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Detailed Geophysical-ERT Investigation for Structural Design of Imja Lake Lowering

For

Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP)

Final Report

Submitted by: MEH Consultants Pvt. Ltd. (MEH), Kathmandu, Nepal

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Executive Summary

The Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP) intendeds to reduce human and material losses from GLOF from Imja Lake (5010 m) in Solukhumbu District by reducing the GLOF hazard risk in 27 settlements in the downstream valley by reducing Lake Level by more than 3 m through construction of an open channel. As a part of the project the task of "Detailed Geophysical-ERT Investigation for Structural Design of lmja Lake Lowering" was awarded to the MEH Consultants Pvt. Ltd. Kathmandu. The project period was from 30 September to 31 December, 2014. The main objectives of the work were (i) to identify at least 3 most suitable open channel alignments, (ii) to prepare longitudinal and transverse profile using ERT, (iii) to provide geological, geotechnical, geophysical-ERT related inputs to the survey and design thematic team for the selection of appropriate design parameters and safety measures and (iv) and to recommend remedial measures for digging out open channel by more than 3 m for mitigating adverse effects if any on buried ice, seepage and piping etc.

The study was carried out in four phases, namely, desk study, field study, laboratory analysis and office work. The base line information on geophysical, geological and geotechnical results by the previous workers related to glaciers, GLOFs and Imja Lake in Nepal were collected and reviewed during the desk study phase. Field investigation (ERT survey, geological and geo-technical studies) was carried out at the Imja Lake area from 10 October to 5 November, 2014. Laboratory tests were carried out to evaluate the properties of soil and construction material. The office work included data interpretation, preparation of geological maps, cross sections, evaluation of alternative open channel alignments and to recommend appropriate appropritate design parameters and safety measures.

The Imja Lake lies geologically in the Higher Himalaya of Nepal with metamorphic crystalline basement rocks such as gneisses, schists and granite. An E-W extending regional normal fault system (South Tibetan Detachment System) passes from just north of the Imja Lake. Regional seismic data show that this area lies in one of the seismically high hazard zones of the Nepal Himalaya. The minimum peak ground acceleration (PGA) value for this area is 400 gal for 10% exceedace in 50 years.

The topography of the end-moraine complex forming the dam of the Imja Lake is uneven with several linear depressions that are parallel/sub-parallel to the existing channel. The depressions represent the paleo-channels of the lake drainage. The natural slopes of side valleys and moraine dam surface is mostly stable (<30°). A few thermokarsts and isolated ponds are present in the NE part of the lateral moraine. They are away from the proposed canal alignments and will not have significant impact on the stability of the dam.

Although the strength of the moraine could not be estimated with the help of Schmidt Hammer Test, testing of individual boulders show they are made up of high strength materials. The rock boulders are suitable for rip-rap and gabion constructions. In-situ permeability test shows that the material is highly permeable with permeability value ranging from 0.004 to 0.353. This permeability value should be considered as minimum for the area as the tests were carried out at sites with materials dominated by fine sediments.

The end-moraine material is made up of very inhomogeneous, poorly sorted angular clasts ranging in size from fine clay to several meters large boulders. The fine material in the end-moraine (after removal of boulder and cobble) is mostly gap-graded and non-plastic. It implies that the fine soil also have high permeability.

Quarry sites for construction material have been identified at three places. One site is located between existing channel and alternative alignment L1 (south of existing channel), the other two sites are between alternative alignments R1 and R2 (north of existing channel). Laboratory tests carried out on materials finer than cobble and boulder show relatively higher alkali reactivity (900 to1139) and flakiness index (30%). Therefore, the materials are not suitable to use as aggregate in natural condition. However, the aggregate quality may be improved by addition of missing grade, use of low-alkali cement and removal of flaky materials by sieving /washing. The maximum quantity of gravel and sand that can be extracted from three sites is approximately 8500 m^3 and 6800 m^3, respectively.

The ERT investigation was carried out along five longitudinal and five transverse profiles of 200 to 300 m length. Based on the apparent resistivity values, the sub-surface materials have been divided into water-saturated moraine (resistivity<2,500 Ωm), frozen moraine (resistivity=2,500-20,000 Ωm) and dead ice (resistivity>20,000 Ωm). ERT data show that dead ice is present at the

moraine in the form of isolated patches to massive sheets reaching thickness more than 25 m. Low-resistivity zones (<2500 Ωm), more likely to represent the water-saturated moraine, were found almost along all the ERT profile lines. Similar results were obtained from the GPR survey along the ERT profile lines.

The four alternative canal alignments selected by surface observations have been evaluated on the basis of various parameters such as level of dead ice with reference to lake level, geo-technical strength of soil, field permeability, presence of instabilities, slope of canal alignment, and depth of excavation required to drawdown the lake level by 3 m. The ERT investigation shows that the R2 and L1 are not feasible for 3 m draw down of the Imja Lake as the canal will approach to the dead ice along R2 and will cross the dead ice along L1.Remaining two alignments (R1 and EC) are feasible for construction of canals for lowering of the Imja Lake by 3 m and also for the construction of power canal/diversion canal. The existing channel (EC) is the most suitable alignment because the dead ice is absent, length of alignment is minimum (210 m), depth of excavation is minimum (3 m) and slope of the alignment is gentle.

Following recommendations have been made from the present study:

1. The existing channel has been recommended as the best alternative for the drawing down of the Imja Lake by 3 meters from geotechnical and geological points of view. The R1 is suitable for power canal and DC is suitable for diversion canal.

2. The fact that the area lies in the seismically high hazard zone (PGA>400 gal) should be considered during designing of any engineering structures.

3. Appropriate lining materials such as geomembranes should be used to reduce the permeability of the channel bed and banks.

4. Either angular aggregates should be mixed or flaky aggregates should be removed by sieving/washing process to reduce the flakiness index of the fine aggregates.

5. Low-alkali cement or slag cement should be used to reduce the alkali-silica reactivity of aggregates.

6. The moraine is not consolidated and could be easily destabilized during excavation. Therefore, the slopes of the canal banks and canal profile should not be greater than 30°. Appropriate measures such as stone rip-rap should be applied to protect the channel bed and banks from scouring and failure.

7. The surface of dead ice is very irregular. Slight deviation of canal alignment may transect the dead ice and destabilize the dam. Therefore, excavation should be made exactly along the recommended alignment.

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List of Acronyms

CBEWS: Community Based Early Warning System

CFGORRP: Community Based Flood and Glacial Lake Outburst Risk Reduction Project

DC: Direct Current

d-GPS: Differential Global Positioning System

DHM: Department of Hydrology and Meteorology

DNPWC: Department of National Park and Wildlife Conservation

ERT: Electrician Resistivity Tomography

GLOF: Glacial Lake Outburst Flood

GPR: Ground Penetration Radar

GSHAT: Global Seismic Hazard Assessment Program

HKH: Himalaya-Karakoram-Hindukush

HMGWP: High Mountain Glacier Watershed Program

IS: Indian Standard

KU: Kathmandu University

MBT: Main Boundary Thrust

MCT: Main Central Thrust

MFT: Main Frontal Thrust

MHz: Mega Hertz

MoHA: Ministry of Home Affairs

MW: Mega Watts

NPD:National Project Director

NPM: National Project Manager

PGA: Peak Ground Acceleration

PMU: Project Management Unit

RMR: Rock Mass Rating

RRCAP: Regional Resource Centre for Asia and the Pacific

STDS: South Tibetan Detachment

TAG: Technical Advisor Group

UNDP: United Nations Development Programme

UNEP: United Nations Environment Programme

UNU: United Nations University

USAID: United States AID

USCS: Unified Soil Classification System

VDCs: Village Development Committees

WECS: Water and Energy Commission Secretariat

1. Introduction

1.1. Background and Context

Recent reports have indicated that glaciers continue to retreat worldwide as a result of contemporary warming trends. Twenty four new glacial lakes have formed and thirty four have grown significantly during the past 50 years in the Mt. Everest region of Nepal. The appearance and danger posed by glacier lakes in this region has prompted calls for assessments of the increasing risk to communities downstream of the lakes, and in some cases implementation of risk reduction actions (e.g., at Tsho Rolpa, and proposed for Imja Lake). The Khumbu region of Nepal has experienced two Glacial Lake Outburst Flood (GLOF) events in recent years. One of them is Nare in 1977 and the other is Dig Tsho in 1985. Both the GLOFs caused substantial damage downstream. Twelve new and/or growing lakes within the Dudh Koshi watershed of the Khumbu region have been designated as “potentially dangerous glacial lakes” based on the use of time-lapse satellite imagery. Imja Lake, located in the Khumbu region of Nepal (27.9^o N, 86.9^o E), has been investigated for more than 20 years. The lake has experienced particularly rapid growth in area and volume since the early 1960’s, leading to concern over the risk of a catastrophic GLOF event. Imja Lake is thought by some to be among the most dangerous glacial lakes in the Khumbu region. A GLOF event would result in significant downstream damage, e.g., upon the village of Dingboche and Phakding, 8 km and 33.6 km downstream of the lake’s outlet, respectively. ICIMOD (2011) reported that the vulnerable population in village areas downstream of Imja Lake is about 96,767, and that as many as 7,762 people likely would be affected directly by a GLOF event.

Present project intended to reduce human and material losses from GLOF from Imja Lake (5010 m) in Solukhumbu District by reducing the GLOF hazard risk in 27 settlements in the downstream valley by reducing Lake Level by more than 3 m through construction of an open channel.

Community Based Flood and Glacial Lake Outburst Risk Reduction Project/ Department of Hydrology and Meteorology (CFGORRP/DHM) intended to hire a service provider (Geophysical ERT Team) for undertaking “Detailed Geophysical-ERT Investigation for lmja Lake Lower Design” (Service) for input to technical design of the Lake lowering. The Geophysical-ERT assessment work was awarded to the MEH Consultants Pvt. Ltd., Kathmandu, Nepal and a contract

agreement was signed between MEH Consultants Pvt. Ltd. (Contractor) and UNDP on 30 September, 2014. The contract period was from 30 September to 31st December, 2014. The field work was carried out from 10 October to 5 November, 2014.

The tasks assigned for the Geophysical-ERT team (see TOR in Annex I) have been completed. This report presents the details of the methodology adapted for the study, findings and recommendations of the study.

- Review on scientific assessment data on Glacial Lake and GLOFs in Nepal including scientific assessment data on Imja Glacial Lake.
- Geological maps, cross-sections and ERT-sections.
- Interpretation of geophysical-ERT results to confirm the sub-surface features.
- Laboratory test results of soil, rock and construction material samples.
- Recommendation on best alternative for open channel alignment.

1.2. Study Area

The study area is lmja Lake and its associated glaciers and the moraine dam at 5010 m in Solukhumbu District, east Nepal (Figures 1 and 2). The study area is remote and inaccessible by road and the nearest airport is at Lukla. The trekking routes are through Namche, Tengboche, Pangboche, Dingboche, Chhukung and finally to lmja Lake. The hotel facilities are available from Lukla to Chhukung. It takes about 6 days trek from Lukla to reach the Imja Lake. Camping and food had to be arrange during entire field work in the Lak area.

The Imja Lake is among the 20 most potentially dangerous glacial lakes identified by ICIMOD in 2010, and one of the most high-risk glacial lakes in the entire Hindu Kush-Himalayan region based on the rate of growth of the lake. The lake did not actually exist in the early 1960s. Satellite images at the time indicate only a few small supraglacial ponds in its present location. Between 1975 and 2002, the area of the lake grew rapidly from 0.3 km^2 to 0.86 km^2 (Bajracharya et al. 2007). The rate of retreat of the Imja Glacier is among the highest recorded in the Hindu Kush-Himalayan region at a staggering 42 meters per annum from 1962 to 2009 (ICIMOD 2009).

Figure 1: Location of the Imja Lake.

Figure 2: Imja Lake and surrounding in Google map.

The first topographic survey of Imja Glacial Lake was done in April 1992 by Yamada (1992). Topographical survey was carried out at the end moraine and the dead ice area of the Imja Lake in October 2001 and in April 2002 by the team of Akiko Sakai (Sakai et al. 2007) and Watanabe et al. (1995). ICIMOD with the help of various Nepalese academic and governmental organizations carried out topographic survey of Imja Lake from 4 May to 2 June 2009. First bathymetric survey of Imja Lake was conducted by WECS in 1991 (WECS 1991). During the survey the study team observed 99 m of maximum depth of Imja Lake. Further they calculated the melting rate at the bottom of the lake which was estimated to be 3.3 m $year^{-1}$. A bathymetric survey conducted by a team of Somos-Valenzuela between September 22 and 24, 2012 using a Biosonic Echo-Sounder MX sonar unit mounted on an inflatable raft (Somos-Valenzuela et al. 2014). According to the survey the maximum depth has increased from 98 m to 116 m since 2002, and that its estimated volume has grown from 35 million m^3 to 63.8 million m^3.

Reducing the volume of Imja Lake through an artificial controlled drainage system was identified as the most suitable GLOF mitigation measure, combined with a system to monitor the risks of a GLOF at Imja Lake and a low-tech community-based EWS (CBEWS).

2. Objectives and Scope

The main objectives of the present study are as follows:

a) To identify at least 3 most suitable open channel alignments (longitudinal profile) and conduct transverse profile at suitable spacing for 3D profile to assess sub-surface conditions of the moraine dam from ERT.

b) To prepare longitudinal, transverse and 3D profile using ERT.

c) To provide geological, geotechnical, geophysical-ERT related inputs to the survey and design thematic team for the selection of appropriate design parameters and safety measures.

d) To recommend remedial measures for digging out open channel by more than 3 m for mitigating adverse effects if any on buried ice, seepage and piping etc.

The work was carried in four phases namely inception, field investigation, draft report preparation and final report preparation phases. The main task during the inception phase was to gather

baseline information on geophysical, geological and geotechnical results by the previous workers and to make field work plans and strategies. Field work was carried out to select at least three best suitable open channel alignments with consultation with other thematic teams. The main scope of the field work was to carry out ERT longitudinal and transverse profiling, to carry out geological and engineering geological investigation, geo-technical field tests, construction material survey, assessment of instabilities and sampling of rocks, soils and construction materials. The main scope of the work during the draft and final report preparation phases was to prepare geological maps, cross-section, to interpret the ERT results to confirm the sub-surface features, to carry out various laboratory tests on soil and construction material samples and to provide geophysical and geotechnical/geological assessments and provide design inputs to the survey and design thematic teams.

The scope of the present work has been elaborated in the TOR in Annex I.

3. Methodology

Present study involves desk study, field study, laboratory testing and office work. Desk study was carried out during the inception phase.

3.1. Desk Study

Results of previous works related to the Imja Lake published in various reports and journals were reviewed, field investigation tools and techniques were finalized, work plans and schedules were prepared and data collection sheets were prepared during the desk study phase. Equipments to be carried to the field were verified and checked and logistic arrangements were made for the field work.

3.2. Field Study

Field study was carried out for the Electric Resistivity Tomography (ERT) Survey and geological and engineering geological study.

3.2.1. Electrical Resistivity Tomography (ERT) Survey

Electrical resistivity tomography (ERT) is a geophysical technique for imaging sub-surface structures, based on the electrical properties of subsurface materials, from electrical resistivity measurements made at the surface. Apparent resistivity values are measured by resistivity meter and are converted to true resistivity by mathematical inversion method. The final resistivity model is interpreted based on resistivity values to obtain a geological model of the ground. In general, water saturated layers and clay rich layers tend to have lower resistivity value, and high resistivity regions generally indicate bedrock or presence of ice in the subsurface. Approximate resistivity values for some geological materials and ice has been given below (Table 1).

Table 1: Resistivity of common geological materials and dead ice.

Material	Resistivity Ω m	Resistivity Ω m
Groundwater	10-100	Loke (1999)
Alluvium	10-800	Loke (1999)
Sea water	0.2	Loke (1999)
Clay	1-100	Loke (1999)
Sandstone	$8\text{-}4x10^3$	Loke (1999)
Limestone	$50\text{-}4x10^2$	Loke (1999)
Quartzite	$100\text{-}2x10^8$	Loke (1999)
Matrix rich morainic material	<1000	Hausler et al (2000)

Coarse clastic morainic material	5000-10000	Hausler et al (2000)
Debris with melting ice	10000-20000	Hausler et al (2000)
Dead Ice	$1000\text{-}10x10^5$	Hausler et al (2000)
Dead Ice	>10000	ESS (2008)

In the present study "ABEM Terrameter SAS 300C" resistivity meter was used for the ERT survey. Data acquisition was implemented utilizing Dipole-Dipole electrode array. Data Processing was done using standard software (RES2DINVx32 ver. 3.71) manufactured by GEOTOMO (Malaysia). The instrument can measure resistivity from as low as 0.05 miliΩm to 1999000 Kilo Ωm. For every ERT profile line an Inverse Model Resistivity Calculation was applied using computer software to estimate required true resistivity sections beneath the profiles. The resistivity sections were transformed into geo-electric sections showing the possible geological formation including their boundaries. Such geo-electric sections were presented as "Geo-cross Section" for each ERT profiles of at the end moraine of the Imja Lake. Details of the ERT principles have been given in Annex II.

3.2.2. Engineering Geological Field Study Methods

3.2.2.1. Geological and Engineering Geological Mapping

The field study was carried out with the help of Brunton compass, geological hammer, measuring tape; topographic base maps, GPS, altimeter, digital camera, hand lens and 10% dilute Hydrochloric Acid etc.

At first reconnaissance survey was carried out across different sections in the study area to have an idea about the overall bedrock geology and moraine materials. Regional geological mapping of the project area and its surroundings was carried out in 1:10,000 scale. Geological information was gathered both by the direct field observation and interpretation of the Google map.

Engineering geological mapping of the proposed canal alignment area was carried out at 1:5,000 scale. Topographic survey map prepared by the design and survey thematic team was used to plot the engineering geological information. Route traverse method was used to trace the important geological features such as rock outcrops, characteristics of the moraine deposit, unstable slopes, sink holes, thermokarsts etc.

Samples of bed rocks and moraine materials were collected for the laboratory tests.

3.2.2.2. Construction material survey

The construction material investigation was carried out to confirm the quality and quantity of different aggregates. The investigation was focused mainly on the identification of borrow areas and quarry sites for the fine and coarse aggregates within the easy haulage distance from the proposed canal alignment. To estimate the volume of different sized materials, samples were taken from 1m x 1m x 1m size test pits using hand shovel and peak. Then, cobble and bigger sized materials were separated manually in the field and volume of fine-grained materials (gravel and finer material) and coarse-grained materials (cobble and coarser grained materials) was estimated in the field. The volume of gravel, sand, silt and clay sized materials in the fine-grained materials taken from the given pit size was determined in the laboratory by standard sieving method.

In this way, volume of different sized materials for the given pit size (1 cu m) was determined. The volume of different-sized materials in the proposed quarry site was estimated by multiplying by the volume of proposed quarry site to the volume in given pit size.

3.2.2.3. Schmidt Hammer Test

When the plunger of the rebound hammer is pressed against the surface of the soil, the pring-controlled mass rebounds and the extent of such a rebound depends upon the surface hardness of the material. The surface hardness and, therefore, the rebound is taken to be related to the compressive strength of the material. The compressive strength was calculated using he following formula.

$$\text{Compressive strength} = 0.0126\ (R + 29.8) - 21.1\ \text{N/mm}^2$$

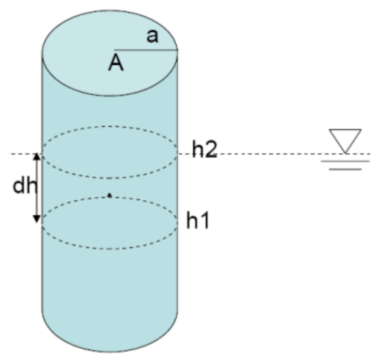
Where, R is the mean rebound number.

Schmidt Hammer Test was carried out in the individual boulders of moraine materials. It only gives the information about the strength of the individual boulder and does not have direct implication to the strength of the moraine mass.

*3.2.2.4. **Constant head permeability test***

The following procedure was followed to determine the field permeability.

- About 0.5 m diameter hole of about 1 m depth was prepared on the ground.
- A PVC pipe of about 3.5 cm diameter and 2 m height was erected on the hole.
- A measuring tape was laid on the inner wall of the PVC pipe to read the effective head of the water.
- It was then filled up with water.
- Water level drop was measured at 30 second interval for 6 minutes.



The permeability was calculated using the following equation.

$$k = \frac{1.4Q'}{\pi(dh)^2} \quad with \quad Q' = \frac{\Delta Q}{\Delta t} = \pi a^2 \frac{h_2 - h_1}{t_2 - t_1}$$

Where, k= coefficient of Permeability, cm/sec

Q= consumption of water in one minute, litre/min

a= radius of hole (cm)

h= effective head, cm

Δt= duration of time

3.3. Laboratory Tests

Samples of soil and aggregates were taken from different sites from the field for laboratory tests. Samples were collected only after removing the boulders and cobbles from the aggregates,

therefore the laboratory test results apply only for the finer materials (finer than cobble) of the end moraine complex.

Laboratory tests were carried out in accordance with IS standard specifications. The laboratory tests include grain size distribution; Atterberg limits (Liquid, Plastic and Shrinkage limits) for the soil samples of end moraine and compaction, gradation, dry density, specific gravity, unit weight, alkali reactivity and flakiness index for the aggregates.

Bed rocks from the side valleys of the Imja Lake were examined under the petrographic microscope to identify the exact rock type and textural properties. Detailed procedures of laboratory tests have been given in Annex III.

3.4. Office work

Geological maps, engineering geological maps and cross sections along with databases of the area were prepared using ArcGIS and AutoCAD and attributes were captured in digital format. Sub-surface features of the end-moraine complex were interpreted on the basis of ERT data and geo-electric sections, geological cross-sections and depth to dead ice maps were prepared. Best alternative channel alignment was recommended based on various parameters.

3.5. Reporting

Reports were prepared after completion of each phases of work and submitted to the DHM. Inception report was submitted after completion of desk study, field investigation report was submitted immediately after returning from the field, draft report was submitted after completion of all the laboratory tests and office work. This final report has been prepared after receiving feedbacks and comments from the Senior Technical Advisor (STA), Technical Advisory Group (TAG) and other project stakeholders.

The methodological scheme of the present work has been summarized in the flow chart (Figure 3).

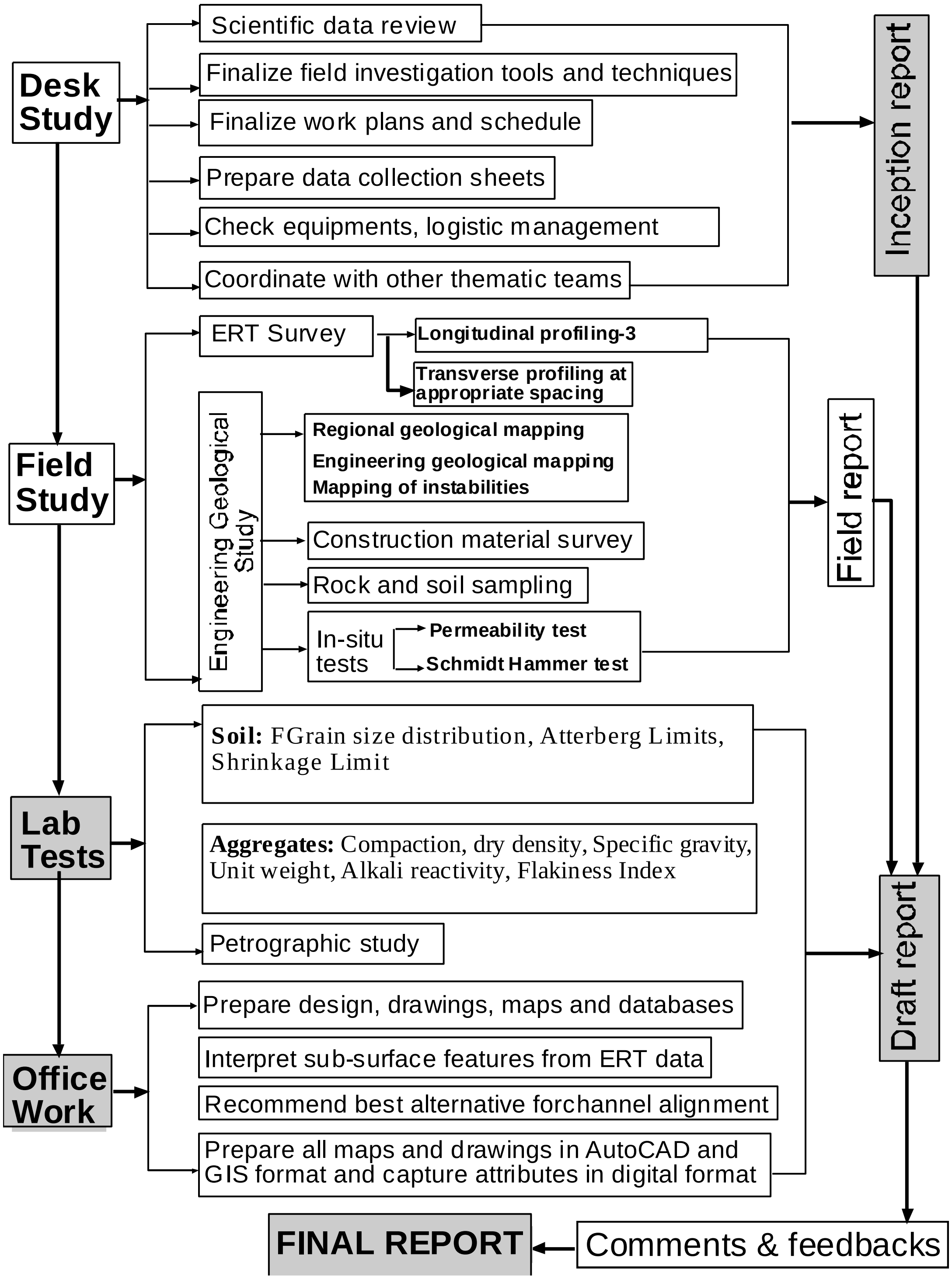


Figure 3: Methodological flow chart.

4. Limitations of the Present Study

There are some limitations for field data collection, laboratory testing and data analysis in the present study. One of the major constraints was bad weather during the field work time. The field work was started work from 10 October. Although first snowfall in the Imja Lake area was expected only in the first week of November, the area was affected by unexpected cyclone HudHud from October 7 to 14. The Imja Lake area received heavy snowfall and temperature dropped sharply creating a very adverse field condition. Therefore, data collection strategy was adversely affected by snow cover.

