard, the SEE will normally be characterized by a level of motion equal to that expected at the dam site from the occurrence of deterministically evaluated MCE or of the probabilistically-evaluated SEE earthquake ground motion with a very long return period, for example 10,000 years for high consequence large dams. Depending on the circumstances e.g. the importance of the dam, the consequences of a dam failure, it is recommended to design safety-critical elements such as the bottom outlet and/or spillway gates for the SEE. It will be required at least that there is no uncontrolled release of water when the dam is subjected to the seismic load imposed by the SEE.

As per the latest ICOLD Guidelines, for medium consequence dams, median value (50th percentile level) is recommended whereas for high consequence dams, the SEE ground motion parameters should be estimated at median plus one (84th percentile level) if developed by a deterministic approach and need not have a mean annual exceedance probability (AEP) smaller than 1/10,000 if developed by a probabilistic approach. For a particular project of importance such as hydropower project, optimum percentile level may be any optimum percentile level between 50th percentile level to 95th percentile level. For ALHPP, 66th percentile level has been worked out and the same is recommended.

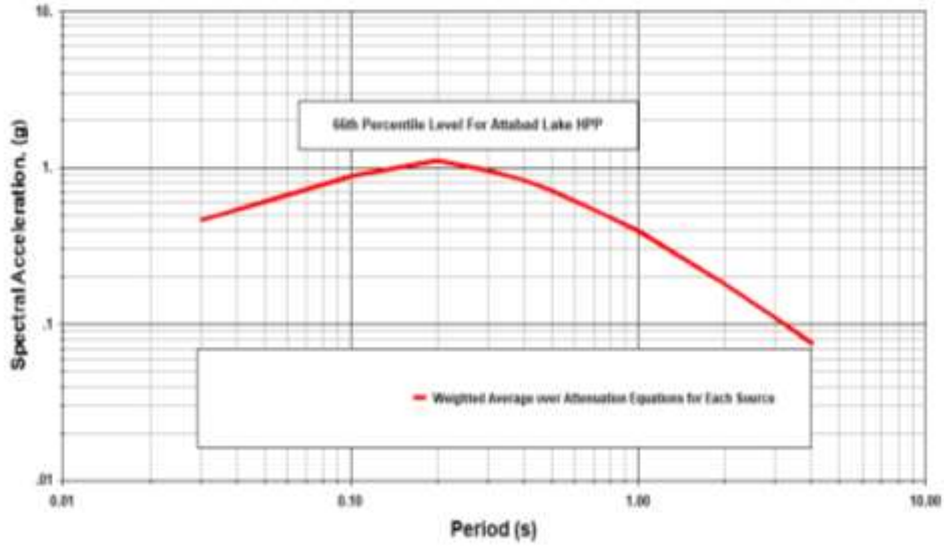

Figure 8-7 Deterministic Spectra at 66th Percentile Level of SEE.

8.8.2 Operating Basis Earthquake (OBE)

The Operating Basis Earthquake (OBE) represents the level of ground motion at the dam site at which only minor damage is acceptable. In theory the OBE can be determined from an economic analysis, but this is not always feasible and, in many cases, it will be appropriate to choose a return period of about 145 years (i.e. a 50 % probability of not being exceeded in 100 years). The dam, appurtenant structures and equipment should remain functional and damage easily repairable, from the occurrence of earthquake shaking not exceeding the OBE.

Since the consequences of exceeding the OBE are normally economic, the circumstances in a particular case may justify use of a more severe or less severe event for the OBE. The resulting return period depends on prevailing conditions.

Because of the above definition, the OBE is the best determined by using probabilistic procedure. OBE ground motions are significantly lower than those for SEE.

8.8.3 Uniform Hazard Spectra (UHS)

Uniform hazard spectra for ALHPP for OBE (145 year return period), DBE (475 year and 2475 years return period) and SEE (10,000-years return period) are presented as **Figure 8-8.**

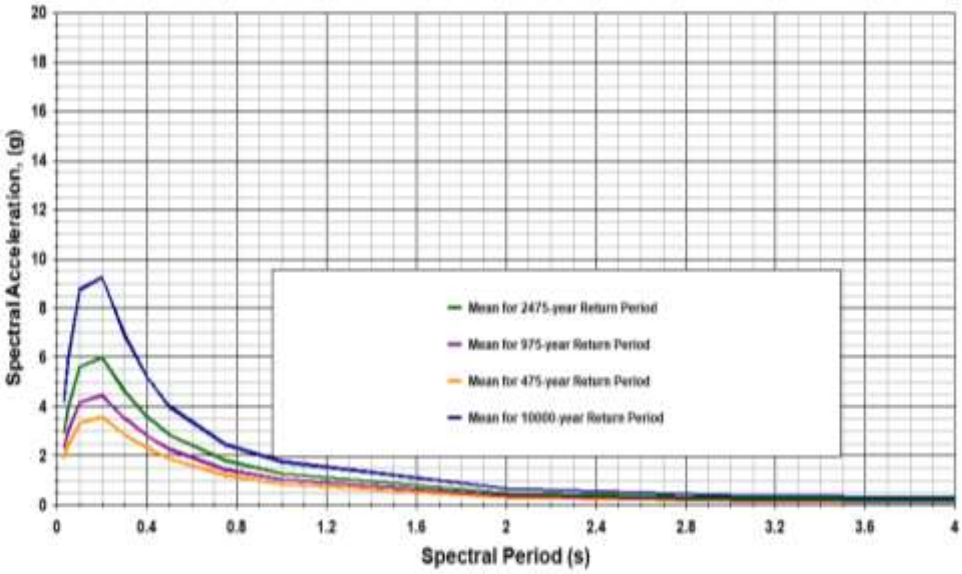

Figure 8-8 Uniform Hazard Spectra (UHS) showing mean hazard for various return periods.