The end-moraine had very rouged topography, mostly covered by snow. The materials contained big boulders, moulds and depressions. This hampered to layout the systematic longitudinal and transverse profile in the area to gather uniform sub-surface data. Most of the ERT profiles had to be carried out, sometimes, in jig jag fashion due to obstructions by big boulders. Additionally, it was difficult to find proper place to insert the electrodes at the required site because of the presence of big boulders on the surface. The information within the 2.5 m depth from the surface was not detected due to electrode spacing (10 m) used in this study. The resolution of the image decreases both horizontally and vertically as the separation between the electrodes is increased to get deeper penetration in the investigation. If physically distinct two types of materials (layers) have similar electrical properties, the identification is complicated and interpretation might deviate from the true condition.

Regional geological mapping of the area was severely hampered by inaccessibility of the bedrock outcrops, steep slopes and snow covers. Most of the boundaries have been drawn on the basis of the distant observations and information gathered from Google map. Preparation of the engineering geological map of the end-moraine part was quite difficult due to covering of moraine material by snow. Therefore, the map is based on observation on limited exposures.

Schmidt rebound test is usually carried out to determine the compressive strength of intact materials (compact soil, bed rock or concrete). However, in the present area, the end moraine materials consisted of very loose and heterogeneous materials ranging from clay size particles to boulders of a few meters. Therefore, determination of compressive strength of moraine mass by Schmidt Hammer method was impossible.

Similarly field permeability test was carried out only in the places where the area is dominated by fine-grained materials (smaller than gravels). In some places the ground was frozen. Therefore, the real field permeability of the moraine material should be higher than estimated, and the design team should use the data accordingly.

The quantity of construction materials is estimated assuming that the area of consideration has homogeneous composition. However, in the present case, the moraine material is so heterogeneous and the grain size and properties of soil may change abruptly change both laterally and vertically. Therefore, determination of ratio of fine aggregates for a small pit and its projection into a large area may not be true. Therefore, the present estimation value should be considered as maximum value.

Soil samples for laboratory tests are biased because only fine-grained materials (gravel and finer materials) could be collected and transported to the laboratory. Therefore, the results presented on grain size distribution (d30, d60, d90), Atterberg limits etc. are only for the fine materials and do not represent the whole moraine materials.

5. Results of the Present Investigation

5.1. Tectonic Setting, Regional Geology and Seismicity of the Imja Lake Area

5.1.1. Tectonic Setting

The Himalaya was formed at the northern margin of the Indian sub-continent due to collision of the Indian and Eurasian plates in the Middle Eocene (Le Fort 1975). Nepal Himalaya can be divided, from south to north, as other regions of the Himalaya, into the following four major tectonic zones: (i) Sub-Himalaya (or Siwalik), (ii) Lesser Himalayan , (iii) Higher Himalayan, and (iv) Tethys Himalaya (Gansser 1964). Each of the zones is characterized by its own lithology, tectonics, structure and geologic history. Four major north-dipping thrusts, i.e., the Main Frontal Thrust (MFT), Main Boundary Thrust (MBT), the Main Central Thrust (MCT) and the South Tibetan Detachment System (STDS) divide these zones as shown in Figure 4. The Imja Lake area is confined to the Higher Himalaya between the MCT in the south and the STDS in the north. The Imja Lake itself is very near to the STDS.

5.1.2. Regional Geology of the Area

Regional geology of the Imja Lake area has been interpreted based on previously published data (Searle 2003) and observations during the present field work.

The regional geological map and cross section, and structural elements of the Imja Lake and surrounding area are given in Figure 5 and 6. The area lies in the Higher Himalaya made up of high-grade metamorphic rocks like calcareous gneisses and schists intruded by leucogranites. The South Tibetan Detachment System (a system of normal faults) extends E-W just north of the Imja Lake. The normal fault system has been locally named as Lhotse Detachment and Chomolongma Detachment (Figure 5 and 6). No other structural lineaments were observed in the field and Google map.

Geological mapping of the project area and its surroundings were carried out in 1:10,000 scale. The geological map and cross section of the area are given in Figures 7 and 8.

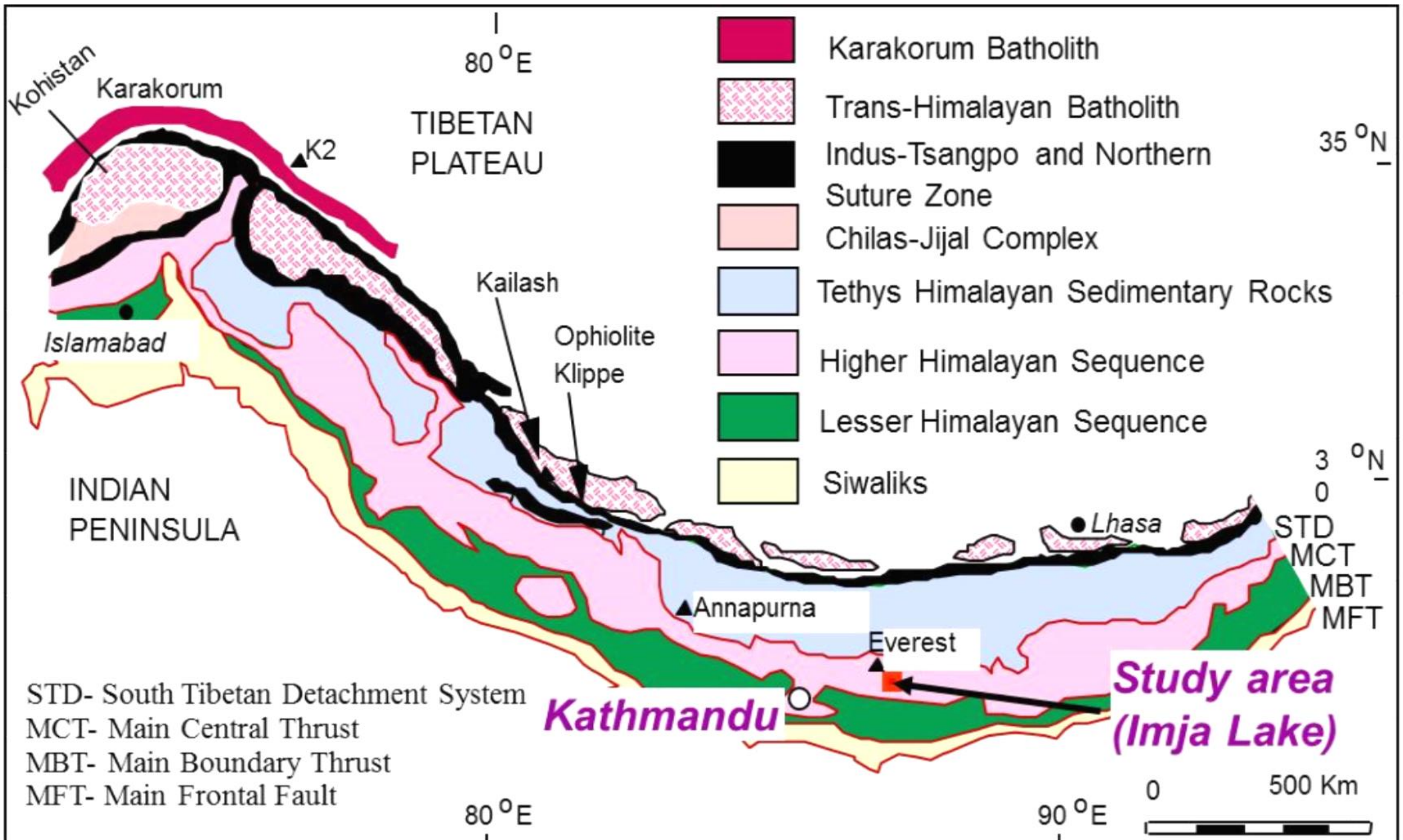


Figure 4: Tectonic setting of Imja Lake area (modified after Gansser 1964).

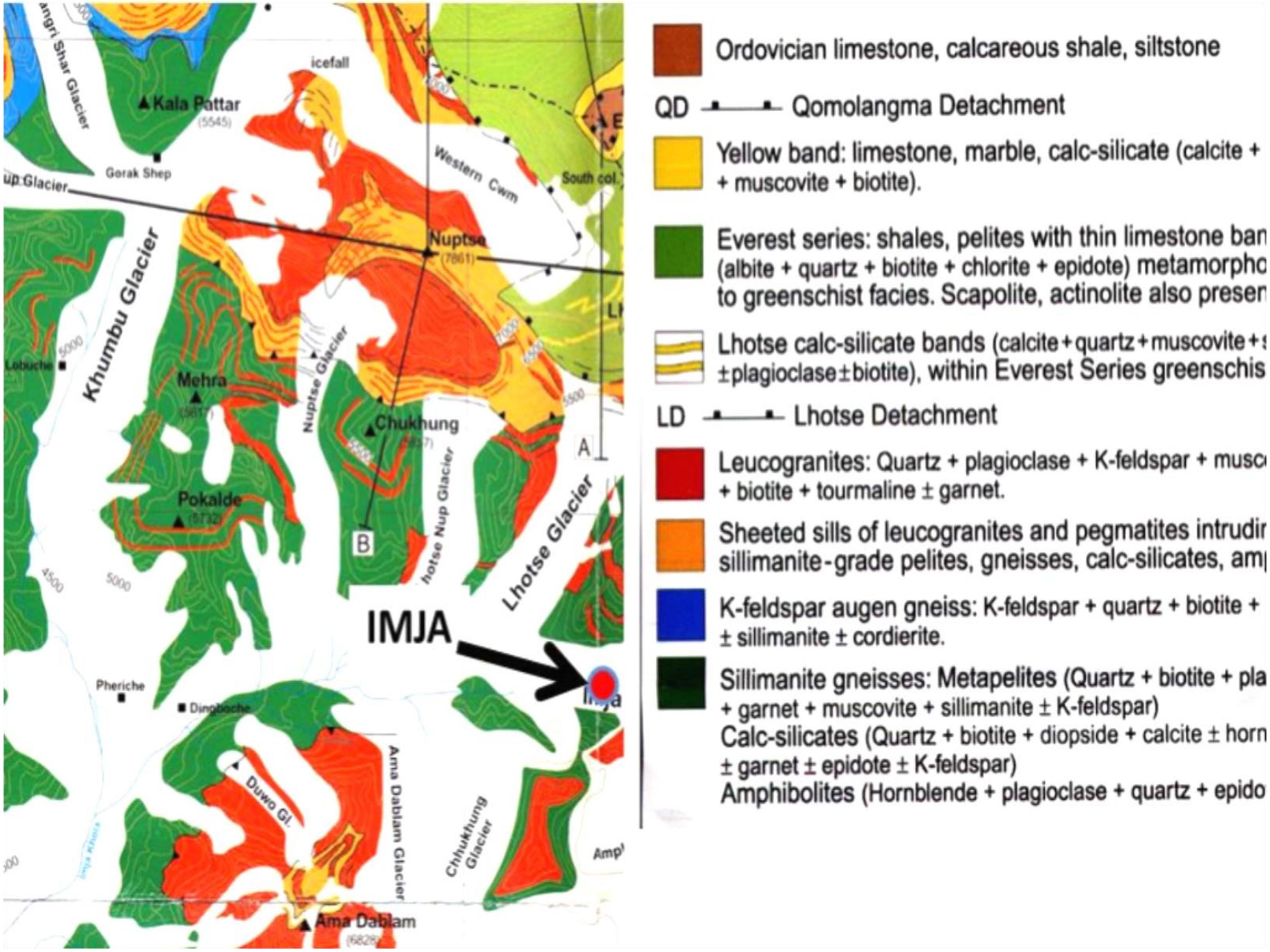


Figure 5: Geological map of the Everest region showing major rock units.

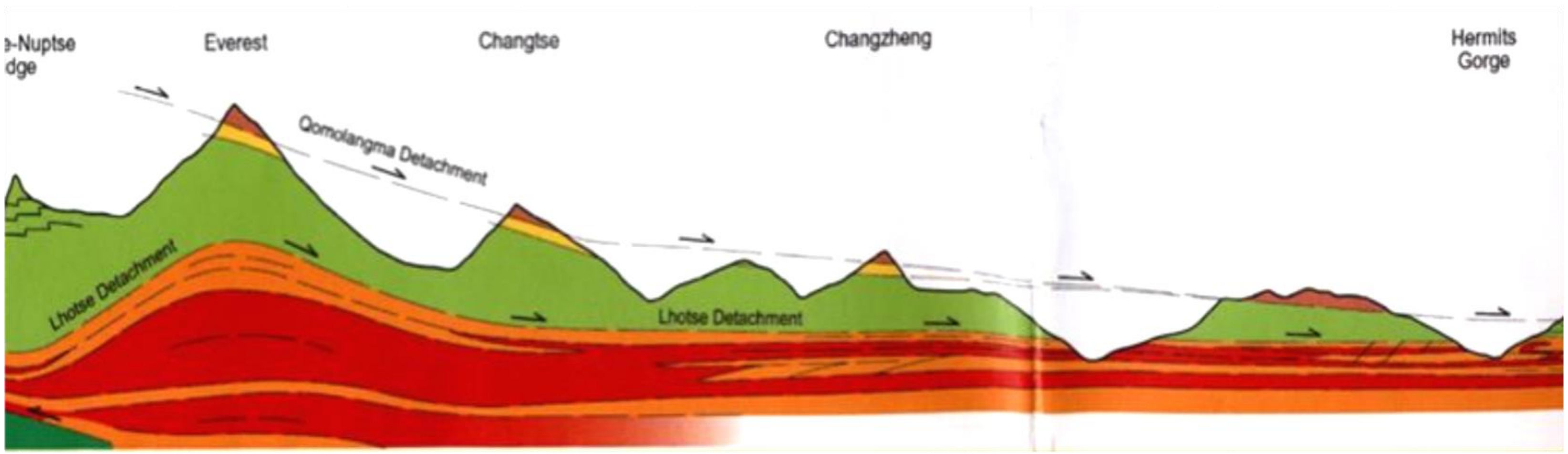


Figure 6. Geological cross-section across the Everest peak (modified after Searle 2003).

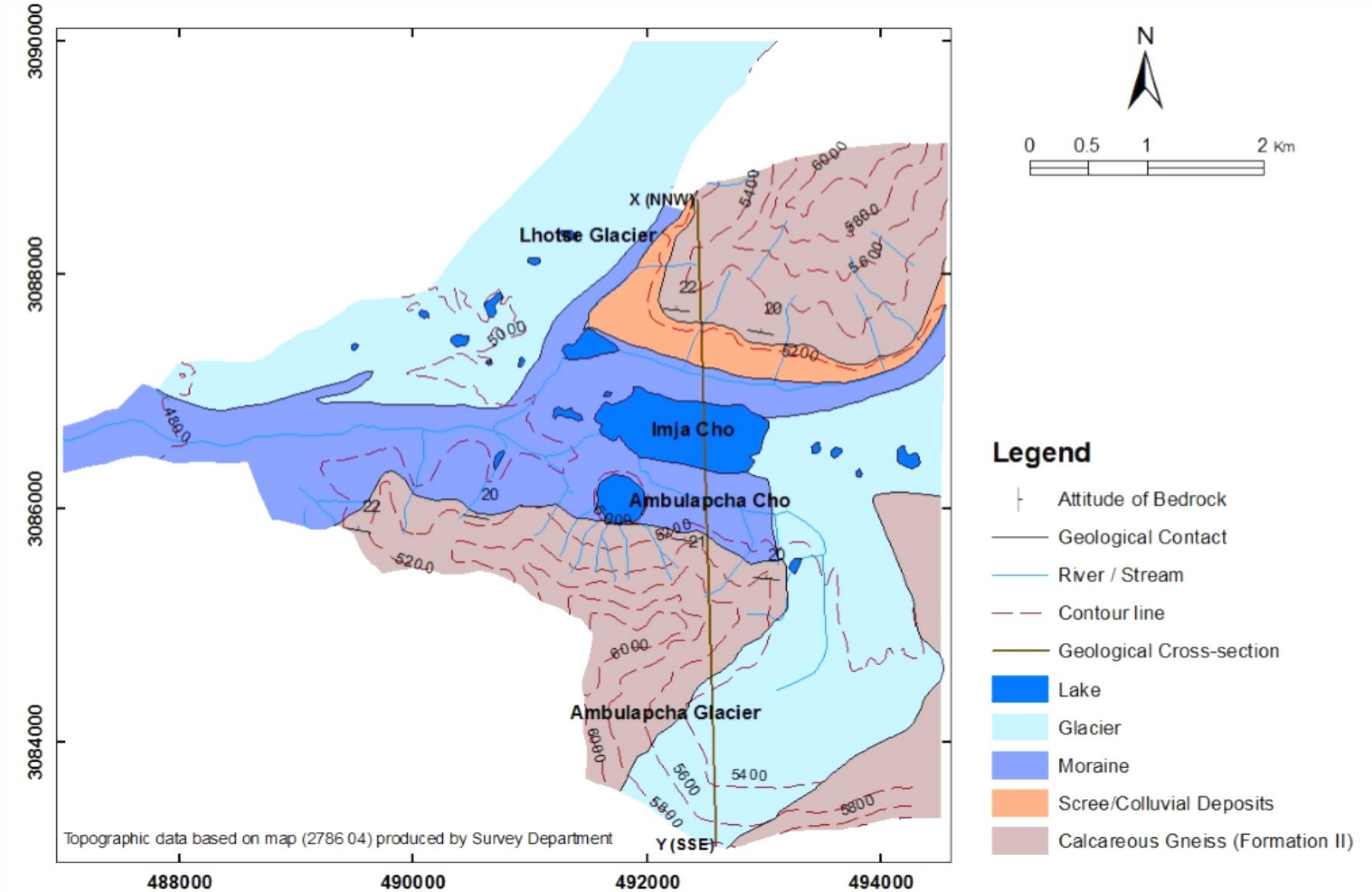


Figure 7: Regional geological map of the Imja Lake area.

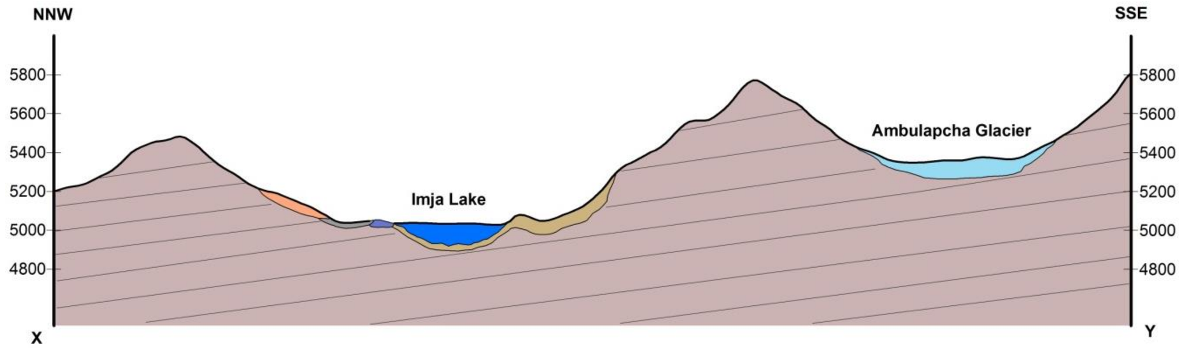


Figure 8: Geological cross section along XY.

Present work revels that the bedrocks of the project area geologically belong to the Higher Himalaya. It is composed of high grade metamorphic rocks like gneisses and schists and some intrusions of granitic veins. Rocks are gently dipping to the NW and show homoclinal structure. Thin sections were prepared from four bedrock samples collected from the side valleys to see the composition of the rock. The metamorphic rock samples are well-foliated, coarse-grained and crystalline gneisses. They are mainly composed of quartz, feldspar, mica, chlorite and garnet (Figure 9). The granitic sample is light grey, fine to medium grained. The rock sample is massive, highly indurated. Quartz, feldspar and biotite are principal mineral (Figure 10).

The Quaternary sediments of the area are mostly moraine materials deposited by various glaciers (Imja Glacier, Lhotse Glacier, Ambulophe Glaciers). The moraine materials fed by different glaciers have different composition due to difference in source. Generally, the moraine in the northern side is dominated by granite and pegematites whereas the moraine in the southern side is dominated by calcareous gneisses and schists. In the regions where the two glaciers meet, the composition of moraine materials is mixed.

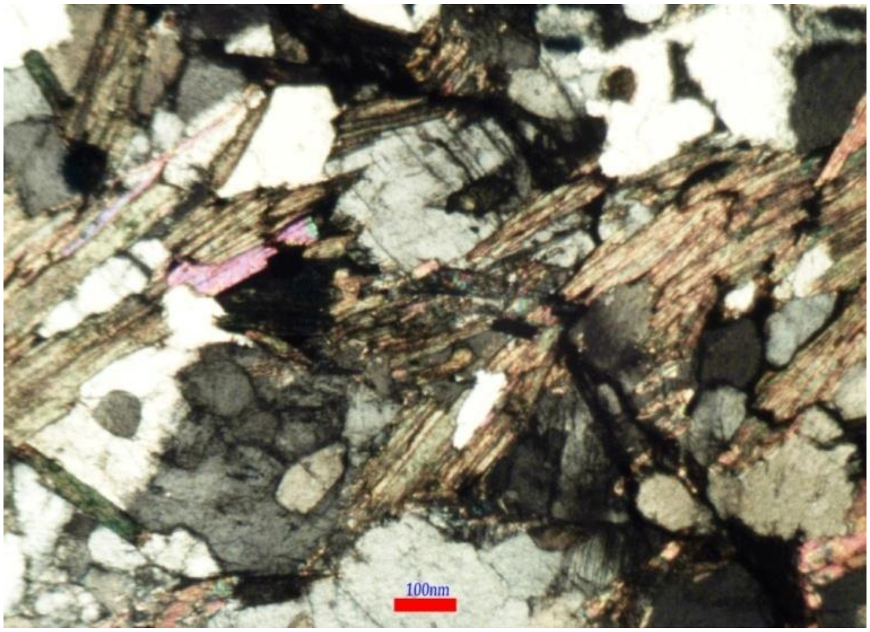


Figure 9: Photomicrograph of gneiss rock (sample L1a). This rock is dominated by flaky (muscovite and biotite) and elongated minerals (purple and greenish minerals) which makes the rock weak. It is the also the source of flaky minerals in construction aggregates.

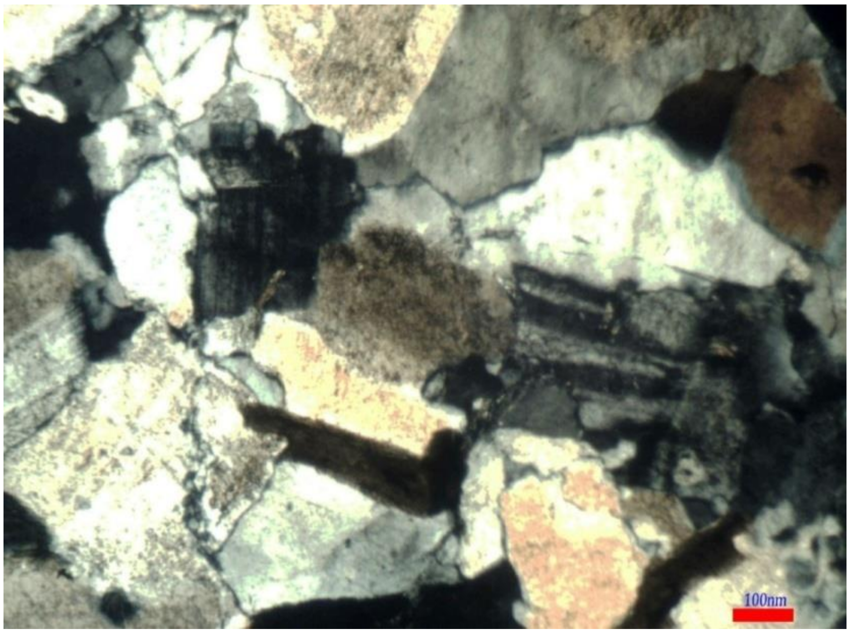


Figure 10: Photomicrograph of granite rock (sample L1). It contains equidimensional grains with interlocked boundaries. It makes the rock strong. The white and gray minerals are quartz and feldspars.

5.2. Seismicity of the Project Area

Earthquakes in the Himalaya are caused because of the ongoing indentation of the Indian Tectonic Plate into the Eurasia. Currently, the Indian Tectonic Plate is moving towards north at an average velocity of about 4 cm a year (Bettinelli et. al. 2006). Approximately half of this convergence is absorbed across the Himalaya resulting in the accumulation of stress in the region because of straining of the crust. Earthquakes occur when the accumulated stress overcomes strength of the rocks or strength of cementing material on the existing geological faults. In the Nepal Himalaya, the earthquakes occur in the depth range of 10 to 25 km.

The project site is situated close to the seismicity belt of Nepal that can be traced all along the Nepal Himalaya (Figure 11). Intense seismic activity has been noticed close to the project site. The belt can be well correlated with the front of the Higher Himalaya (Figure 12a), the maximum horizontal GPS velocity (Figure 12b) and maximum uplift rate (Figure 12c). Large earthquakes are believed to nucleate, at depth, beneath the front of the Higher Himalaya and propagate towards south.

The Main Himalayan Thrust (MHT) is the major geological structure beneath the Himalaya (Figure 12a). It separates underthrusting Indian Tectonic Plate from the overthrusting Eurasian Tectonic Plate. The Main Frontal Thrust (MFT), Main Boundary Thrust (MBT) and the Main Central Thrust (MCT) are inferred to join this mega thrust at depth (e.g. Rajaure et. al. 2013). Currently, the region between the MCT in the north and the MFT in the south is locked relative to stable India whereas the segment of the MHT beneath South Tibet is aseismically creeping. In the last decade the MHT has been imaged very well using electrical imaging technique and receiver function methods.

At present, the MFT is considered to be the most active fault system in Nepal considering the deformation of surface (e.g. Pandey et. al. 1999). This result is based on the study of deformed Holocene terraces along Bagmati and Bakeya Rivers south of Kathmandu (Lave. et. al. 2000). At the time of great earthquakes, it is believed that the nucleation of earthquake occurs at the geometrical ramp (Figure 12a) and propagates towards the south resulting in surface deformation and break close to MFT. Possibly MFT does not rupture during magnitude less than M 8.0 earthquakes and leaves the frontal area stressed to be ruptured in next great earthquake or with

smaller magnitude local earthquake in the south of the ramp. The other thrusts/faults are not considered very active in comparison to the MFT (Pandey et. al. 1999).

It is well known that Nepal falls in one of the seismically active region of the world. Global Seismic Hazard Assessment Program (GSHAP), which is an UN initiative, has published a seismic hazard map (Figure 13) of the region. The study area falls in a very hazard zone which has a peak ground acceleration (PGA) value of over 0.4 g (1 g = 9.8 m/sec^2) for 10 % chance of exceedance in 50 years.

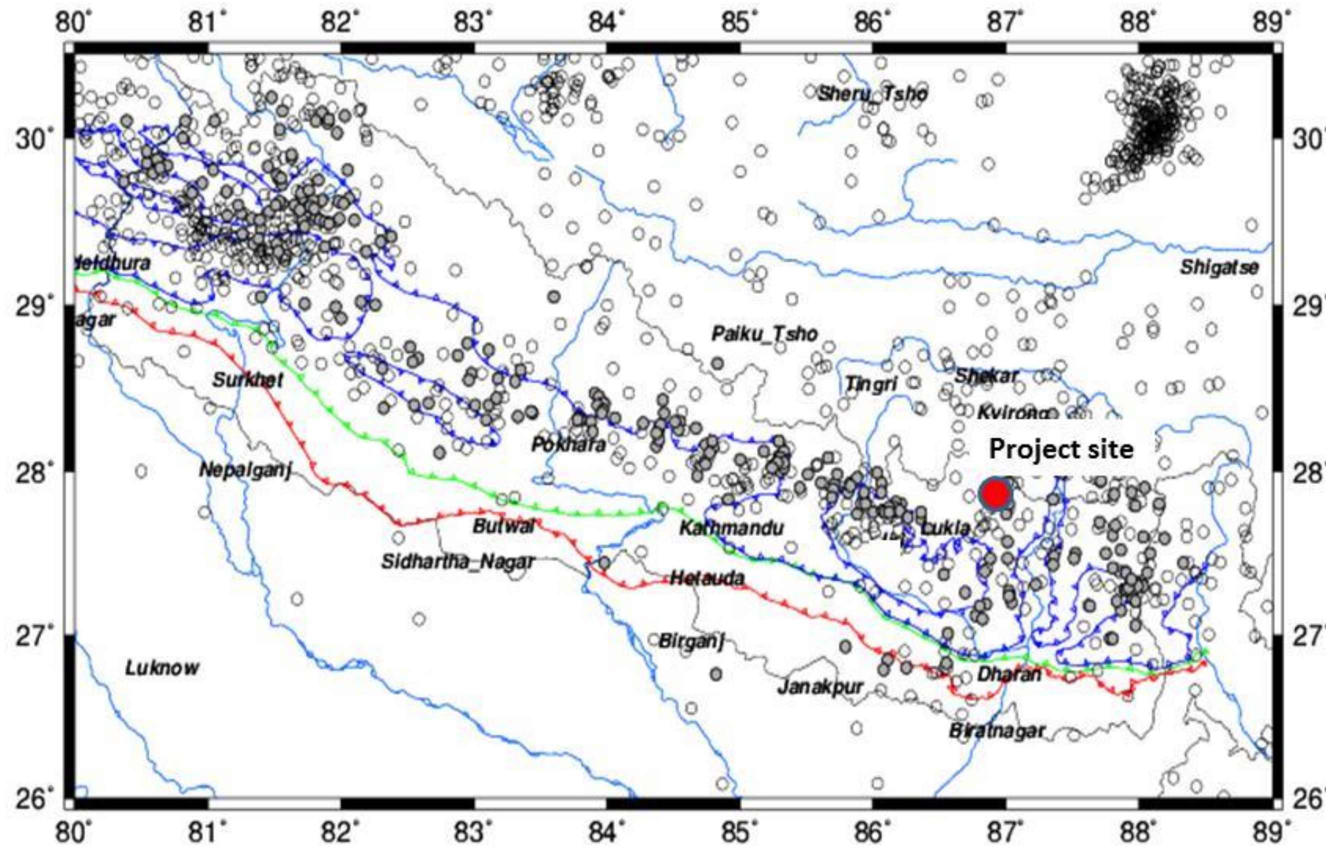


Figure 11: Distribution of earthquakes in the Nepal Himalaya and adjacent region. The open circles stand for M>4.0 earthquakes compiled by International Seismological Centre (ISC/UK). The grey circles are M>4.0 earthquakes reported by Department of Mines and Geology (DMG) Nepal.

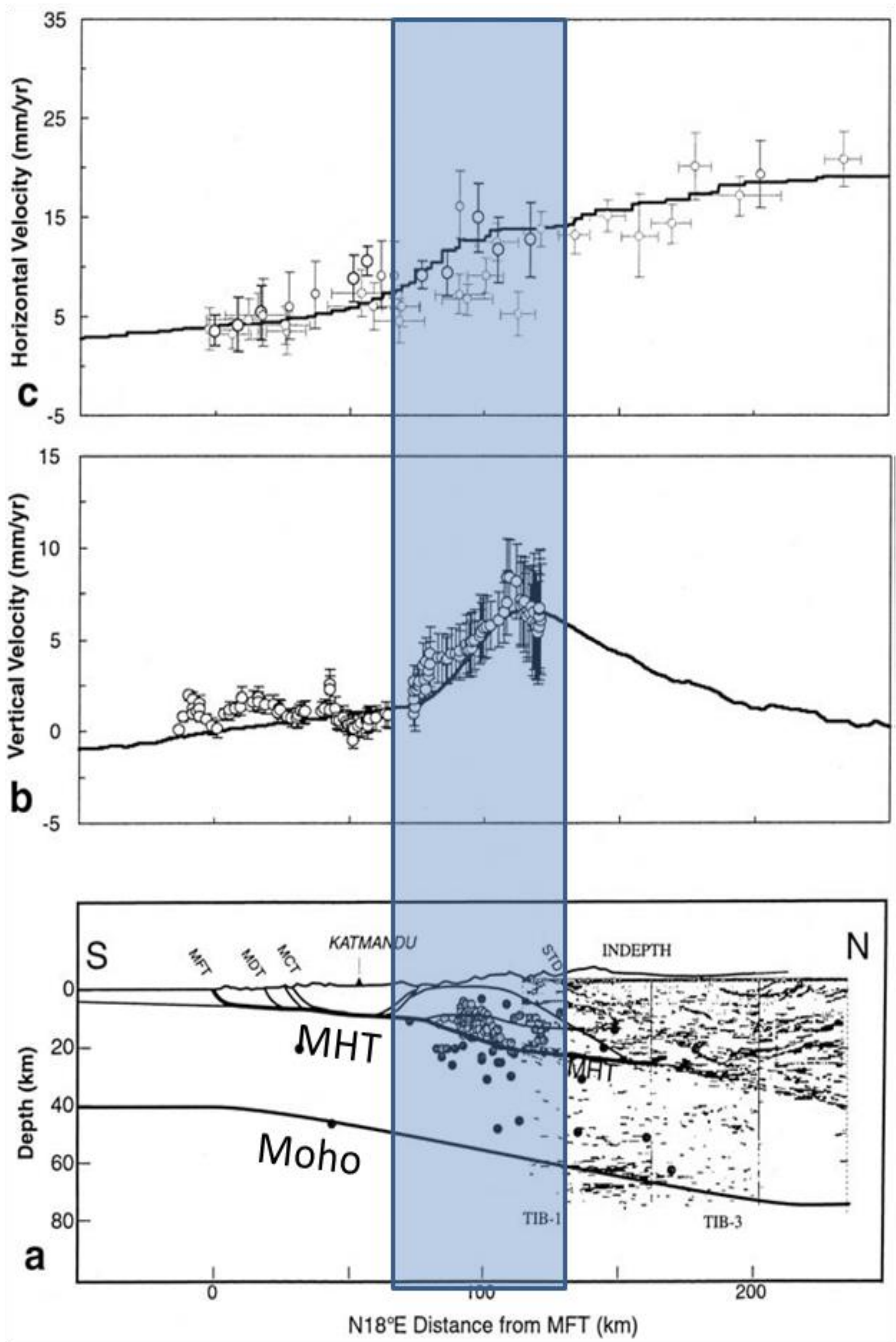


Figure 12: (a) Structural section with seismicity located from three three-component seismic stations installed in 1996 near the longitude of Kathmandu. (b) Uplift rates derived from the measurements along the leveling line that passes through Kathmandu (Jackson and Bilham 1994) and computed from the mechanical model of Cattin and Avouac (2000) (continuous line). (c) Horizontal velocities (Source: Avouac 2003).

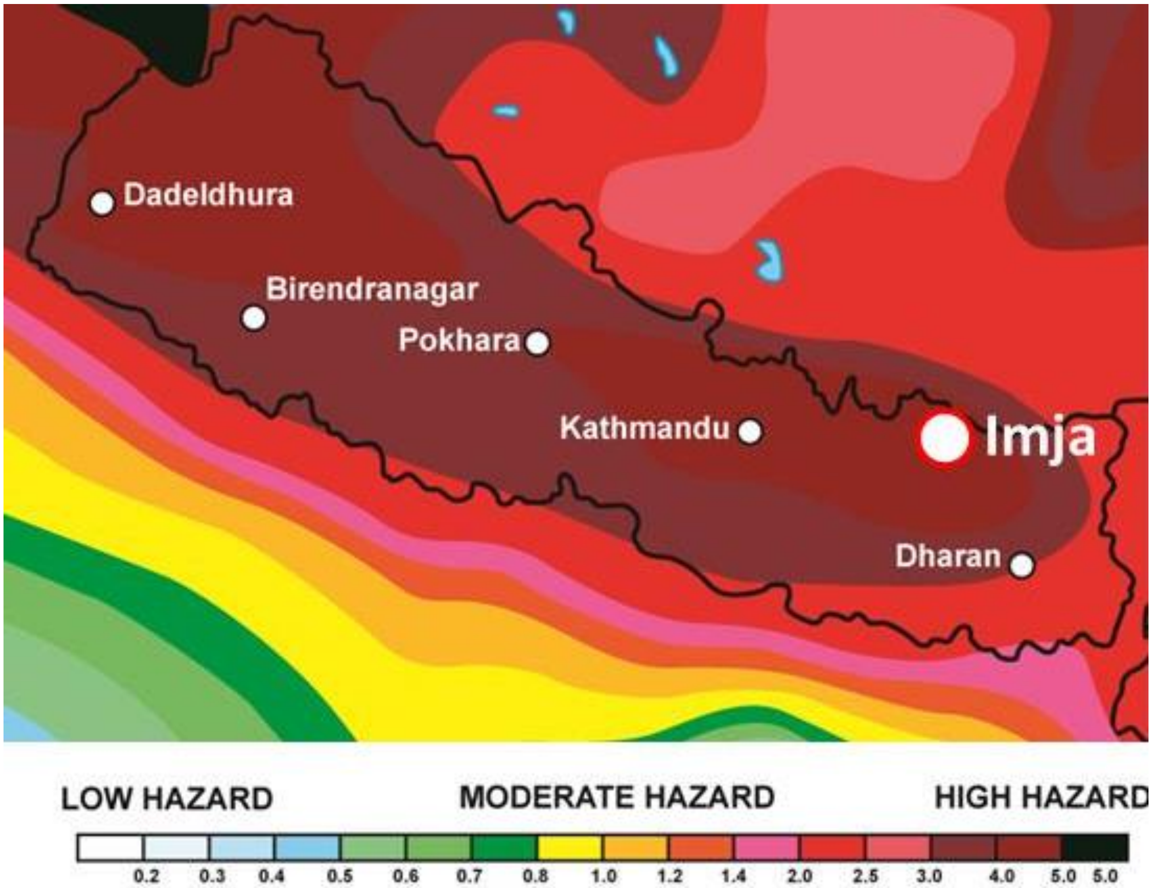


Figure 13: Probabilistic seismic hazard map of the region. The color stands for peak ground acceleration (PGA) for 10% chance of exceedance in 50 years.

5.3. Engineering Geological Condition

Engineering geological map of the Imja Lake area was prepared in 1:5,000 scale. The Imja Lake and surrounding is entirely covered by moraine materials. The moraine material is very loose to poorly compact depending on the places. On the basis of the morphology and position, the moraine can be divided into the lateral and end moraines (Figure 14). The boundary between end moraine and the lateral moraine is arbitrary.

5.3.1. Lateral Moraine

The lateral moraine at the right bank of the Imja Lake (northern side) is dominated by relatively fine materials and seems relatively fresh and elevated. It has formed unstable slopes towards the

lake side. The lateral moraine at the right bank of the Imja Lake (southern side) is quite extensive. Topography of the moraine is very irregular with several ups and down. The moraine mass has been dissected by several palaeo-channels induced most possibly from lake area. Width of the moraine varies from 100 m to 150 m with elevation about 50 m from the lake level. Orientation of coarse-grained materials (e.g. boulders, cobbles and pebbles) is random. It is composed of big boulders to fine clay of varied composition. Dominantly the boulders are of granite, para-gneiss, ortho-gneiss, pegmatites, psammitic schists and marble. The size of these boulders varies from few centimeters to few meters. Fine materials like sand and clay are found in minor amounts as patches. Sands are grey and mica rich while the silt and clay are ash-like colored without organic layers.

5.3.2. End Moraine

It is distributed at the frontal part of the lake. It represents an admixture of cobble and boulder dominated moraine materials deposited in a random fashion. It has acted as a dam for the Imja Glacier Lake. The end moraine surface is uneven with several linear depressions that are parallel to sub-parallel to the existing channel. These could be the paleo-channels of the lake drainage. The moraine material consists of sparsely distributed boulders ranging in size from few centimeters to some meters. The boulders, cobbles and granules are angular to sub-rounded, smooth to striated, and fresh to moderately weathered. Fine materials like silt and clay are found in small patches.

It is difficult to further zoning of the moraine material based on grain size as it is extremely heterogeneous. However, based on the surface distribution of boulders, cobbles, and pebbles the end moraine may be divided into the boulder-dominated, cobble-dominated and pebble-dominated areas (Figure 14). The moraine along the shores of the Lake is pebble-dominated. Main portion (central part) of the end moraine which forms the main dam of the Lake is boulder-dominated. The terminal part of the end moraine is cobble-dominated. This grading is only based on the surface observation of the moraine material may not necessarily imply that the subsurface material is also similar.

5.3.3. Scree/Colluvium Deposits

These deposits are found in the upper reaches of the Imja Lake. It is marked around the 5100 m to 5240 m elevation. These consist of angular fragments of bed rocks falling down from the adjacent hills.

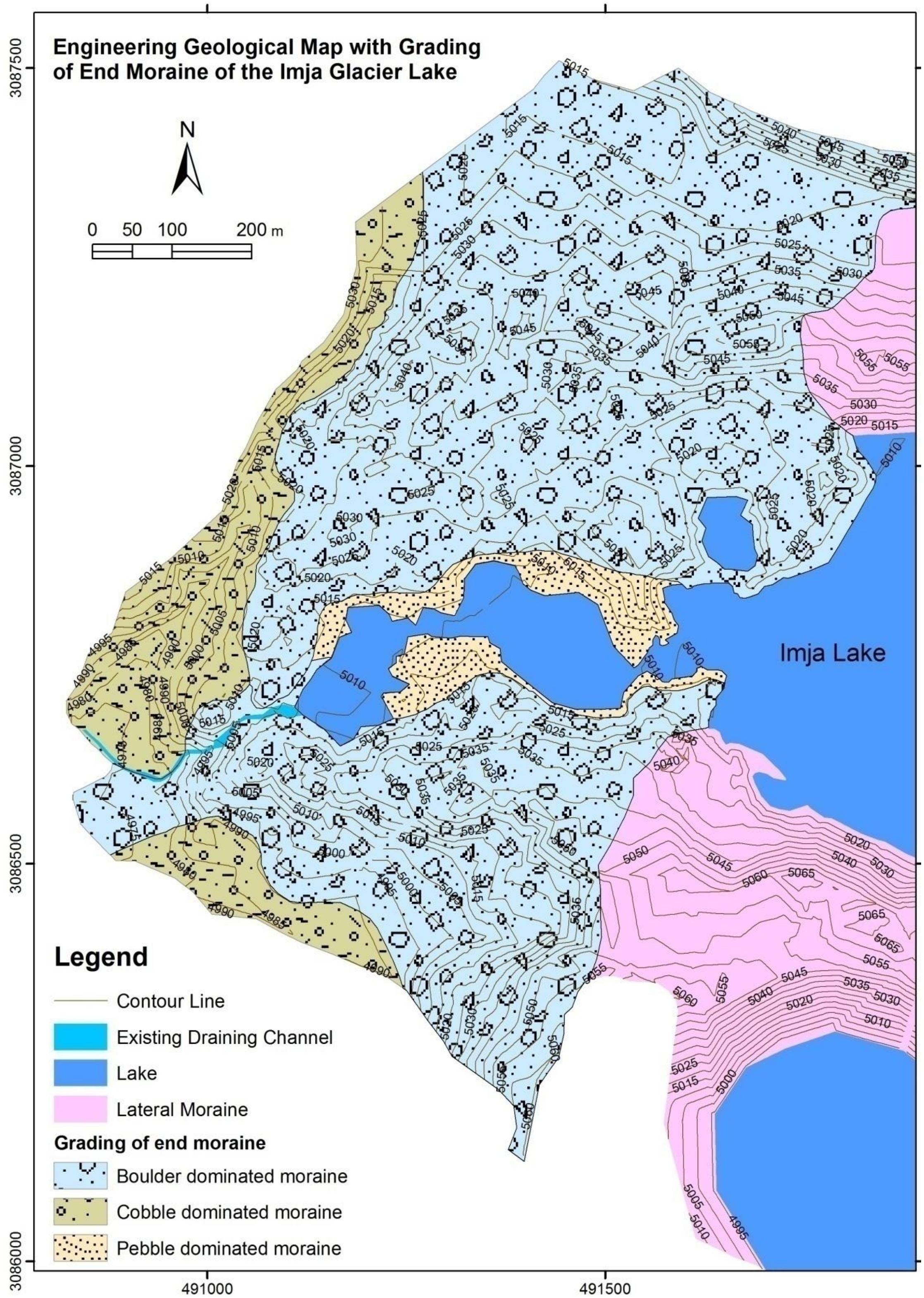


Figure 14: Engineering geological map of the Imja Lake moraine dam.

5.4. Geological Instabilities

Geological instabilities as landslides, unstable slopes, thermokarsts and sink holes around the Imja Lake were assessed both by direct observation in the field and observation of the Google map. The bedrock slopes in the side valleys are quite stable and no signs of potential rock and soil failures were observed at both banks of the Imja Lake.

The ice free moraine material is very loose at most places. Although the natural slopes of moraine surface is within the limit of safety factor (<30°), changes in slopes by natural or anthropogenic activities may destabilize the slopes. Therefore, during canal construction, the slopes should be maintained within the safety limit.

Some paleo-thermokarsts and isolated lakes are found in the NE part of the lateral moraine around the lake. These lakes may join with the main lake in future. It will not have significant impact on the stability of the end-moraine and proposed canal alignments.

5.5. Selection of 4 Suitable Open Channel Alignments for Detailed Study

First of all four alternatives were selected for the lowering of Imja Lake based on the technical judgments from the various thematic team involved in the present study. The following points were taken into consideration while selecting the four alternatives.

- Topographically depressed parts with gentle topography were selected as far as possible so that the ground would not be destabilized during excavation works and depth of cutting would be minimum.
- Length of cutting would be shortest.
- Thermokarsts, voids, elevated moulds, seepages, and exposed dead ice which could destabilize the dam were avoided.
- Efforts were made to overlap the alignments with the paleochannels.

The alignment of those four alternative outlets is shown in the Google map (Figure 15) and survey map (Figure 16). Out of these four routes two alternatives are selected towards the right bank of the Imja Khola and those are named as R1 and R2 where the former is the most near to the right bank while the later far behind the Imja Khola. Similarly, third alternative outlet (L1) is located at

the left bank of the Imja Khola, about 150 m SE from the existing outlet point of the Imja Lake. The fourth alternative (EC) is the present outlet of the Imja Lake.

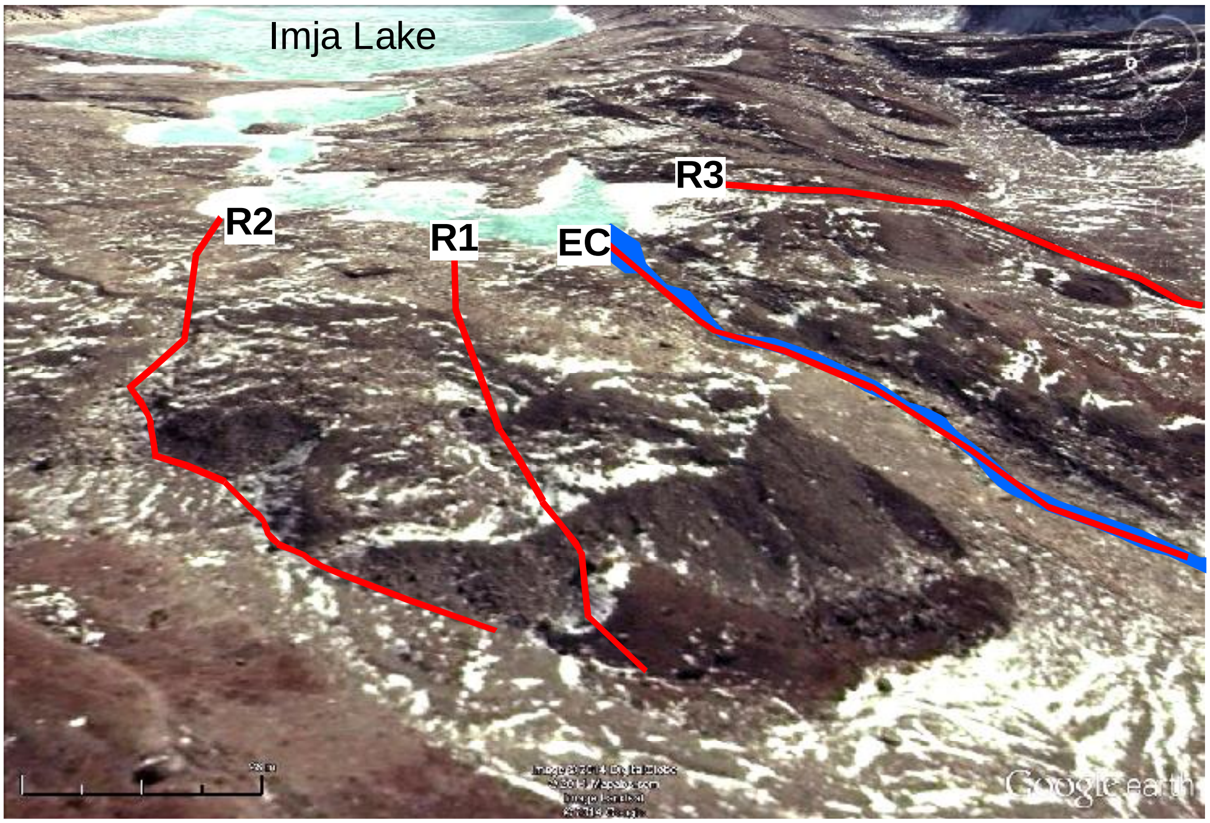


Figure 15: Four suitable open channel alignments selected in the present study Google map.

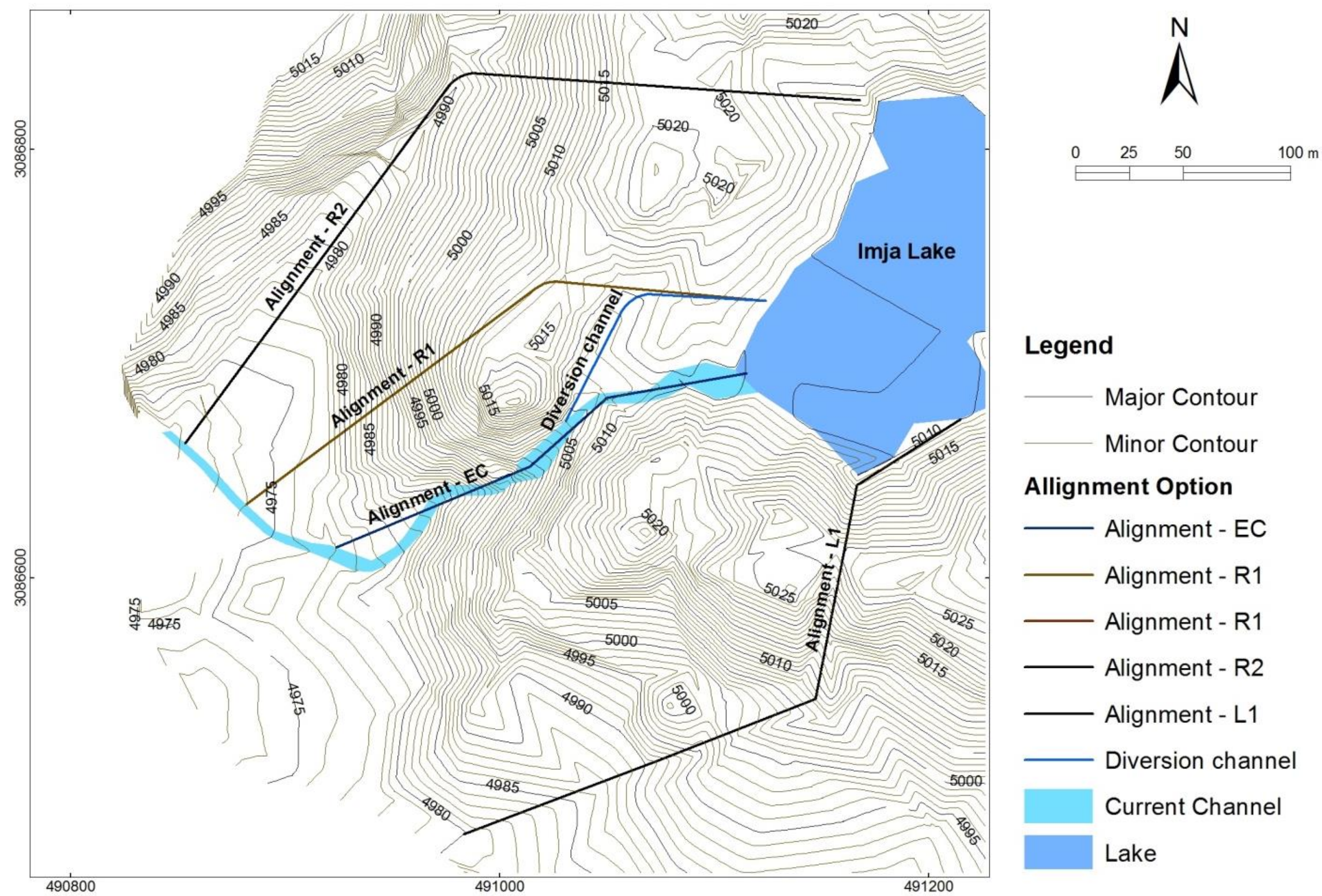


Figure 16: Four suitable open canal alignments shown in survey map.

In-depth study was carried out along the four alternative canal alignments using geo-technical and geophysical-ERT methods.

5.6. Geotechnical Field and Laboratory Tests

5.6.1. Schmidt Hammer Test

The limitations of Schmidt hammer testing in the present area have in already discussed in §4. Due to the presence of loose and large boulders in the moraine, it was impossible to get the strength of the moraine mass as a whole.