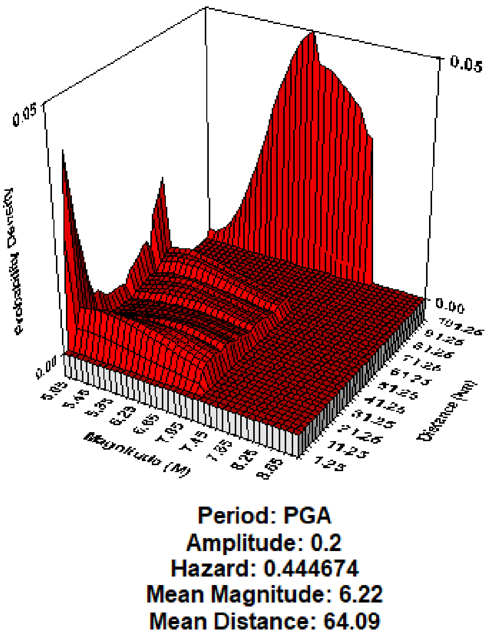

Figure 8-9 Deaggregation of Mean Hazard, Mean Magnitude and Mean Distance.

8.9 CONCLUSION AND RECOMMENDATIONS

Based on the analysis results, the following earthquakes design parameters are concluded and recommended for ALHPP.

<u>Operation Basis Earthquakes (OBE):</u>

OBE at return period of 145 years is recommended as follows:

OBE Horizontal = 0.24 g

OBE Vertical = 0.17 g

Safety Evaluation Earthquakes (SEE):

For the design of dam / weir, the following PGA ‘g’ values for SEE (Safety Evaluation Earthquakes) are recommended:

SEE Horizontal = 0.44g

SEE Vertical = 0.29g

For the design of appurtinent structures including spillway, the following PGA ‘g’ values for SEE (Safety Evaluation Earthquakes) are recommended:

SEE Horizontal = 0.38g

SEE Vertical = 0.26g

9 CONCLUSIONS

- The Project Area lies in Karakorum Block, where rocks of meta igneous provenance are exposed. The rock units represent acidic igneous rocks including Granodiorite and Granitic Gneiss.
- The Project Area lies in the vicinity of collisional tectonic belt, bounded by Main Karakoram Thrust (MKT) in south and Karakorum Fault (strike slip) in northeastern margin. Many local as well as regional faults are present in Project Area.
- Different surface and subsurface investigations including surface geological mapping, drilling, neo-tectonic studies and seismic hazard analysis have been carried out during Feasibility Study. It is observed that overall the area is tectonically disturbed, many deformational features are illustrious of recent operative compressional forces in recently deposited material.
- Different laboratory tests regarding geotechnical parameters for design and foundation evaluation have carried out in the field and in laboratory. The rock core samples as well as soil samples (from UDS and SPT) from different test pits regarding different structures and borrow area have been carried out in Central Material Testing Laboratory (CMTL) Lahore.
- The geotechnical investigations carried out during Feasibility Study indicates that weir is founded at overburden material consist of slided mass. High permeability values encountered during drilling in all borehole is indicative of gaps/cavities in subsurface. One of the major task is to control the seepage through slided mass for the stability of weir and other appurtenant structures. Slope stability at both abutments of weir and sediment flushing channel is very important and crucial task in this regard.
- All the appurtenant structures i.e. sediment flushing channel, power tunnel, surge shaft, penstock and power house are proposed on left side of Hunza River.
- During the Neo-tectonic studies it is observed during field work that there are many active surface geological features regarding the recent tectonic activities operating in the vicinity of the Project Area. These features have been incorporated as parameters in calculation of Peak Ground Acceleration (PGA) “g” value in Seismic Hazard Analysis.
- Both fine and coarse aggregates for construction of overtopping concrete weir and other associated structures are present in the vicinity of Project Area in ample quantities. Clayey silt for blanketing/impervious material, coarse aggregate and rip rap have been investigated and proposed as barrow area while sand and fill materials are proposed to be excavated from river bed.

10 RECOMMENDATIONS

- As active tectonic forces are operative in this area, it is quite important that all the structures should designed according to peak ground acceleration “g” value calculated by seismic hazard analysis.
- The active tectonic forces are responsible for the rolling down of Attabad Slide. Some additional investigations should be carried out at right side slope. At different locations installation of inclinometers and fixation of telltales (Glass strips)/movement pins should be carried out during DED to observe the ground motion.
- Clay blanketing/grout curtain may be required to control the seepage especially through the foundation of weir and sediment flushing channel.
- Special attention should be given for the stabilization of slided mass at both banks of Hunza River, especially along sediment flushing channel and weir area.
- Ample quantity of Angular Boulder Gravels (ABG) present in slided material falls in permissible limits as perceived by laboratory testing. It can be used as rip-rap material to stabilize the slope in upstream area.