In total, five sites were selected for the Schmidt Hammer Test. Out of those, one test was conducted in the bed rock of the side valley adjacent to the project area and rest of the tests were performed

in the cobbles and boulders of moraine composition (Figure 17). The field test data are given in Annex IV.

Figure 17: Schmidt hammer test in the field. Test was carried out only in the boulders.

The average values at different sites are given in the following table (Table 2).

Table 2: Average values of Schmidt hammer test data at 5 sites.

Test site	Location	Material	Average strength (MPa)	Remarks
L1	N $27^0$89.460'00"; E $86^0$49.092'00" and Elv. 5120 m	Paragneisses (bed rock of the side valley)	~240	Good strength
EC (Existing Channel)	N 27053.925'00"; E 86054.452'00" and Elv. 5015 m	Boulder of paragneiss in lateral moraine	~260	Good strength
L3 (3rd alternative outlet site)	N 27053.934'00"; E 86054.459'00" and Elv. 5018 m	Different boulders of end moraine	~215	Good strength
R1 (First alternative canal alignment)	N 27053.997'00"; E 86054.432'00" and Elv. 4984 m	Different boulders of end moraine	~350	High strength
R2 (Second alternative of canal)	N 27054.048'00"; E 86054.442'00" and Elv. 5017 m	Different boulders of end moraine	~380	High strength

The average strength data show that the moraine along R1 and R2 is composed of relatively strong material compared that in L1, EC and L3. It is because the cobbles and boulders in R1 and R2 sites are dominated by granite and pegmatite.

Although the above Schmidt Hammer Test data have no implication on the engineering designing, the data show that the bedrocks of the side valley underlying the moraine have very good strength. It has implication on the stability of surrounding rock slopes. On the other hand, high strength determined on individual boulders of the moraine implies that it would be difficult to break the boulders present in the canal alignments during excavation. Therefore, it would be better to avoid big boulders during the layout of the canal alignment.

5.6.2. Field Permeability Test

In total, five numbers of pits were made on semi-cohesive soils (Figure 18). The size of the pits was of about 30 cm length, 30 cm breadth and 60 cm depth. The PVC pipe of 3.4 cm diameter and about 2 m height was erected on the pit. The soil was re-filled around the pipe tightly (Figure 19).

Three tests were made on the moraine sediments along the proposed canal alignments and the other two tests were away from the proposed canal alignment. The test data are given in Annex V.

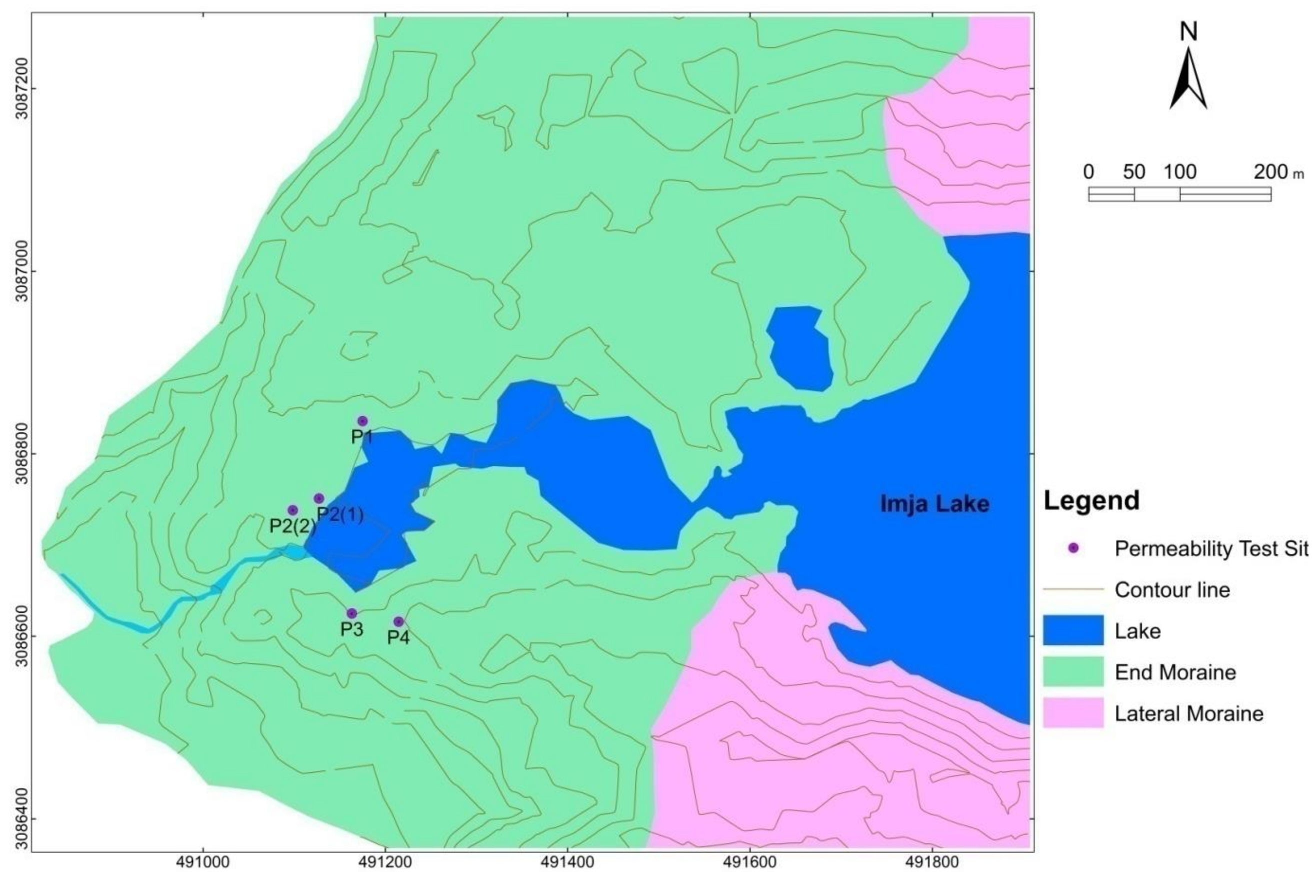


Figure 18: Field permeability test locations (P1-P4).

Figure 19: Photograph showing field permeability test.

Average value of permeability at each test site has been presented in Table 3.

Table 3: Average value of field permeability.

Location	Material	Average Permeability	Remarks
P1	Fine soil	0.0136	Highly permeable
P2 (1)	Fine soil	0.0984	Highly permeable
P2 (2)	Medium grained soil	0.0081	Highly permeable
P3	Fine soil layer	0.3529	Highly permeable
P4	Fine soil layer	0.0040	Highly permeable

The test shows that all the area is highly permeable. As the test was carried out on the area with relatively compact and dominantly finer materials (materials dominated by finer than cobbles), the permeability values do not represent the real in-situ permeability of the end moraine. Actual field permeability may be higher than the data presented in the Table 3.

Very high permeability of the ground may result in seepage and piping and ultimately destabilize channel bed and banks, resulting in failure of the dam. Therefore, the design team should consider appropriate lining materials to reduce the permeability of the channel bed and banks. Grout, clay lining or geomembranes/flexible membranes can be used to reduce permeability. Use of geomembranes or flexible membranes is the most suitable method to reduce permeability in cold environments.

5.7. Construction Materials Survey

Suitable sites for the construction material (sand and gravel) were investigated in the area. Getting natural gravel and sand in large quantities is difficult in the area. However, cobbles and boulders can be crushed to prepare gravel and sand. Three suitable sites (CM-1, CM-2 and CM-3) have been identified for the construction material quarry in the area. The possible sites for construction material have been shown in Figure 20.

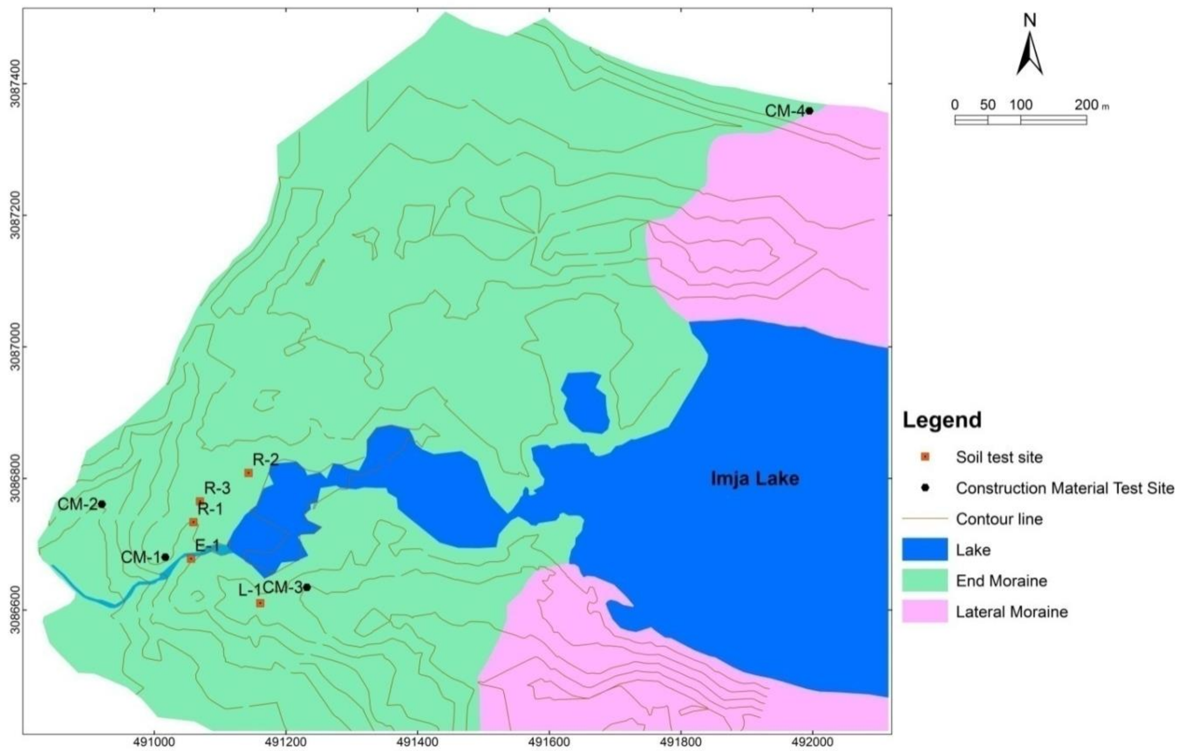


Figure 20: Map showing location of sampling sites for laboratory test of construction material (CM-1, CM-2, CM-3) and soil (L-1, R-1, R-2, R-3, E-1).

The area is mostly dominated by cobbles and boulders. The construction material test sites were selected to avoid big boulders and cobbles. Then the aggregates were excavated from 1m x 1m x 1m pit for the geo-technical analysis. The cobbles were separated in the field by hand picking and the relative volume proportion of cobbles and finer materials (gravel+sand+silt+clay) was estimated in the field. Then the finer material was taken to Kathmandu for laboratory tests. Figure 21 shows filed photograph of one of the possible construction material sites (CM-3).

Figure 21: Sample collection for construction material at site CM-3.

5.7.1. Estimation of Quantity of the Construction Material

The quantity of the construction material (sand and gravel) in each possible site was estimated by multiplying the length (L) and breadth (W) by feasible excavation depth (H) (Table 4).

At first the proportion of gravel and sand from the test pits was determined by sieving in the laboratory. The analysis shows that the samples contain about 25% gravel and 20% sand sized particles in the fine-grained fractions (fraction finer than cobble and boulder). Proportion of the cobble was estimated by hand picking to be about 40% of the total samples. When recalculated to the total volume of materials from the pit (except boulders), average proportion of the gravel and sand comes to be 15% and 12%, respectively. Therefore, the quantity of gravel and sand in three sites have been calculated assuming that the moraine material contain about 15% gravel and 12% sand in average assumed that there is no boulder and composition is homogeneous throughout the deposit. However, it may not be likely the case in the heterogeneous moraine material and the estimation should be considered as maximum.

Table 4: Estimation of construction materials in three possible quarry sites.

	Site CM-1	Site CM-2	Site CM-3	Remarks
Feasible excavation length (m)	80	100	80	This estimation assumes that (i) there is no boulder in the material; (ii) Composition is homogeneous throughout the deposit
Feasible excavation breadth (m)	40	50	40	
Feasible excavation depth (m)	5	5	5	
Total volume of material (cu m)	16000	25000	16000	
Volume of gravel (15%)	2400	3750	2400	
Volume of sand (12%)	1920	3000	1920	

5.8. Laboratory test of soil and aggregates

Soil and aggregate samples were collected from three sites in the field (Figure 38) and were subjected to routine laboratory tests at MEH Geo-Engineering Services (P) Ltd., Sankhamul, Lalitpur. Laboratory tests were carried out in accordance with IS standard specifications. The tests were carried out maintaining the testing frequency for each test. The samples are biased because they were collected after removal of cobble and bigger sized clasts.

5.8.1. Laboratory test results of soil

The samples were collected from five different sites in the field and were subjected to the following tests:

- Grain Size Distribution
- Atterberg Limits
- Shrinkage Limit

The test data have been given in Annex VI. The average values have been summarized in the following table (Table 5).

Table 5: Summary of laboratory test data on soil samples. The test results are biased because samples were taken only after removal of cobble and bigger sized clasts.

Sample No.	Grain size distribution	Atterberg Limits	Shrinkage Limit	Remarks
R-1	D30= 4.9 D60= 10	Non-plastic	Non-plastic	Gap-graded gravel (GW)

	D90= 10.3			
R-2	D30=0.015 D60= 0.035 D90= 0.15	Liquid Limit=31.53; Plastic Limit=0; Plasticity Index=31.53	30.52	Low Compressible silt (ML)
R-3	D30= 0.25 D60= 6.5 D90= 10.2	Liquid Limit=36.45; Plastic Limit=0; Plasticity Index=36.45	31.16	Gap-graded silt with 0.3 mm to 0.8 mm size missing.
E-1	D30= 1.6 D60= 7.9 D90= 10.2	Non-plastic	Non-plastic	Gap-graded gravel (GW)
L-1	D30= 0.095 D60= 0.2 D90= 7.0	Non-plastic	Non-plastic	Gap-graded sand (SW)

The laboratory test data show that the fine material is gap-graded and non-plastic. It implies that the fine soil also have relatively high permeability. High permeability of the material has been evidenced by the in-situ permeability test. Therefore, appropriate measures to reduce the permeability have been already discussed.

5.8.2. Laboratory test results of aggregates

Samples of construction materials collected from three sites were subjected to the following tests for their suitability as aggregates.

- Compaction
- Dry density
- Specific gravity
- Unit weight

- Alkali Reactivity
- Flakiness Index

Details of laboratory test data of construction materials (aggregates) have been given in Annex VII. Average values have been summarized in the following table (Table 6). The test data show that site CM-2 and CM-3 consist of high quality aggregates.

Table 6: Summary of laboratory test data on aggregates. The tests were carried out only after removal of cobble and bigger sized clasts. Therefore, the results are biased and represent only to the fine aggregates.

S. N.	Compaction (%)	Dry density (gm/cc)	Specific gravity	Unit Weight or bulk density (Kg/lit)	Alkali reactivity	Flakiness Index (%)	Remarks
CM-1	5.2	2.16	2.7	1.92 (compacted), 1.73 (loose)	973 (Deleterious)	30.15	Can be used as only base course
CM-2 (RB)	4.3	2.08	2.72	1.76 (compacted), 1.62 (loose)	1139 (Deleterious)	39.92	Can be used as base course as well as other high quality works
CM-3	4.9	2.17	2.67	1.82 (compacted), 1.60 (loose)	1021 (Deleterious)	38.70	Can be used as base course as well as other high quality works
Indian Standard value		>2.0 gm/cc	2.67-2.7		Non deleterious	Less that 15% but should not exceed 25%	

Based on the test summary in Table 6, the construction material in all of the sites are of fair quality for concrete aggregate. The samples are well-graded. The maximum dry densities are more than 2.0 gm/cc at different moisture content. Hence, the materials are suitable for using as base course. Specific gravity and water absorption of all samples lie in the specified range. The most remarkable is the high alkali reactivity (973 to 1139) and flakiness index (>30%) of the samples. Therefore, the materials are not suitable to use as aggregate in natural condition. To reduce the alkali silica

reactivity of the concrete, low-alkali cement may be used. Another option is to use slag cement. Slag cement works synergistically with portland cement to increase strength, reduce permeability, improve resistance to chemical attack and inhibit rebar corrosion. The flakiness index of the aggregate may be reduced by sieving /washing or addition of angular aggregates.

5.9. ERT investigation

5.9.1. Layout of the profile lines

Geophysical ERT investigation was carried out along 10 profile lines, 5 longitudinal (ERT10, ERT 8, ERT 2, ERT1, ERT 4) and 5 transverse (ERT 3, ERT7, ERT 6, ERT 9, ERT 5) to detect the sub-surface feature of the end moraine. The ERT profile lines were selected to get maximum sub-surface data along 4-selected open channel alignments. The length of the ERT profile lines range from 200 m to 300 m and the depth of penetration are up to 25 meters, therefore the interpretation should be valid up to 25 meters only. The layouts of the profile lines are given in the Figures 22.

Data acquisition was done using Dipole-Dipole electrode array. The electrode spacing was considered in a way to have information of the ground for a sufficient depth. The maximum unit electrode spacing was 10 m. The total length of the profiles is about 2500 m. The ERT field data along each profile is given in Annex VIII.

Data Processing was done using RES2DINVx32 ver. 3.71. Topographic correction has been made wherever necessary.

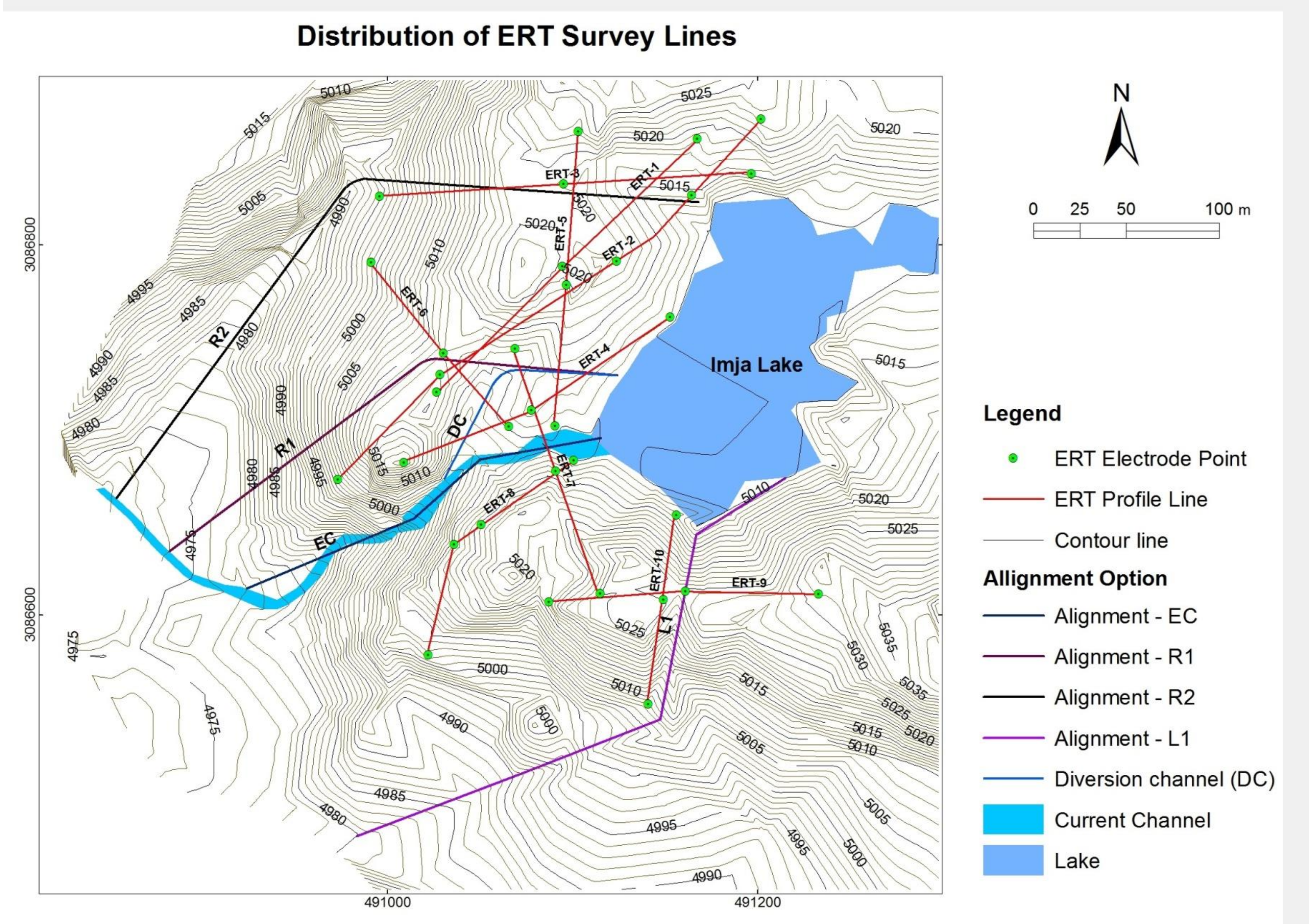


Figure 22: ERT profile line shown in topographic map.

5.9.2. Interpretation of sub-surface features from the ERT data

Geophysical ERT methods have been applied in glacial lake study to understand the subsurface features and dead ice in the Thulagi (Pant and Reynolds 2000; Figure 23) and Tsho Rolpa Lakes of Nepal (Oyo Corporation 1985). Those studies have proved that ERT method is effective in detection of sub-surface dead ice.

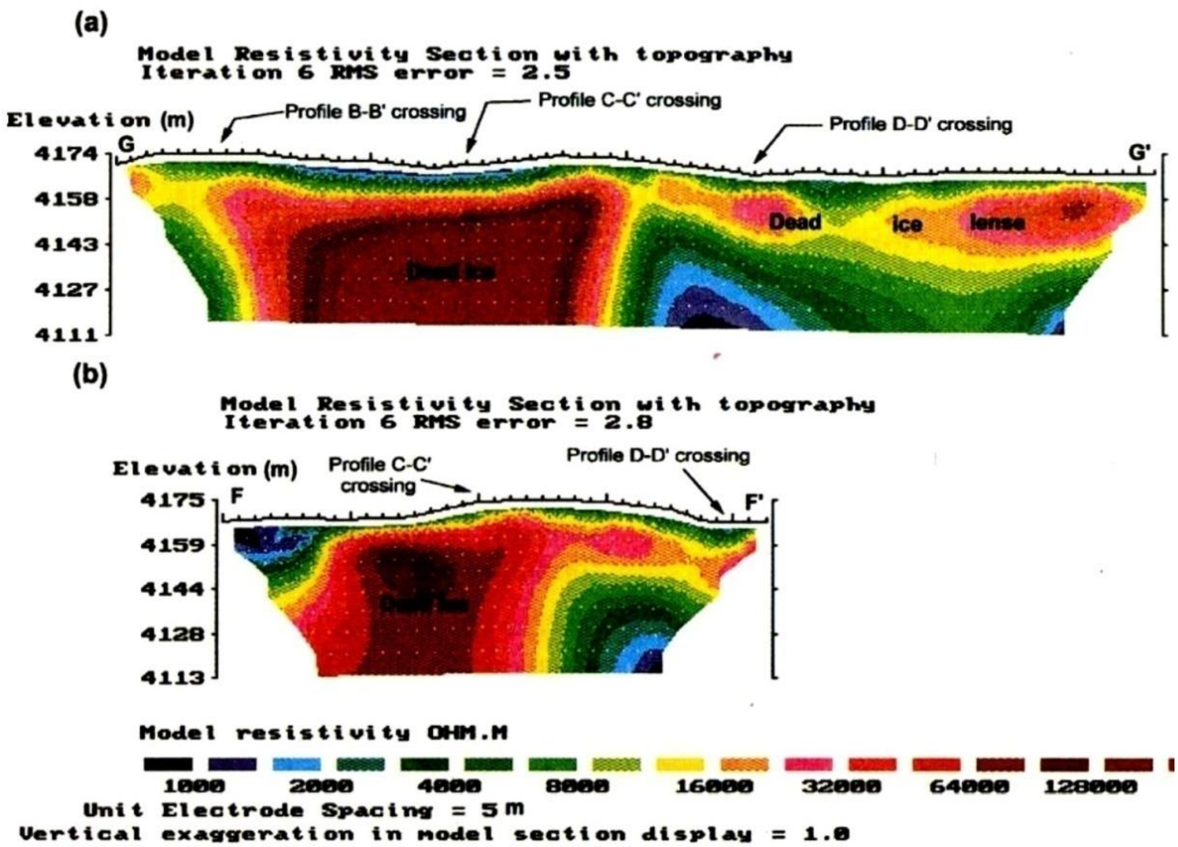


Figure 23: ERT profile across Thulagi Glacier Lake dam showing the dead ice (Pant and Reynolds 2000).

In the present study, the ERT profile lines have been interpreted on the basis of the resistivity values of some known materials as shown in Table 1. The interpretation of the sub-surface materials has been made on the basis of resistivity values and observed field condition. Subsurface zone showing low resistivity values (<2500 Ωm) has been interpreted as the water-saturated moraine because existence of water along the sediment grain boundaries and pores spaces increases the conductivity of the material and hence decreases the resistivity. Sub-surface zone showing exceptionally high resistivity values (>20,000 Ωm) has been interpreted as massive dead

ice. It is because ice is very poor conductor and expresses high resistivity. Sub-surface zone with intermediate values (2500 to 20,000 Ωm) have been considered as frozen moraine. This interpretation is in accordance with Pant and Reynolds (2000).

5.9.2.1. Profile 1

The ERT-1 Profile is about 200 meters in length in NE-SW direction. It is at the right bank to the Imja Lake. The model section shows resistivity values ranging from 900 to over 65,000 Ωm. The minimum depth to dead ice is at 6 meters at chainage between 120-150 m. The interpretation of sub-surface material based on ERT data is given in Figure 24.

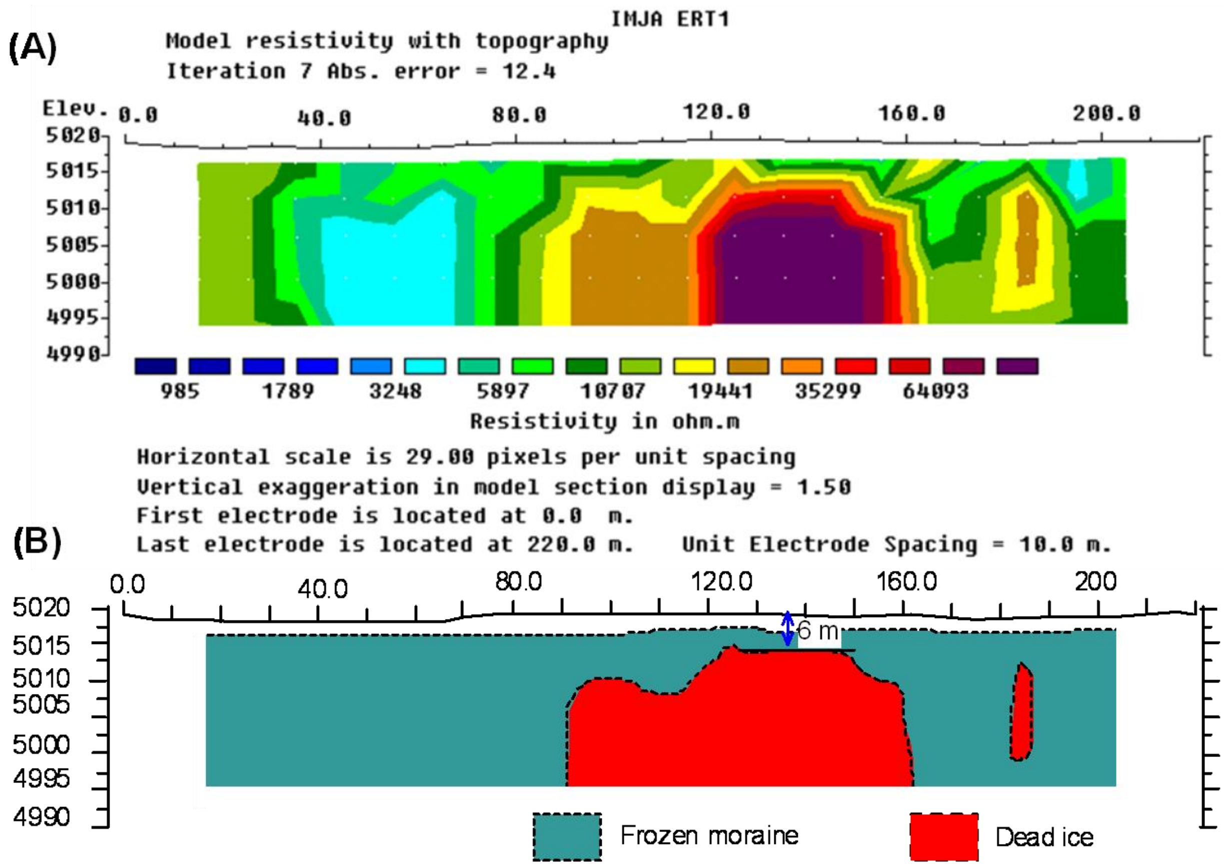


Figure 24: A. Inverse resistivity section along profile ERT-1. The purple color at the right possibly represents dead ice. B. Geological Cross-section interpreted from the geo-electric section.

The ERT profiles were compared with the GPR profile along the same line to confirm the sub-surface interpretation of the data. Interpretation of GPR data are given in Figures 25 and 26. The results obtained from both investigations are comparable and are shown in Table 7.

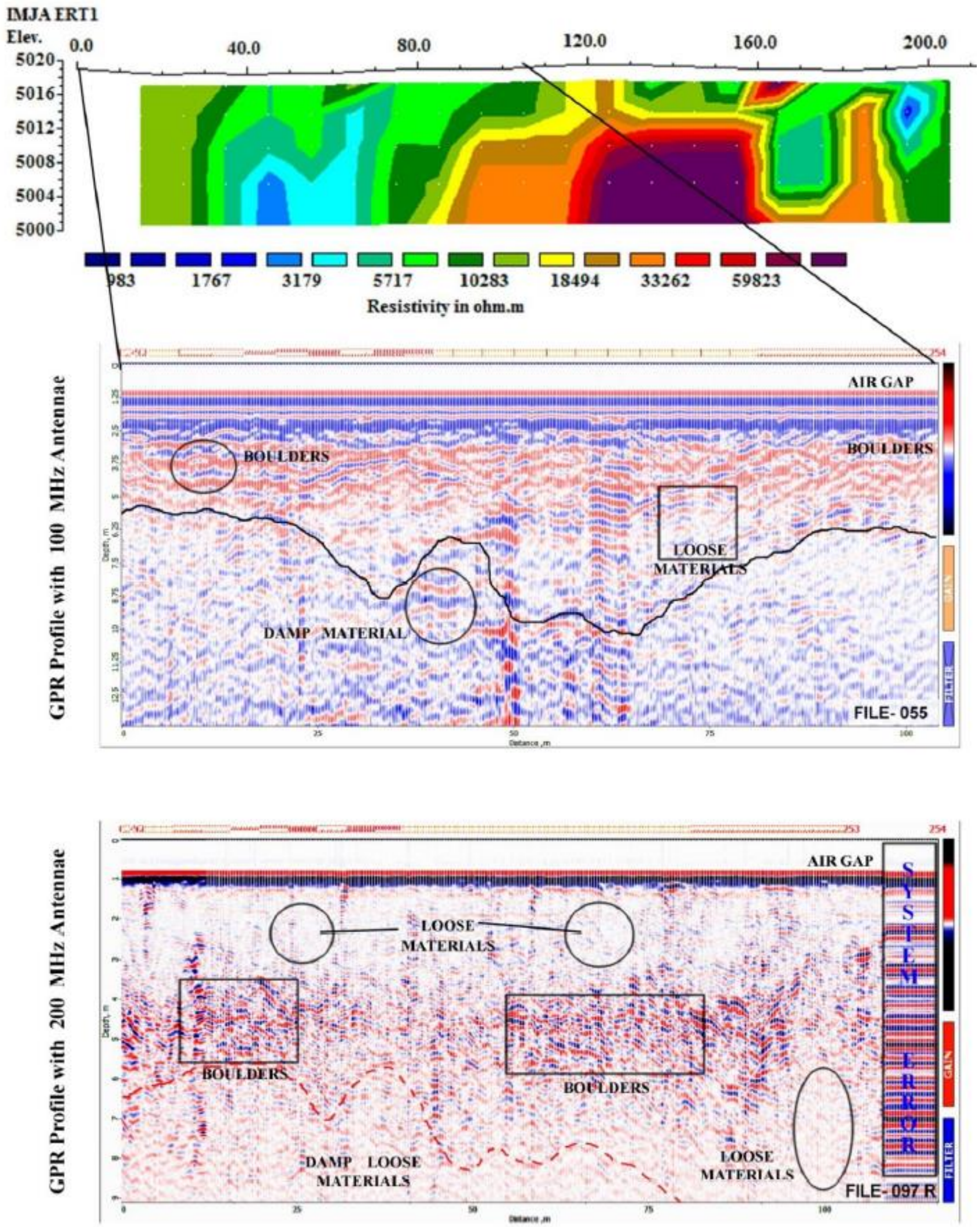


Figure 25: GPR profiles of 100 MHz (middle) and 200 MHz (bottom) antennas showing presence of glacial materials (boulders, loose materials, buried ice etc.) related to the ERT profile 1 (top). The Figure is continued to Figure 26.

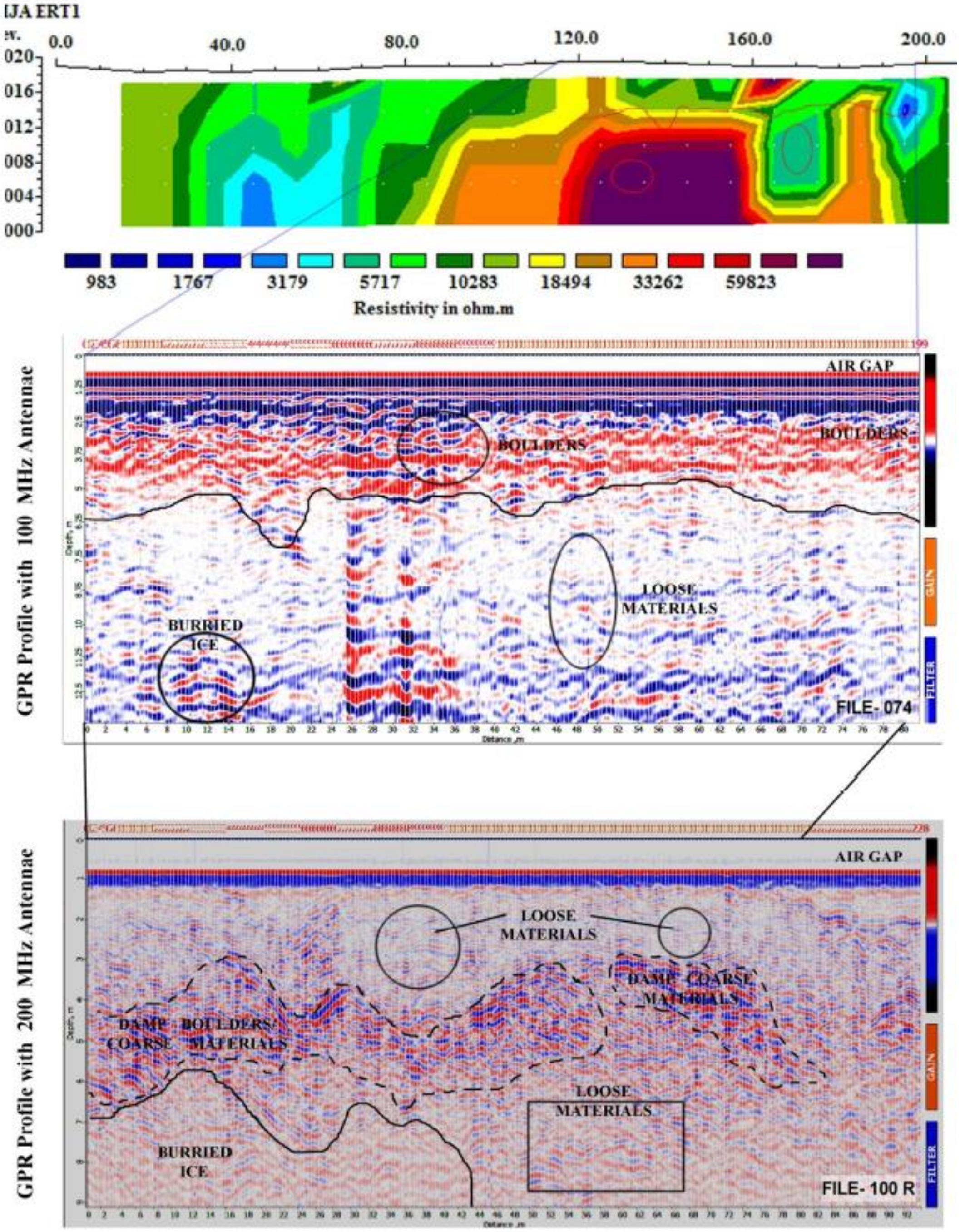


Figure 26: GPR profiles of 100 MHz (middle) and 200 MHz (bottom) antennas showing presence of glacial materials (boulders, loose materials, buried ice etc.) related to the ERT profile 1 (top). Continued from Figure 25.

Table 7: Interpretation of sub-surface condition along ERT profile 1.

Chainage (m)	ERT findings		GPR Findings	
	Depth (m)	**Inferred material**	**Depth (m)**	**Inferred material**
0-90	0-25	Frozen moraine	**0-12**	**Loose material**
90-120	0-10	Frozen moraine	0-10	Loose material
	10-25	Dead ice	below 10	Dead buried ice
120 -150	0-6	Frozen moraine	0-7	Loose material
	6-25	Dead Ice	below 7	Dead buried ice
150-160	0-10	Frozen moraine	0-8	Loose material
	10-25	Dead ice	below 8	Dead buried ice
160-180	0-20	Frozen moraine	0-12	Loose material
	20-25	Dead ice		
180-190	0-10	Frozen moraine	0-12	Loose material
	10-25	Dead ice		
190-210	0-25	Frozen moraine	0-12	Loose material

Investigations by both the methods have shown buried ice (dead ice) almost in the same positions along the profile and almost at the same depth.

The ERT results were verified in similar way along each profile (profile 1 to 10) the interpretations by ERT and GPR are shown in the tables to follow.

5.9.2.2. Profile 2

The ERT-2 Profile is about 300 meters in length in NE-SW direction (Figure 27). It is at the right bank of the Imja Lake. The model section shows resistivity values ranging from 2000 to over 90,000 Ωm. Based on the resistivity values, dead ice can be inferred at two places, one at chainage 80 m and the other between chainages 150 m and 240 m. The minimum depth of the dead ice in this profile is 5 m. Water-saturated moraine exists at two places along this profile. The sub-surface interpretation of the profile 2 is given in Figure 25 and Table 8.

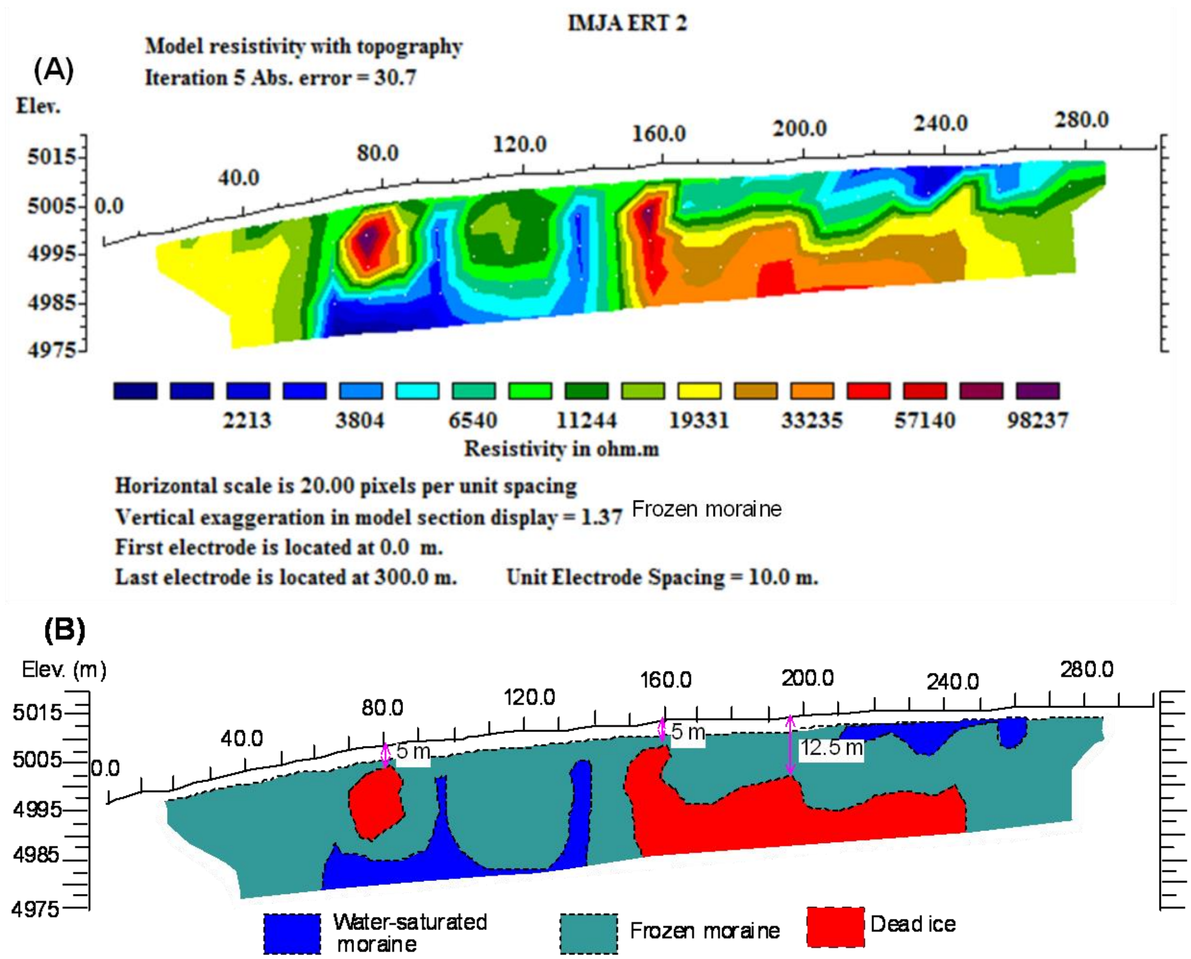


Figure 27: A. Inverse resistivity section along profile ERT-2. The purple color at the right possibly represents dead ice. B. Geological Cross-section interpreted from the geo-electric section.

Table 8: Interpretation of sub-surface condition along ERT profile 2.

Chainage (m)	ERT findings		GPR Findings	
	Depth (m)	Inferred material	Depth (m)	Inferred material
0-60	0-25	Frozen moraine	0-12	Loose material
60-70	0-20	Frozen moraine	0-12	Loose material
	20-25	Water-saturated moraine		Loose material
70-90	0-5	Frozen moraine	0-4	Loose material
	5-20	Dead ice	Below 4 m	boulders
	20-25	Frozen moraine		Loose material
90-100	0-20	Frozen moraine	0-12	Loose material
	20-25	Water-saturated moraine		Loose material
100-130	0-7	Frozen moraine	0-12	Loose material
	7-25	Water-saturated moraine		Loose material
130-140	0-25	Frozen moraine	0-12	Loose material
140-150	0-5	Frozen moraine	0-6	Loose material
	5-30	Dead ice	below 6	boulders
150-200	0-13	Frozen moraine	0-8	Loose material
	13-30	Dead ice	below 8	
200-210	0-20	Frozen moraine	0-12	Loose material
	20-25	Dead ice		
210-250	0-10	Water-saturated moraine	0-12	Loose material
	10-18	Frozen moraine		
	18-25	Dead ice		
250-280	0-25	Frozen moraine	0-12	Loose material/boulder

5.9.2.3. Profile 3

The ERT-3 Profile is about 200 meters in length in E-W direction. It is at the right bank of the Imja Lake and runs across the end moraine ridge. This profile runs along a paleo-channel of the outlet. The model section shows resistivity values ranging from 2000 to over 2,00,000 Ωm. Possibly dead ice exists at the western extremity of the profile line (right hand in the figure). The Dead ice exists at 9 meters below surface along this profile. Water saturated moraine is noticed near the water body in the lake between 40 and 100 m chainage. The sub-surface interpretation of the profile 3 is given in Figure 28 and Table 9.

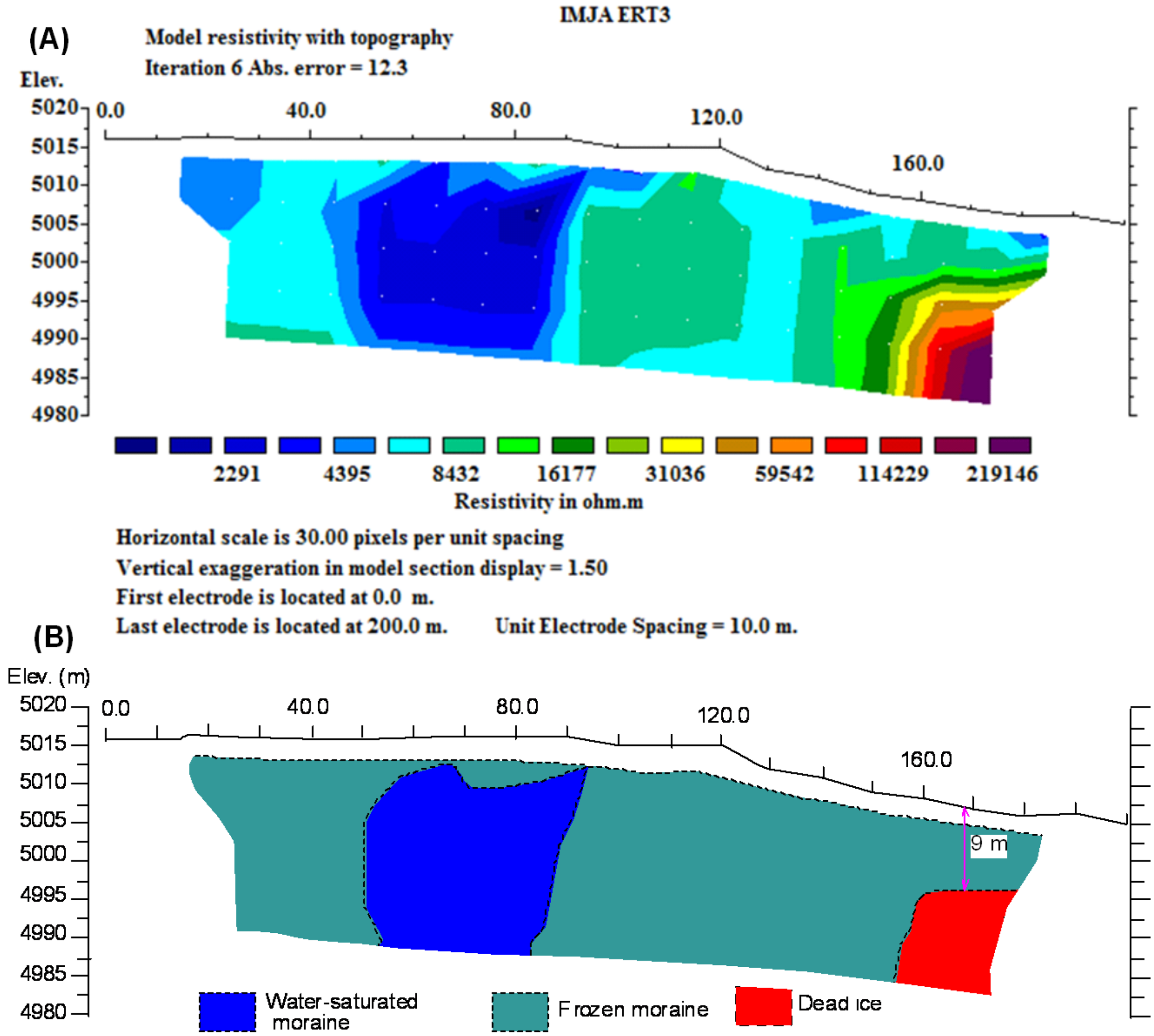


Figure 28: A. Inverse resistivity section along profile ERT-3. The purple color at the right possibly represents dead ice. B. Geological Cross-section interpreted from the geo-electric section.

Table 9: Interpretation of sub-surface condition along ERT profile 3.

<table>
<tr><th rowspan="2">Chainage (m)</th><th colspan="2">ERT findings</th><th colspan="2">GPR Findings</th></tr>
<tr><th>Depth (m)</th><th>Inferred material</th><th>Depth (m)</th><th>Inferred material</th></tr>
<tr><td>0-50</td><td>0-25</td><td>Frozen moraine</td><td>0-12</td><td>Loose material</td></tr>
<tr><td rowspan="2">50-95</td><td>0-7</td><td>Frozen moraine</td><td rowspan="2">0-12</td><td rowspan="2">Loose material</td></tr>
<tr><td>7-25</td><td>Water-saturated moraine</td></tr>
<tr><td>85-160</td><td>0-25</td><td>Frozen moraine</td><td>0-12</td><td>Loose material</td></tr>
<tr><td rowspan="2">160-180</td><td>0-9</td><td>Frozen moraine</td><td>0-8</td><td>Loose material</td></tr>
<tr><td>9-25</td><td>Dead ice</td><td>Below 8</td><td>Buried ice</td></tr>
</table>

5.9.2.4. Profile 4

The ERT-4 Profile is about 160 meters in length in E-W direction. It is at the right bank of the Imja Lake and runs across the end moraine ridge. The model section shows resistivity values ranging from 1000 to over 80,000 Ωm. Possibility of dead ice exists between chainage 50 m and the eastern extremity. The shallowest level of dead ice is at about 8 m below the surface at chainage 95 m. In other points it is at about depper than 14 m. Water saturated pockets are observed above 10 meters at the eastern extremity, whereas frozen moraine is present at the in entire section. The sub-surface interpretation of the profile 4 is given in Figure 29 and Table 10.

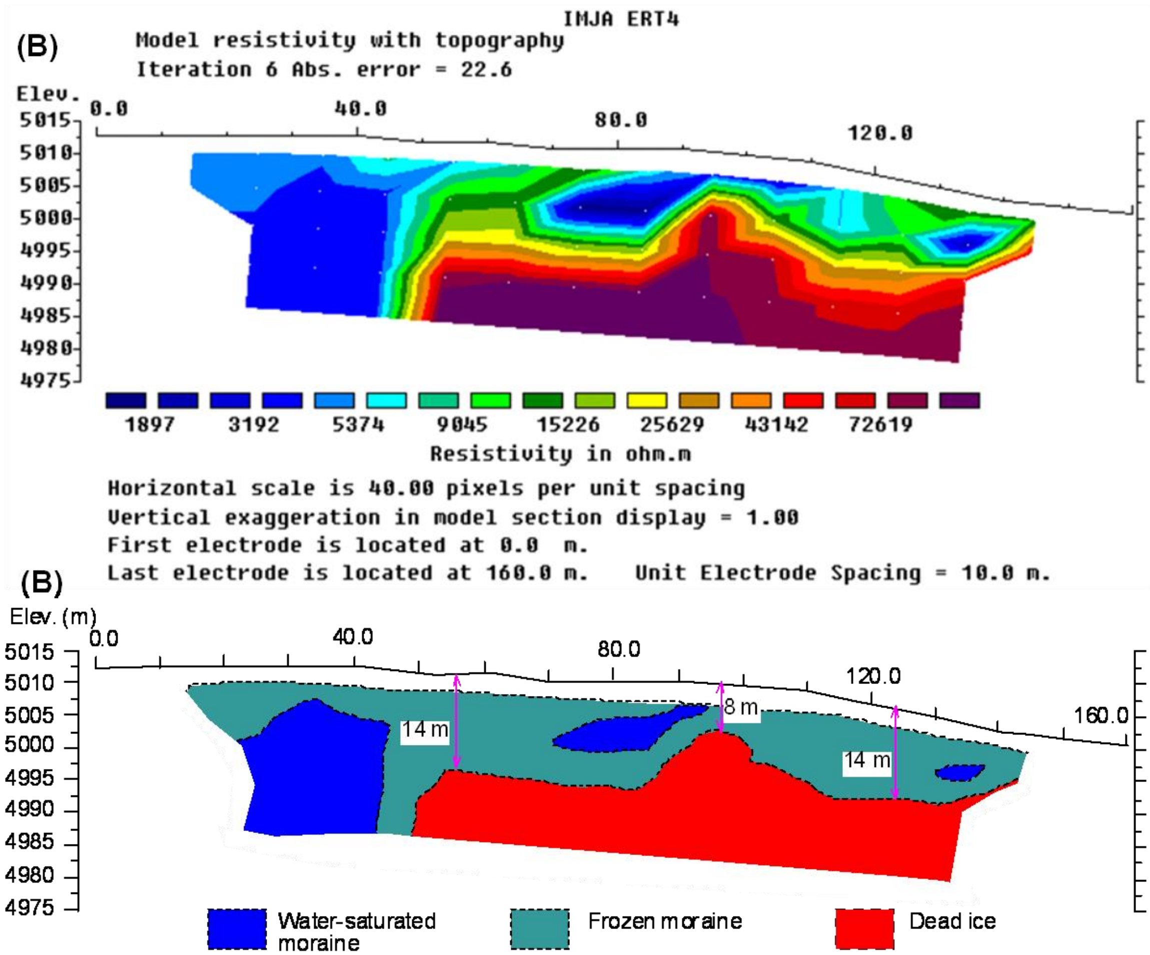


Figure 29: A. Inverse resistivity section along profile ERT-4. The purple color at the right possibly represents dead ice. B. Geological Cross-section interpreted from the geo-electric section.

Table 10: Interpretation of sub-surface condition along ERT profile 4.

	ERT findings		**GPR Findings**	
Chainage (m)	**Depth (m)**	**Inferred material**	**Depth (m)**	**Inferred material**
0-20	0-11	Frozen moraine	0-4	boulders
	11-25	Water-saturated moraine	Below 4	Damp materials
20-45	0-5	Frozen moraine	0-5	boulders
	5-25	Water-saturated moraine	Below 5	Damp materials
45-50	0-25	Frozen moraine	0-12	Damp materials
50-70	0-14	Frozen moraine	0-12	Damp materials
	14-25	Dead ice		
70-90	0-7	Frozen moraine	0-12	Damp materials
	7-12	Water-saturated moraine		
	12-14	Frozen moraine	0-4	Damp materials
	14-25	Dead ice	Below 4	Buried ice
90-110	0-8	Frozen moraine	0-5	Damp materials
	8-25	Dead ice	Below 5	Dead ice
110-140	0-14	Frozen moraine	0-12	Damp materials
	14-25	Dead ice		

5.9.2.5. Profile 5

The ERT-5 Profile is about 200 meters in length in E-W direction. It is at the right bank to the Imja Lake and runs approximately parallel to the end moraine ridge. The resistivity model section shows resistivity values ranging from 1,000 to over 70, 000 Ωm. Possibly dead ice exists at two places, one at chainage 40-50 m and the other at the northern extremity of the profile line (right hand in the Figure 32). The dead ice exists below 6 meters along this profile. The high resistivity value at 60 meters possibly is isolated dead ice or a big boulder. The sub-surface interpretation of the profile 5 is given in Figure 30 and Table 11.

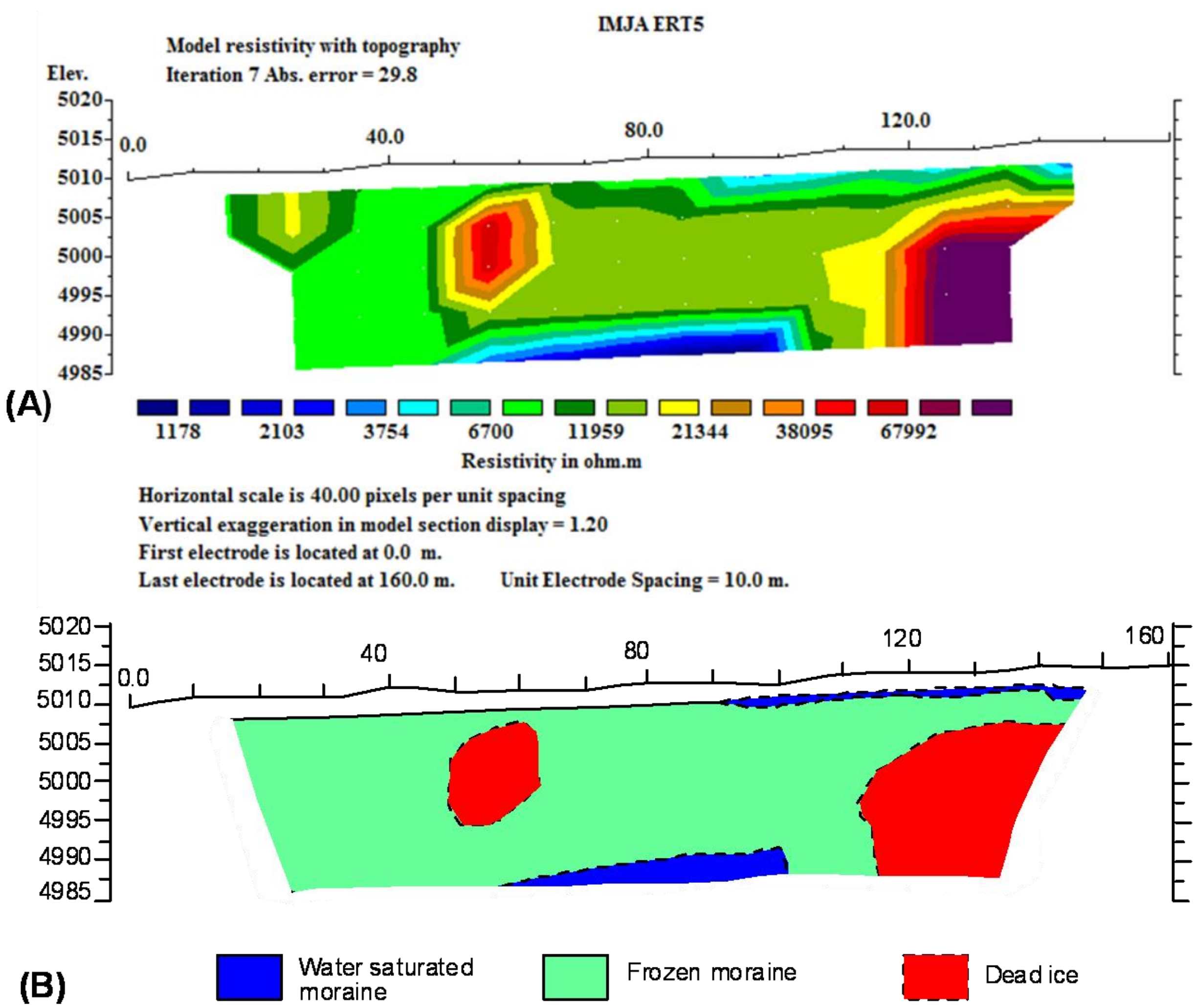


Figure 30: A. Inverse resistivity section along profile ERT-5. The purple color at the right possibly represents dead ice. B. Geological Cross-section interpreted from the Inverse resistivity section.

Table 11: Interpretation of sub-surface condition along ERT profile 5.

	ERT findings		**GPR Findings**	
Chainage (m)	**Depth (m)**	**Inferred material**	**Depth (m)**	**Inferred material**
0-50	0-25	Frozen moraine	0-12	**Boulders/loose materials**
50-65	0-5	Frozen moraine	0-12	Boulders/loose materials
	5-18	Dead ice		
	18-25	Frozen moraine		
65-100	0-22	Frozen moraine	0-12	Boulders/loose materials
	22-25	Water-saturated moraine		
100-115	0-5	Water-saturated moraine	0-12	Boulders/damp materials
	5-25	Frozen moraine		
115-150	0-5	Water-saturated moraine	0-8	Boulders/damp materials
	5-10	Frozen moraine	**Below 8 m**	Buried dead ice
	10-25	Dead ice		

5.9.2.6. Profile 6

The ERT-6 Profile is about 160 meters in length in NW-SE direction. It is at the right bank to the Imja Lake and runs across the end moraine ridge. The model section shows resistivity values ranging from 400 to over 1, 40,000 Ωm. possibly dead ice exists between 20 and 110 m chainage. At chainage 55 m and 85 m, dead ice is at shallow level, i.e., 5 m from the surface. At chainage 70 m, the dead ice at deeper level, i. e., 11 m from the surface (Figure 29). Frozen moraine occupies most of the section. Saturated moraine lies at the extreme end at chainage 130 m. The sub-surface interpretation of the profile 6 is given in Figure 31 and Table 12.

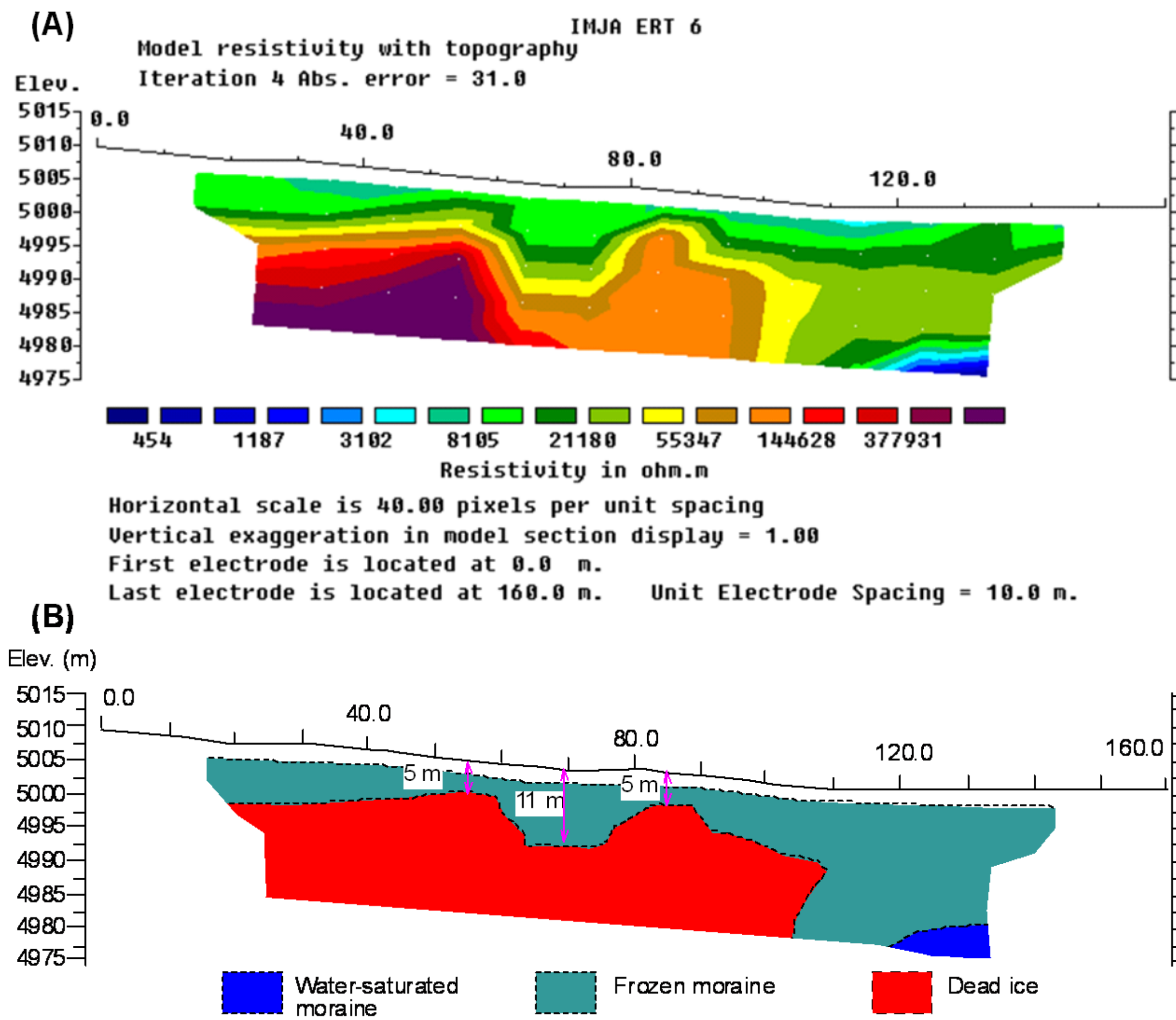


Figure 31: A. Inverse resistivity section along profile ERT-6. The purple color at the right possibly represents dead ice. B. Geological Cross-section interpreted from the geo-electric section.

Table 12: Interpretation of sub-surface condition along ERT profile 6.

	ERT findings		GPR Findings	
Chainage (m)	**Depth (m)**	**Inferred material**	**Depth (m)**	**Inferred material**
0-60	0-8	Frozen moraine	0-10	Boulders/loose materials
	8-25	Dead ice	Below 10	Dead buried ice
60-80	0-11	Frozen moraine	0-12	Boulders/loose materials
	11-25	Dead ice		
80-90	0-8	Frozen moraine	0-9	Boulders/loose materials
	8-25	Dead ice	Below 9	Buried dead ice
90-110	0-8	Frozen moraine	0-7	Boulders/loose materials
	8-25	Dead ice	Below 7	Buried dead ice
110-120	0-25	Frozen moraine	0-12	Boulders/loose materials
120-140	0-20	Frozen moraine	0-12	Boulders/loose materials
	20-25	Water-saturated moraine		

5.9.2.7. Profile 7

The ERT-7 Profile is about 200 meters in length in NW-SE direction. It crosses the outlet of Imja Lake. The model section shows resistivity values ranging from 900 to over 80,000 Ωm. The dike like structure at 80 meter represents the existing outlet of the lake and shows no ice is present in the entire depth represented in the figure. Possibly dead ice exists between 40 and 80 meter below 15 meter. Similarly, possibility of dead ice exists after 100 m. The sub-surface interpretation of the profile 7 is given in Figure 32 and Table 13.

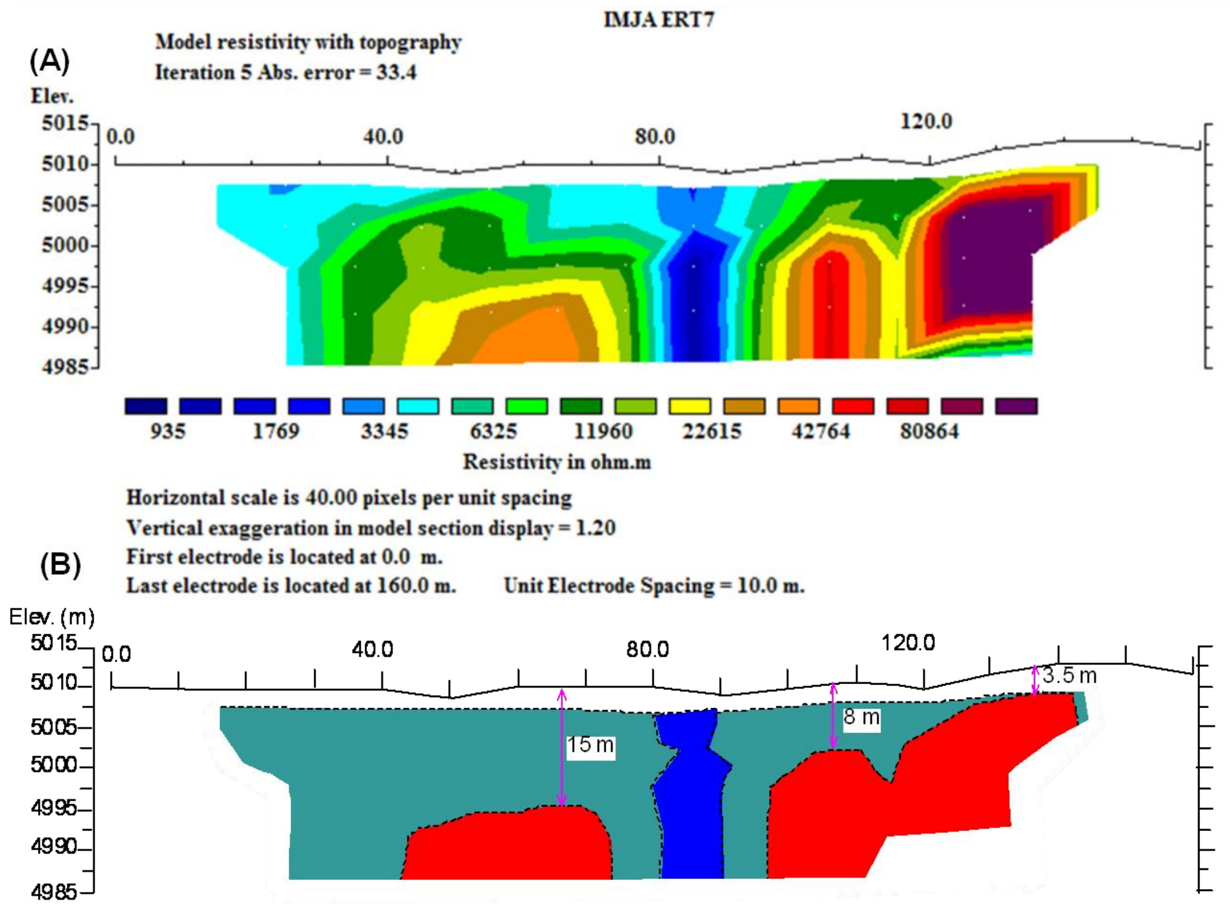


Figure 32: A. Inverse resistivity section along profile ERT-7. The purple color at the right possibly represents dead ice. B. Geological Cross-section interpreted from the geo-electric section.

Table 13: Interpretation of sub-surface condition along ERT profile 7.

	ERT findings		GPR Findings	
Chainage (m)	**Depth (m)**	**Inferred material**	**Depth (m)**	**Inferred material**
0-40	0-25	Frozen moraine	0-12	Damp material/loose material
40-75	0-15	Frozen moraine	0-12	Damp material/loose material
	15-25	Dead ice		
75-80	0-25	Frozen moraine	0-12	loose material
80-90	0-25	Water-saturated moraine	0-12	Damp material
90-100	0-25	Frozen moraine	0-12	Loose material/boulder
100-120	0-8	Frozen moraine	0-8	Loose material/boulder
	8-25	Dead ice	Below 8 m	Dead buried ice
120-150	0-3.5	Frozen moraine	0-5	Loose material/boulder
	3.5-25	Dead ice	Below	Loose material/boulder

5.9.2.8. Profile 8

The ERT-8 Profile is about 180 meters in length at the left bank of the outlet of the lake. The model section shows resistivity values ranging from 4000 to over 45,000 Ωm. Possibly dead ice exists at the chainage 55 m and 175 m at a depth of 8 m (Figure 33). The dead ice exists below 5 meters along this profile. Frozen moraine is noticed in most part of the section. The sub-surface interpretation of the profile 8 is given in Figure 33 and Table 14.

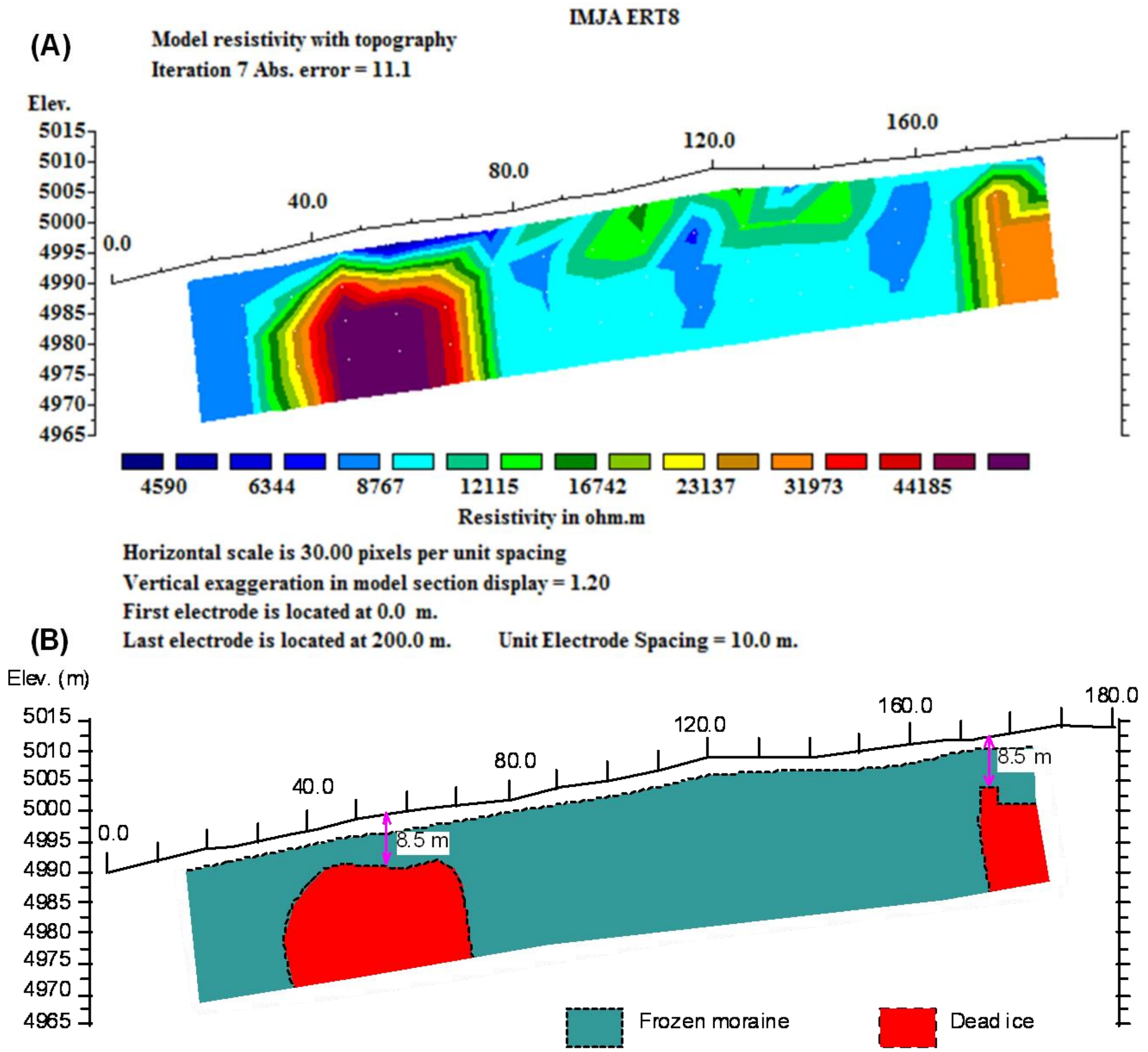


Figure 33: A. Inverse resistivity section along profile ERT-8. The purple color at the right possibly represents dead ice. B. Geological Cross-section interpreted from the geo-electric section.

GPR surveys were carried out at both banks of the outlet channel (Fig. 33(C)). The GPR surveys were implemented using 100 MHz and 270 MHz frequencies having depth of penetration 6 m and 12 m respectively. The left bank shows the possibility of ice between chainage 35 to 56 meters of the Profile 237 (from west). Likewise, the right bank shows possibility of presence of ice at 35 to 55 meters from the western end of the Profile 236, below 6.5 to 12 meters (GPR Report, page 50).

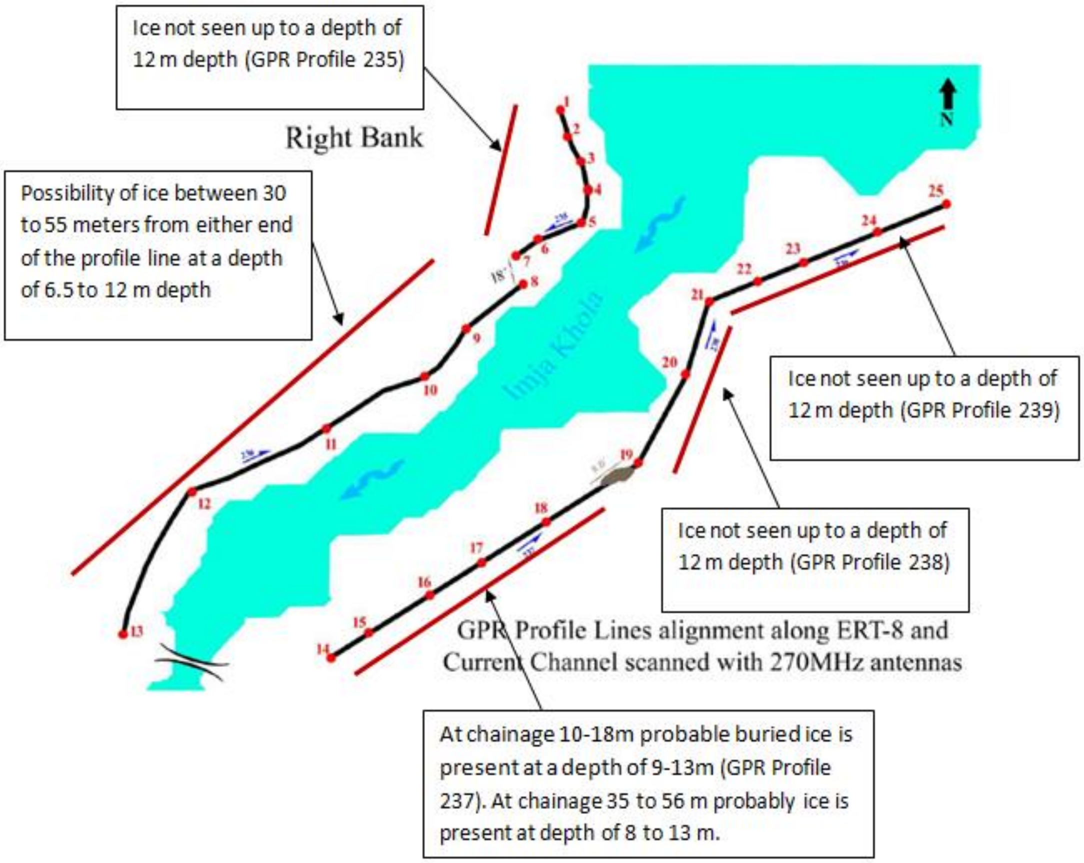


Figure 33 (C): GPR profiles along right and left bank of the outlet of Imja Lake. The survey was carried out clockwise using 100 MHz frequency and anticlockwise using 270 MHz frequency. The depth of penetration of 100 MHz and 270 MHz is 6 and 12 m respectively.

Table 14: Interpretation of sub-surface condition along ERT profile 8 (left bank).

	ERT findings		**GPR Findings**	
Chainage (m)	**Depth (m)**	**Inferred material**	**Depth (m)**	**Inferred material**
0-35	0-25	Frozen moraine	0-12	Boulders/damp materials
35-70	0-8.5	Frozen moraine	0-7	Loose materials/boulders
	8.5-25	Dead ice	Below 7	Dead buried ice
70-170	0-25	Frozen moraine	0-12	Loose materials/boulders
170-180	0-8.5	Frozen moraine	0-6	Loose materials/boulders
	8.5-25	Dead ice	Below 6	Dead buried ice

5.9.2.9. Profile 9

The ERT-9 Profile is about 100 meters in length in NW-SE direction. It is at the left bank to the Imja Lake and runs across the end moraine ridge. The model section shows resistivity values ranging from 6000 to over 60,000 Ωm. possibly dead-ice exists at chainage 65 m along the profile line. The approximate depth of dead ice is 7.5 m from the surface. Most part is occupied by frozen moraine. The sub-surface interpretation of the profile 9 is given in Figure 34 and Table 15.

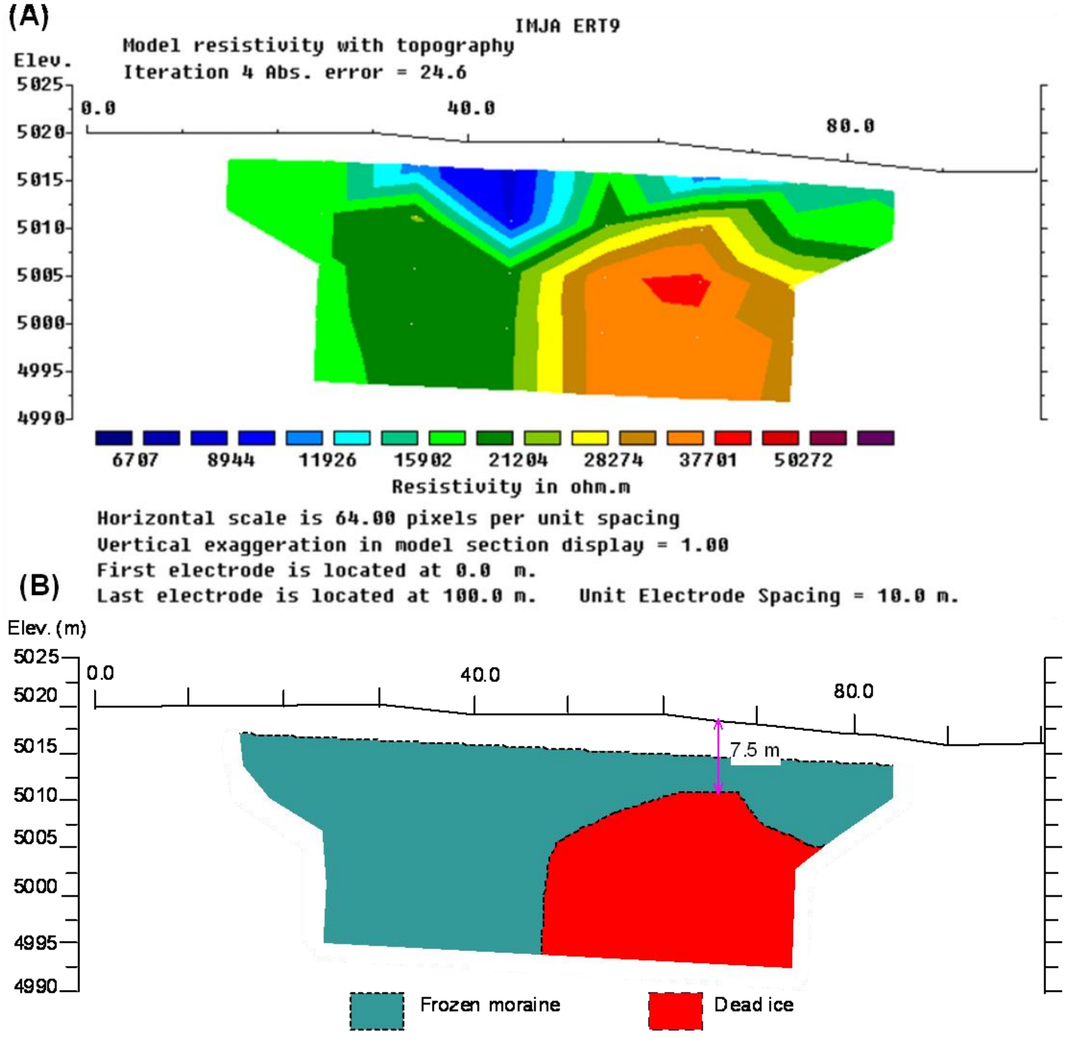


Figure 34: A. Inverse resistivity section along profile ERT-9. The purple color at the right possibly represents dead ice. B. Geological Cross-section interpreted from the geo-electric section.

Table 15: Interpretation of sub-surface condition along ERT profile 9.

	ERT findings		GPR Findings	
Chainage (m)	**Depth (m)**	**Inferred material**	**Depth (m)**	**Inferred material**
0-48	0-25	Frozen moraine	0-12	Boulder/damp material
48-80	0-7.5	Frozen moraine	0-6	Boulder/damp material
	7.5-25	Dead ice	Below 6	Buried dead ice

5.9.2.10. Profile 10

The ERT-10 Profile is about 200 meters in length in almost NE-SW direction. It is at the left bank to the Imja Lake and runs parallel the end moraine ridge. The model section shows resistivity values ranging from 1000 to over 1, 35,000 Ωm. Most part of the section is occupied by frozen moraine. Dead ice is possibly present between chainage 20 to 100 m. Minimum depth of dead ice surface is about 5 m at chainage 80 m. The sub-surface interpretation of the profile 2 is given in Figure 35 and Table 16.

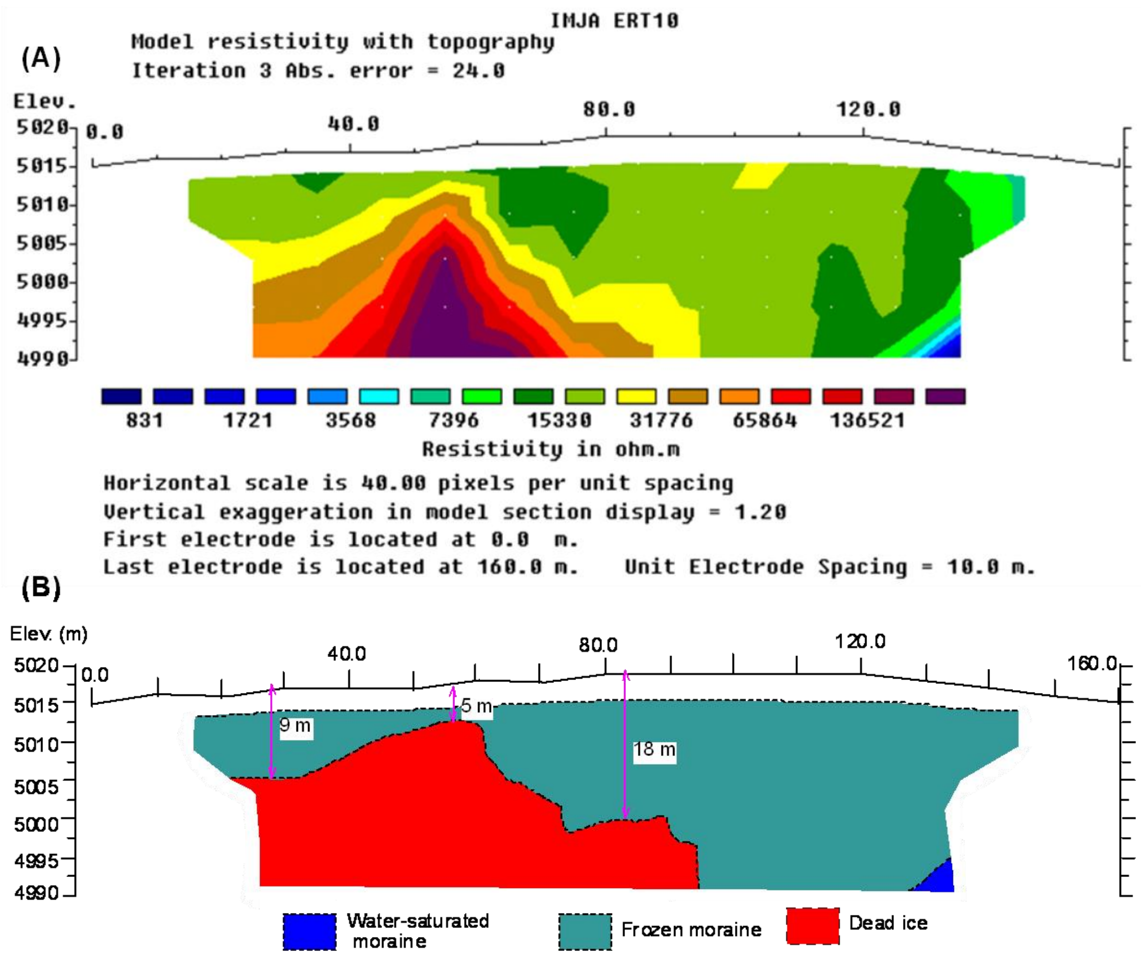


Figure 35: A. Inverse resistivity section along profile ERT-10. The purple color at the right possibly represents dead ice. B. Geological Cross-section interpreted from the geo-electric section.

Table 16: Interpretation of sub-surface condition along ERT profile 10.

	ERT findings		**GPR Findings**	
Chainage (m)	**Depth (m)**	**Inferred material**	**Depth (m)**	**Inferred material**
0-30	0-13	Frozen moraine	0-12	Boulder/loose material
	13-25	Dead ice		
30-40	0-9	Frozen moraine	0-8	Boulder/loose material
	9-25	Dead ice	Below 8	Buried dead ice
40-50	0-7	Frozen moraine	0-6	Boulder/loose material
	7-25	Dead ice	Below 6	Dead buried ice
50-60	0-5	Frozen moraine	0-5	Boulder/loose material
	5-25	Dead ice	Below 5	Dead buried ice
60-75	0-13	Frozen moraine	0-12	Boulder/loose material
	13-25	Dead ice		
75-95	0-18	Frozen moraine	0-12	Boulder/loose material
	18-25	Dead ice		
95-140	0-25	Frozen moraine	0-12	Boulder/loose material

6. Interpretation of Results

From geological and engineering geological points of view, the end-moraine complex has almost uniform properties in all parts. The basement, crystalline metamorphic, rock of the Imgja Lake is gently northward sloping,. The moraine material is made up of non-stratified angular clasts ranging in size from several meters large boulders to fine clay-sized particles. Laboratory testing carried out in fine-material (material ranging from gravel to clay) from the moraine shows that it is well-graded and non-plastic.

Although the strength of the moraine could not be estimated with the help of Schmidt Hammer Test, testing of individual boulders show they are made up of high strength materials. The rock boulders are suitable for rip-rap and gabion constructions.

The moraine material is loose and highly permeable in all parts. Minimum average permeability value was measured in the southern bank of the existing outlet of the Imja Lake. As the test was carried out in the fine-material dominated sites, actual permeability of the moraine should be higher than the measured values.

The sub-surface features along each profile line were interpreted on the basis of ERT data. The ERT interpretations were also compared with the GPR interpretations for cross-verification. In most of the cases the results from both the investigations correspond very well. An attempt has been made to deduce the distribution of dead ice in the end-moraine complex. Figure 36 shows the approximate depth of dead ice at different points along the ERT profile lines. The map shows that dead ice is extensive in the northern part (right side) of the existing channel compared to that in the southern part (left side). Dead ice is present along all proposed alternative canal alignments except along the existing channel. The dead ice is present in the form of isolated patches (ERT Profiles 1 and 5) of about 5 m thick to massive sheets reaching thickness more than 25 m.

In the area between R1 and R2, the depth of dead ice varies from 4.5 m to 25 m, but mostly it is below 10 m from the surface. In the area between R1 and EC, dead ice is most extensive and is in shallower depth. The depth of dead ice varies from 5 m to 12 m. In the area between EC and L1, the dead ice is very sparse and depth varies from 5 to 15 m from the surface.

GPR surveys show presence of ice from chainage 35 to 56 meters of the Profile 237 (from west) along the left bank of the outlet channel. This survey was carried out parallel to ERT-8 profile at the left bank however the ERT deviates towards east, whereas the GPR profile runs for a length of about 200 m parallel to the flowing channel. GPR survey along the right bank do not show the presence of ice up to a depth of 12 m but shows ice after about 150 m from the northerly end of the profile line.

ERT survey across the existing channel (ERT profile 7) excellently detected a narrow conduit of very low-resistivity material (<2500 Ωm) exactly at the position of the existing channel implying that the low-resistivity material represent the water-saturated moraine. Such low-resistivity zones, more likely to represent the water-saturated moraine, were found at chainages between 60-140 m and 210-260 m along ERT profile-2, at chainage between 50-90 m along ERT profile-3, at chainages 40 and 80 m along ERT profile-4 and at chainage 40 m along ERT profile-9.

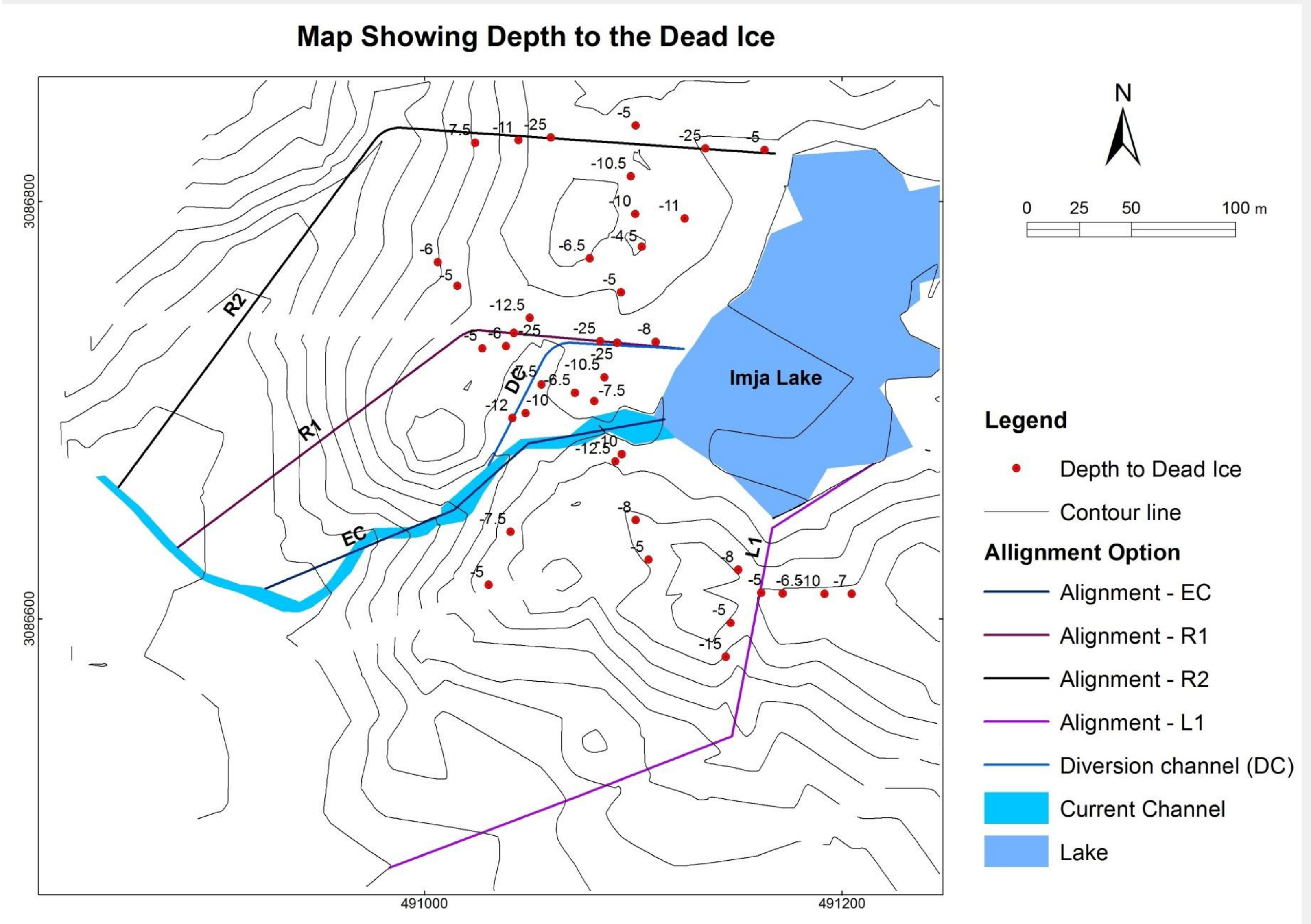


Figure 36: Map showing depth of dead-ice at different locations of end moraine of the Imja Lake deduced from ERT survey. The red dot indicates location and number indicates depth in meters.

The four alternative canal alignments and selected by surface observations have been evaluated on the basis of various parameters such as level of dead ice with reference to lake level, geo-technical strength of soil, field permeability, presence of instabilities, slope of canal alignment, and depth of excavation required to drawdown the lake level by 3 m.

The cross-sections along four alternative alignments with the position and level of dead ice with reference to the present lake level are given in Figures 37, 38, 39 and 40.

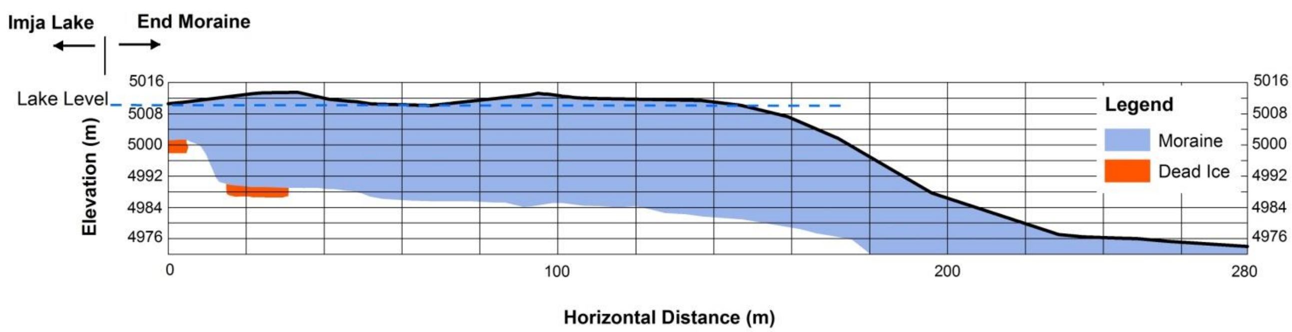


Figure 37: Geological cross-section along alternative canal alignment R1.

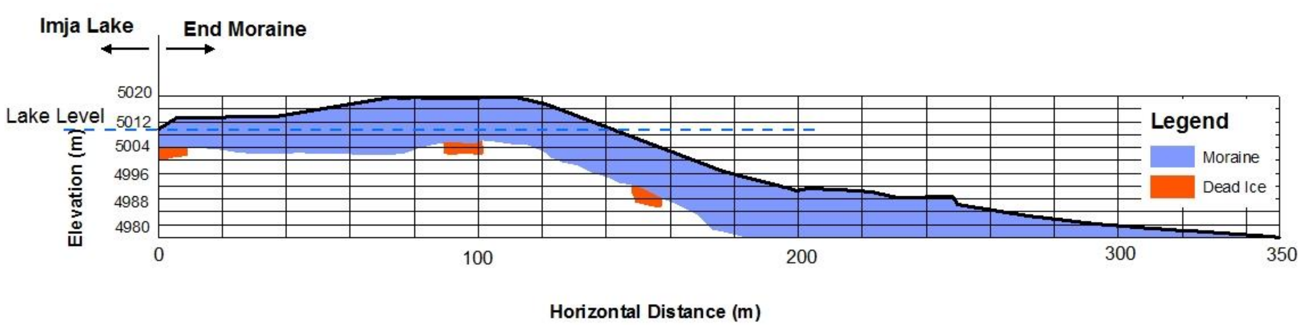


Figure 38: Geological cross-section along alternative canal alignment R2.

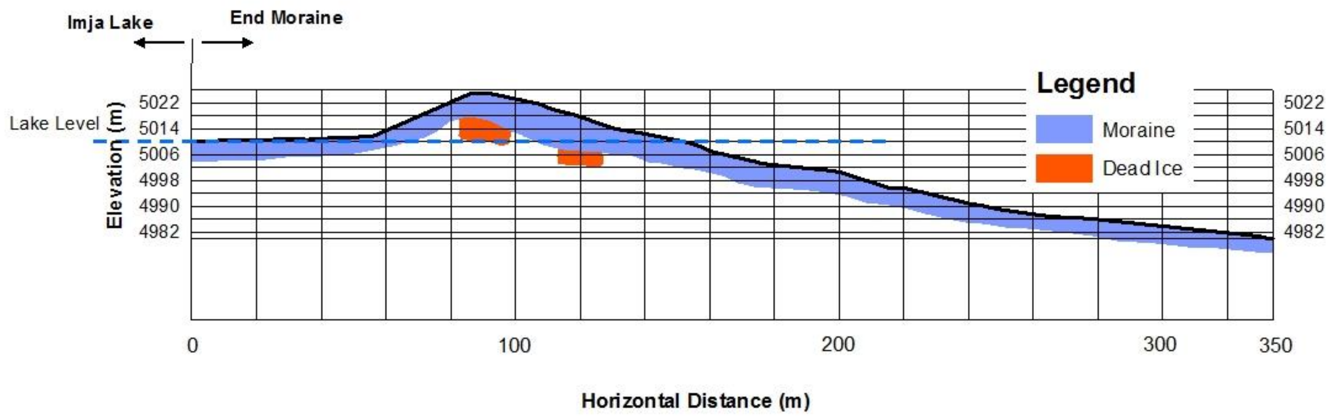


Figure 39: Geological cross-section along alternative canal alignment L1.

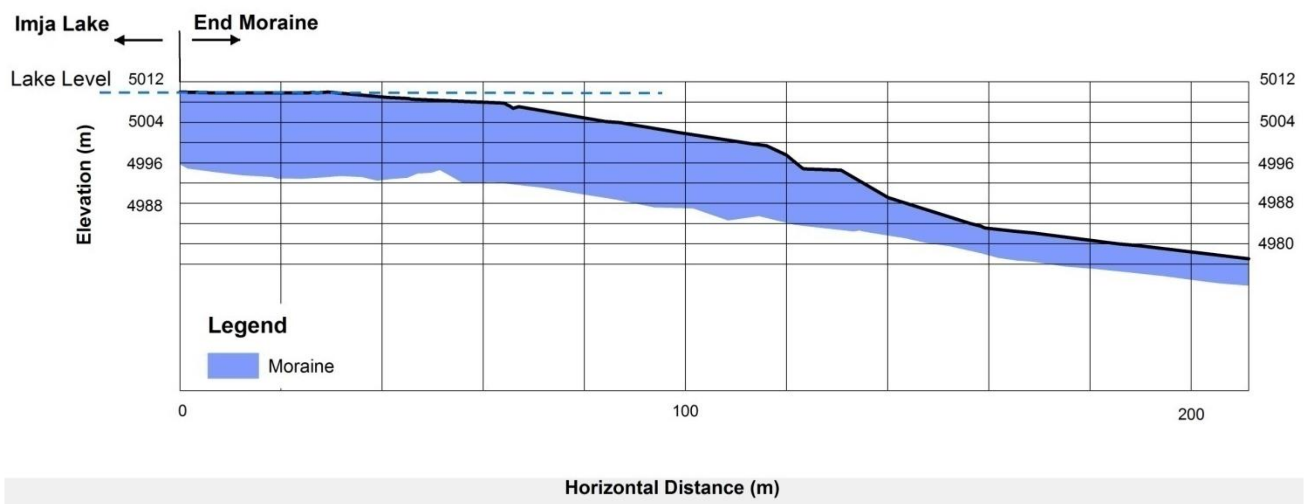


Figure 40: Geological cross-section along alternative canal alignment EC.

Various parameters used for evaluating the best alternative alignment along the proposed four alternative alignments have been summarized in the following table (Table 17).

Geophysical observation shows that dead ice is possibly present below three alternative alignments. With reference to present lake level, dead ice is below 10 m along R1, below 4 m along R2, above 8 m along L1. Therefore, R2 and L1 are not feasible for 3 m draw down of the Imja Lake as the canal will approach to the dead ice along R2 and will cross the dead ice along L1. These two alignments have longest length (350 m) and depth of excavation is also higher (R2=15 m, L1=19 m). Therefore, R2 and L1 are not recommended for canal alignments.

Remaining two alignments EC and R1 are feasible for construction of canals for lowering of the Imja Lake by 3 m and also for the construction of power canal respectively. The existing channel (EC) is the most suitable alignment because dead ice is not detected in the area of interest for different structures' emplacement based on GPR survey conducted along both banks and ERT survey (Profile 7) of the channel. Additionally, the length of the alignment is minimum (210 m), depth of excavation is minimum (3 m) and slope of the alignment is gentle.

Table 17: parameters used for selecting best alternative alignment along the proposed four alternative alignments.

Canal alignment	Presence of dead ice	Level of dead ice with reference to lake level	Geo-technical strength of soil	Field permeability of soil	Presence of instabilities	Slope of alignment	Length of canal alignment	Depth of excavation for 3 m draw down of lake	Recommendations
R1	Yes	10 m below	Sound	Higly permeable	No	Steep	280 m	12 m	Recommended for power canal alignment/diversion canal
R2	Yes	4 m below	Sound	Higly permeable	No	Steep	350 m	15 m	
L1	Yes	8 m above	Sound	Higly permeable	No	Gentle	350 m	19 m	
EC	No		Sound	Higly permeable	No	Gentle	210 m	3 m	Recommended for water drawdown

Appropriate alignment for the diversion canal has been identified between EC and R1 (Figures 36 and 41). Along this alignment, possibility of dead ice is not observed within 15 m depth from the present lake level and length of excavation is minimum (140 m).

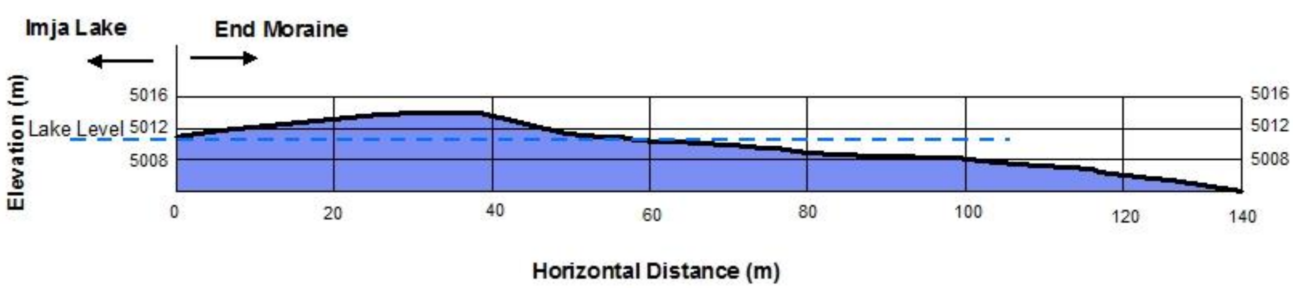


Figure 41: Geological cross-section along diversion canal alignment.

7. Conclusions and Recommendations

The Imja Lake lies geologically in the Higher Himalaya of Nepal with high strength metamorphic crystalline basement rocks such as gneisses and schist. Regional geological assessment of the area reveals that a regional normal fault system (South Tibetan Detachment System) passes approximately E-W just north of the Imja Lake. Besides this, no other active tectonic structures were identified in the area. Regional seismic data show that this area lies in one of the seismically high hazard zones of Nepal Himalaya. The minimum peak ground acceleration value for this area is 400 gal for 10% exceedace in 50 years.

The moraine material is made up of poorly sorted angular clasts ranging in size from fine clay to several meters large boulders. The distribution of material is inhomogeneous and in-situ permeability is very high. The natural slopes of side valleys and moraine dam is mostly within the limit of safety factor (<30°). Possible quarry sites for construction material have been identified at three places, one between EC and L1 (south of existing channel) and the other two between R1 and R2 (north of existing channel). The aggregates show high alkali-silica reactivity and flakiness index. The maximum quantity of gravel and sand that can be extracted from three sites is 8500 m^3 and 6800 m^3, respectively.

ERT and GPR investigations confirm the possibility of presence of dead ice under the end moraine. The depth of penetration in the case of ERT is up to 25 m and that in the case of GPR is up to 12 meters only. The dead ice is more extensive in the northern side of the existing channel compared to that in the southern side of the existing channel. The dead ice is present both as isolated blocks to massive sheets reaching thickness more than 25 m.

The proposed alternative alignments have been evaluated on the basis of various parameters such as presence or absence of dead ice, depth of dead ice, length of alignment, minimum depth of excavation, slope of the alignment, geotechnical strength of soil, field permeability and presence of instabilities. On the basis of above parameters, the existing channel has been found as most suitable alignment for draw down of Imja Lake by 3 m. The R1 is suitable for power canal construction. The diversion canal construction is suitable between EC and R1.

The following recommendations are made for selection of appropriate design parameters and safety measures.

1. The existing channel has been recommended as the best alternative for the drawing down of the Imja Lake by 3 meters from geotechnical and geological points of view. The R1 is suitable for power canal and DC is suitable for diversion canal.

2. The area lies in the seismically high hazard zone with minimum peak ground acceleration of about 400 gal. This fact should be incorporated during designing.

3. The end moraine has very high permeability. The design team should consider appropriate lining materials to reduce the permeability of the channel bed and banks. Geomembranes or flexible membranes are most suitable lining materials for cold environments.

4. The moraine consists of very few amounts of construction aggregates. The quantity estimated in this study is on biased samples and should be considered as maximum amount that could be extracted. On the other hand the samples show high alkali silica reactivity and flakiness index. To reduce the alkali silica reactivity of the concrete, low-alkali cement may be used. Another option is to use slag cement. The flakiness index of the aggregate may be reduced by sieving /washing or addition of angular aggregates.

5. The moraine is not consolidated and could be easily destabilized during excavation. Therefore, the slopes of the canal banks and canal profile should not be greater than 30°. Appropriate measures should be applied to protect the channel bed and banks from scouring and failure. Stone rip-rap on the channel bed and banks is one of the suitable methods to protect.

6. The surface of dead ice is very irregular. Slight deviation of canal alignment may transect the dead ice and destabilize the dam. Therefore, excavation should be made exactly along the recommended alignment.

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ANNEXES

Annex I-TOR of the present study

Terms of Reference (TOR)

"Detailed Geophysical –ERT Investigation Required for Structural Design of Imja Lake Lowering, Solukhumbu District"
Under Component I of CFGORRP

1. Background

Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP) is a joint undertaking of the Government of Nepal (GON), Global Environment Facility (GEF) and the United Nations Development Programme (UNDP). The project is being implemented by Department of Hydrology and Meteorology (DHM) under the Ministry of Science, Technology and Environment (MoSTE) as the lead Implementing Agency. The project working areas include Solukhumbu in the hill and Mahottari, Siraha, Saptari and Udaypur districts in the Terai.

The main objective of the CFGORRP is to reduce human and material losses from Glacier Lake Outburst Flood (GLOF) in Solukhumbu district and catastrophic flooding events in the Terai and Churia Range. For achieving this objective, the project has been streamlined into two main Components. Component I is specifically aligned towards reducing GLOF risks arising from Imia Lake and the Component II aims to reduce human and material losses from recurrent flooding events in the four flood prone districts of Churia and Terai.

This TOR refers to the activities of the First Component (Component I) of the project which aims to reduce human and material losses from GLOF from Imja Lake (5010 m) in Solukhumbu District by reducing the GLOF hazard risk in 27 settlements in the downstream valley by reducing Lake level by more than 3 m through construction of an open channel. In order to accomplish the above mentioned task,

CFGORRP/DHM intends to hire a service provider (referred herein as the "Geophysical ERT Team") for undertaking detailed Geophysical-ERT assessment of Imja Lake for input to technical design of the Lake lowering. The project has also envisioned forming three other thematic teams as a multi disciplinary approach for the entire structural design work. The other thematic teams comprise of (a)Topographical Survey and Design (b) Bathymetry and Hydrology/Glaciology and (c) Geophysical GPR thematic teams. Although these teams would have independent functions, however they need to work in a coherent group under the overall coordination and guidance of the Topographical Survey and Design Thematic Team.

2. Objective:

The main objective of this task is to undertake a detailed geophysical investigation -ERT of end moraine complex of Imja Lake.

The specific objectives of this task include but not limited to the followings:

a) To identify at least 3 most suitable open channel alignments (longitudinal profile) and conduct transverse profile at suitable spacing for 3D profile to assess sub-surface conditions of the moraine dam from ERT.
b) To prepare longitudinal, transverse and 3D profile using ERT.
c) To provide geological, geotechnical and geophysical-ERT related input to the Survey and Design Thematic Team for the selection of appropriate design parameters and safety measures.
d) To recommend remedial measures for digging out open channel by more than 3 m for mitigating adverse effects if any on buried ice, seepages, piping etc.

3. Study area:

The study area is Imja Lake and its associated glaciers and the moraine dam at 5010 m in Solukhumbu District. The study area is remote and inaccessible by road and the nearest airport is at Lukla. The trekking routes are through Namche, Tengboche, Pangboche, Dingboche, Chhukung and finally to Imja Lake. The hotel facilities are available from Lukla to Chhukung. The service provider needs to arrange camping and foods for entire field investigation period at the Lake.

4. Scope of the work:

The scope of the works includes inter–alia, but are not limited to the following:

Desk Study Phase for Inception Reporting:

a) Consult with key stakeholders at national level such as Water and Energy Commission Secretariat (WECS), Department of National Park and Wildlife Conservation (DNPWC), United Nations Development Programme (UNDP), United States AID (USAID), International Centre for Integrated Mountain Development (ICIMOD), Kathmandu University (KU,) High Mountain Glacier Watershed Program (HMGWP) for data and information generated on geophysical prospections through previous work on glacier, glacial lakes etc.

b) Appraise, review, and refine all available scientific data and information generated by previous field assessments undertaken at Imja Lake by different organizations and institutions to collect baseline information on geophysical, geological and geotechnical results and any other studies. Review all recent studies conducted by CFGORRP on ongoing programs, collate and update information and reports for design related work.

c) Coordinate, discuss and team up with other thematic teams to have common understanding on project area, study methodology and to collect information on the composition of moraine materials, density, porosity, voids, material strength etc. for structural design and for ensuring safety factor.

d) Review and refine field investigation tool and techniques, plans and schedules, data collection methodologies to ensure appropriate and adequate data collection for geophysical ERT and geological studies and other thematic team's mapping.

e) Evaluate the general geological, seismicity and tectonic settings of the Imja Lake and its surroundings for overall assessment of Imja Lake and the surroundings.

f) Share the ERT/GPR related information to the GPR thematic team and vice versa.

g) Prepare and submit inception report along with necessary checklists, formats and questionnaires to be used in the field to gather data.

Field Investigation Phase:

a) Undertake joint field visit with other thematic teams and hold discussion between them for data capturing, coverage/density, methodologies and quality of data and to select most appropriate 3 channel alignments.

b) Consult with local level stakeholders like Sagarmatha National Park (SNP), District Development Committee (DDC), Village Development Committee (VDC), Khumbu Area Conservation Committee (KACC); local NGOs and CBOs for having required information on the lake, its catchment, geological and geotechnical data and information.

c) Undertake reconnaissance survey with all other thematic teams to identify at least 3 suitable location for open channel alignment.

d) Undertake a detailed geotechnical and geophysical ERT survey on overall composition of moraine dam, density, voids, sinks, material strength etc. for moraine dam stability and design parameters.

e) Conduct detailed geophysical assessment (ERT), longitudinal and transverse profiles at suitable spacing to generate 3D profile within the selected alignments. Share the results with GPR thematic team to validate the results and recommend the best alignment including alternative alignments.

f) Conduct field survey to prepare a geotechnical / geological map of the lake area that is covered by the Survey and Design Thematic Team. Prepare engineering geological map of the Lake and its surroundings, particularly focusing on lateral moraines, glacier terminus and end-moraine complex. Prepare geological cross sections (of about 10 samples) and longitudinal profiles along the channel alignment. Conduct various in-situ tests such as Schmidt Hammer Tests, Permeability Tests (about 5 numbers).
g) Assess most appropriate quarry sites meeting required quantity and quality of the construction materials.
h) Collect soil samples to determine soil size distribution, material strength and physical and chemical properties for design.
i) Conduct geotechnical assessment of the moraine dam complex and lateral moraines to assess features like thermokarst, sinks, void ratio, d30, d60, d90, lineaments and old outlet channels etc. to evaluate characteristics of moraine materials and stability of moraine dam.
j) Acquire other relevant field based data and information that are required as inputs to the Survey and Design Thematic Team from geological and geophysical ERT Thematic Team.
k) Guide, coach and mentor PMU/DHM personnel in building their technical capacity in data acquisition, interpretation and analysis using ERT.
l) Prepare and submit field report.

Office Work for Draft and Final Reporting Phases:

a) Prepare design, drawings, maps (geological map, cross-sections, ERT 3 D map etc.), database on geological and geophysical –ERT on topographical base maps at appropriate scales prepared by Survey and Design thematic team.
b) Interpret and analyze geophysical ERT results after extensive consultation and coordination with Geophysical GPR thematic team to confirm sub-surface features like buried ice, voids, characteristics of matrix etc.
c) Cross verify the ERT results with those of GPR to improve ERT assessment on subsurface features and recommend best alternatives for open channel alignment
d) Conduct various tests on the soil samples collected from the field to find the particle size distribution, soil strength etc.
e) Provide geophysical and geotechnical / geological assessments and provide design inputs to the survey and design thematic team particularly on appropriate parameters, subsurface features such as buried ice, instabilities comparing the results between ERT and GPR.
f) Capture all GIS based attribute data in digital format proposing suitable canal alignments with clearly marking ERT, GPR investigation lines, benchmarks and other appropriate features.
g) Prepare geophysical-ERT, geotechnical and geological maps improvised with GPR assessments in GIS environment with proper attribute tables.
h) Prepare all the geophysical, geotechnical and geological maps, design, drawings into digital format at appropriate scale using AutoCAD tools.
i) Prepare draft final report presenting key findings on geological, geotechnical and geophysical-ERT data and information, test results, geological mapping and other related input.
j) Prepare final report after incorporating the comments and feedbacks from the international consultant, PMU/DHM and other stakeholders.

5. Deliverables and Timeline

a) Inception Report (Within 10th October 2014):

The Geophysical-ERT Thematic Team shall provide three hard copies of Inception Report along with an electronic file. The report shall include:

- A concise description on the findings on the scientific and other data and information collected during inception reporting phase.
- A detailed design methodology and work plan, equipment, tools and techniques to be used, data collection methods with appropriate data and information collection sheets.
- Formats, checklists and questionnnaires to be used in the field investigation program.
- A detailed field work plan on work coordination, collaboration towards generating the inteneded outcomes.

b) Field Investigation and Report: (Within 20th November 2014)

The Geophysical-ERT Thematic Team shall provide three copies hard copy of field investigation report along with an electronic copy and the report shall include:

- Key field findings information, maps, sections, database etc. derived from the field study, which can be implied to the structural design.
- Field thematic data and reports, key features, key information on 3 alignments particularly on geological, geotechnical and geophysical ERT data and information.

c) Draft Report: (Within 10th December 2014)

The Geophysics ERT Thematic Team shall provide five copies of draft report along with an electronic version. The report shall include:

- **Comprehensive and complete** geological, geotehcnical and geophysical ERT reports with all design, maps, drawings, 3 D profiles, sections and database teams for ensuring cost effectivess and safe structural design for open channel construction.

d) Final Report (Within 31st December 2014):

After incorporating the comments from the international consultant, PMU/DHM and other stakeholders, the Geophysical ERT Thematic Team will prepare and submit five copies of Final Report along with an electronic copy.

The Final Report should include:

- Revision of draft reports with incorporation of all feedbacks, comments and submit for review and comments to TAG, PMU/ DHM, International Consultant and other stakeholders.

6. Guidance, Supervision & Quality assurance

The Geophysical ERT Thematic Team will work under the general guidance and supervision of the National Project Director (NPD), National Project Manager (NPM) and PMU/DHM. All key outputs/deliverables including designs, reports including inception / draft / final will be subjected to review/appraisal at various levels by international consultant, Senior Technical Advisor (STA), Technical Advisory Group (TAG) and project stakeholders as appropriate. However, on technical matters, the Team will work specifically in close consultation and supervision of STA, International Consultant, TAG and Project stakeholders.

The following are some general guidance and requirements for undertaking the above tasks:

a. The Geophysical ERT Thematic Team will include and encourage an active participation of professionals from PMU/DHM as part of the study team in the overall exercise including field assessment, data collection, interpretation and analysis towards developing the institutional capacity of DHM without claiming any additional cost. The logistics support for this activity will be provided by PMU/DHM.
b. The Team shall possess, handle and operate Geophysical equipment such ERT and software, experience on handling GPR equipment and processing result is highly encouraged.
c. The Geophysical ERT Thematic Team will encourage to use locally available expertise and human resources to the extent possible as part of the capacity enhancement of local professionals. Similarly, the

Team will encourage to employ local people preferably from Khumbhu Area as far as possible as field staffs to ensure ownership of the project by local communities.

d. The Geophysical ERT Thematic Team will not be provided with logistics support (lodging, fooding, camping), tickets (travel) and transportation of equipment (porter and cargo).

e. The supervision, monitoring and evaluation of field work of the Survey and Design Team will be conducted jointly by CFGORRP/DHM, techincal advisory group (TAG) and International consultant (if deemed necessary) for ensuring quality of work and for its timely completion.

Annex II-Principles of ERT Survey

Principle

Electrical resistivity tomography (ERT) is a geophysical technique for imaging sub-surface structures, based on the electrical properties of subsurface materials, from electrical resistivity measurements made at the surface

The electrical resistivity survey was carried out injecting direct (DC) current into the ground through two current electrodes. The resulting potential difference at two different electrode locations was measured with the help of two potential electrodes. For the current value (I) and the observed voltage difference value (V), an apparent resistivity value (ρ_a) was calculated as follows.

$$(\rho_a) = k*V/I$$

Where, k is the geometrical factor which depends on the arrangement of the four electrodes (two current electrodes and two potential electrodes).

The resistivity value (ρ_a) thus calculated is just "*apparent resistivity*" observed on account of the cumulative influence of different subsurface layers which may have different electrical properties in the subsurface. An "*apparent resistivity*" value of a homogeneous ground will give the true resistivity value for the same electrode arrangement. The apparent resistivity values are converted into the "*true resistivity*" by mathematical inversion method.

The final resistivity model is interpreted based on resistivity values to obtain a geological model of the ground. This step requires some *a* priori geologic information of the study area, which is obtained during the field survey. In general, water saturated layers and clay rich layers tend to have lower resistivity value, and high resistivity regions generally indicate bedrock or presence of ice in the subsurface. Approximate resistivity values for some geological materials and ice has been given below.

Equipment

The measurement was done using the instrument "ABEM Terrameter SAS 300C" resistivity meter, manufactured in Switzerland. Stainless steel electrodes were used to inject current into the ground

and stainless steel electrodes were used as potential electrodes to measure the resulting voltage. Necessary electric cables, connectors, multimeter, magnetic compass, and GPS etc. were used as accessories. Salt water was utilized to give good contact between electrode and the ground wherever it was required.

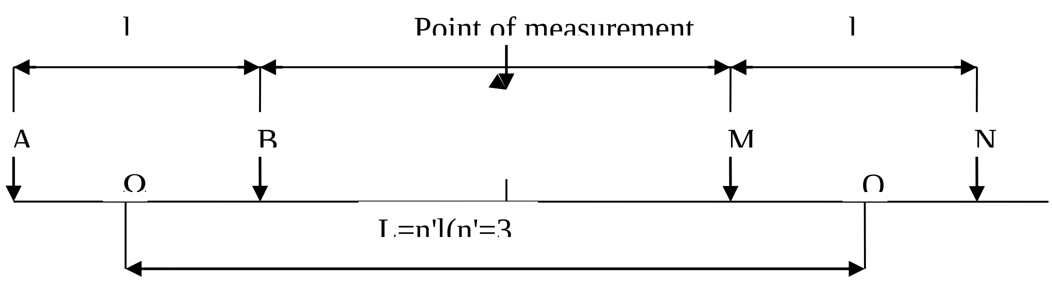
ABEM Terrameter SAS300CResistivitymeter to be used for ERT survey in the field.

FERT equipment and cables used in the field.

Placing of electrodes along the profile line for survey.

Data acquisition was implemented utilizing Dipole-Dipole electrode array. The schematic diagram showing the arrangement of electrodes for the Dipole-Dipole arrays are shown in the following figures. The Dipole-Dipole array, which is sometimes called the double dipole, array has two current electrodes (A and B) and two potential electrodes (M and N) aligned along and exterior to each other. The Dipole-Dipole array is defined by the following lengths: l = AB, l = MN and L = OΩ = spacing, O and Ω being the centers of MN and AB respectively.

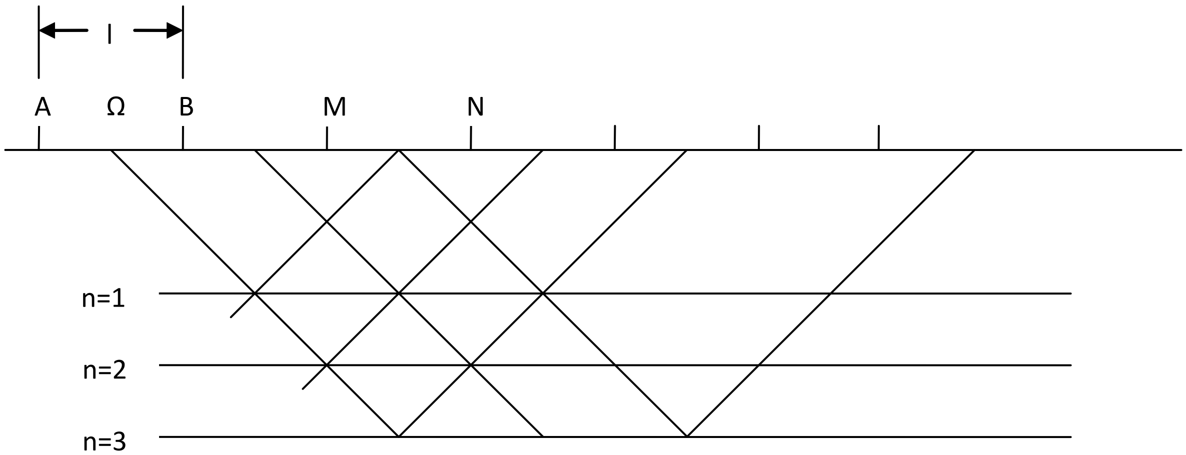
In practice, geophysicists always use a symmetrical Dipole-Dipole, where BM = OΩ – l = L – l = nl; n is a whole number equal to or greater than 1. The figure shows the location of electrodes for n=1, 2 and 3. Some authors define the Dipole-Dipole by 0Ω = L = n'l, n' = n+1.



Dipole-Dipole array.

Since this array is symmetrical, one can consider the point of measurement as being at the center of segment OΩ (or the mid-point of BM) which is the center of symmetry of the configuration. The depth of investigation increases with the spacing: L = l (n+1) = n'l; that is, with n of n' when the length l = AB = MN is fixed.

One can carry out resistivity profiling at a constant depth of investigation by moving, after each measurement, the whole quadripole ABMN a fixed distance called a "leap" which is generally equal to l. But usually one takes resistivity readings corresponding to several investigation depths (several values of n). Then, the following procedure is used for one position of AB, several measurements are made by moving the electrodes M and N along the survey line with a leap=l; stations M1N1 (n = 1), M2N2 (n = 2), M3N3 (n = 3), etc., then AB is moved to A'B' (by a leap = l), and one measures between M'1N'1, M'2N'2, etc., the survey is carried on with A"B" current electrodes and measurement between M"1N"1, M"2N"2, etc.



Dipole-Dipole Pseudo section.

The plotting points are located at the intersection of 45º lines drawn from mid-points **Ω** and O of each dipole, which gives the values for deeper and deeper earth. The equal value curves of the resistivity value measured can then be traced on vertical sections.

Obviously, this presentation is only a rough picture of the phenomenon in the vertical plane passing through the survey line, since the depth of investigation does not depend solely on the geometry of the measuring configuration; it also depends on the resistivity contrast of the layers in question. Thus, one must not consider these sections as true depth readings. They are generally called pseudo-sections.

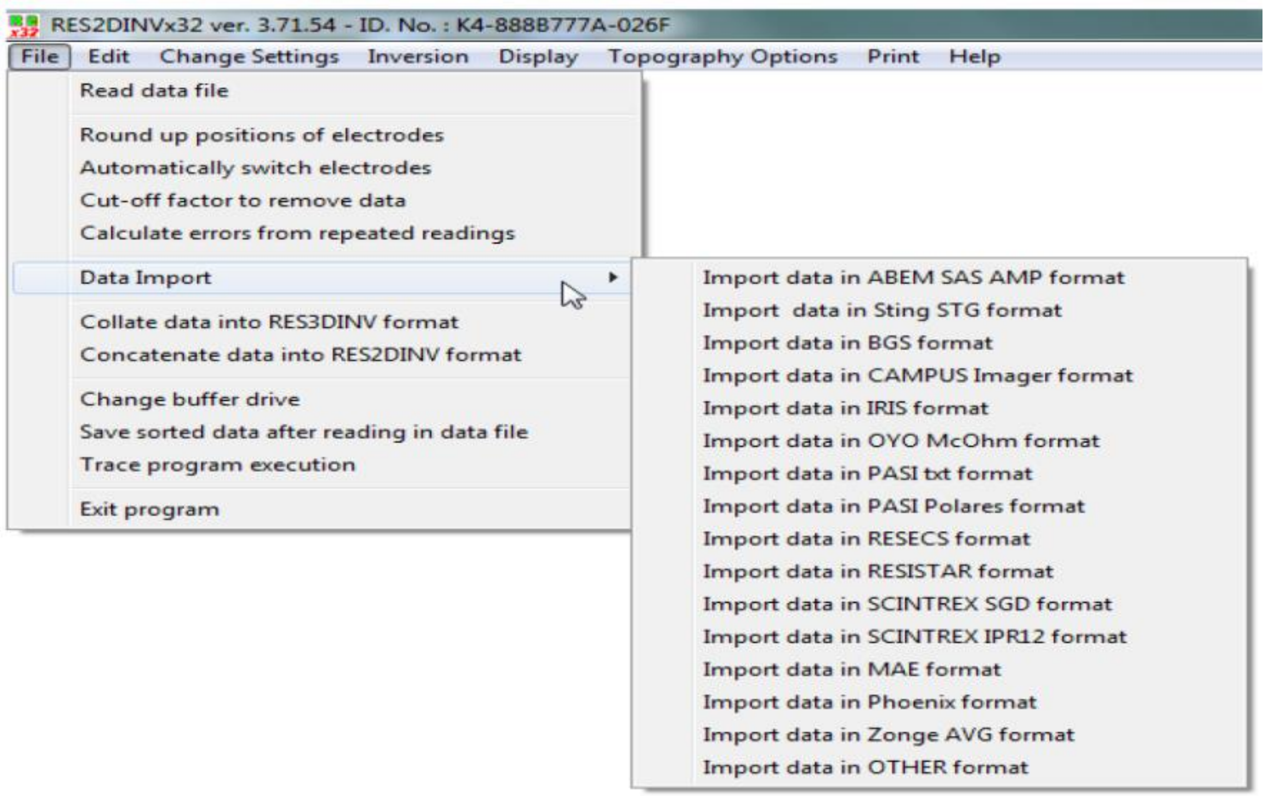
Data Processing and Interpretation

Data Processing was done using standard software (RES2DINVx32 ver. 3.71) manufactured by GEOTOMO (Malaysia) (Figure 7). The software is designed to operate, as far as possible, in an automatic and robust manner with minimal input from the user. It has a set of default parameters which controls and guides the inversion process. In most of the cases, the default parameters give reasonable results. The instrument can measure resistivity from as low as 0.05 miliΩm to 1999000 Kilo Ωm.

The 2D resistivity model used by this program divides the sub-surface into a number of rectangular blocks. The purpose of this program is to determine the true resistivity of the rectangular blocks

that will produce an apparent resistivity pseudo-section that agrees with the actual field observations.

The program calculates 2D apparent resistivity pseudo-section models using the measured apparent resistivity along the profile lines. Subsequently based on the help of the calculated apparent resistivity values, an Inverse Resistivity Model Section is computed. The techniques applied for the inversion were the smooth model and robust model (also called block or polygon model). In such section, the bottom of the Inverse Model Section represents the depth of investigation (median depth).



RES2DINVx32 ver. 3.71 window with data import and analysis options.

Annex III- Procedures of Laboratory Tests

Grain Size Distribution

The soil sample taken from site was sieved through a set of IS sieves. Mass retained on each sieve was taken to determine cumulative retained. After completing mechanical analysis, the results were plotted on a semi-log graph with particle size as abscissa (log scale) and the percentage smaller than the specified diameter as ordinate. The effective sizes d30, d60 and d90 were calculated using the grain-size distribution curve.

Atterberg Limits

Atterberg Limits (Liquid Limit, Plastic Limit and Shrinkage Limit) of the soil samples were calculated following the standard methods suggested by Indian Standards.

The Liquid Limit of fine-grained soil is the water content at which soil behaves practically like a liquid, but has small shear strength. Its flow closes the groove in just 25 blows in Casagrande's liquid limit device.

The Plastic Limit of fine-grained soil is the water content of the soil below which it ceases to be plastic. It begins to crumble when rolled into threads of 3 mm dia.

The Shrinkage Limit is the maximum water content expressed as percentage of oven-dry weight at which any further reduction in water content will not cause a decrease in volume of the soil mass.

Compaction

Air-dried soil material and large enough to provide about 6 kg of material passing a 19-mm IS sieve was taken. The sample was mixed thoroughly with a suitable amount of water initially. The mould with base plate attached, was weighed in gm. The moist soil was compacted into the mould, with the extension attached, in five layers of approximately equal mass (around 1 kg). Each layer was given 25 blows from the 4.9 kg hammer dropped from a height of 450 mm above the soil uniformly over the surface of each layer. The extension was removed and the compacted soil was leveled off carefully to the top of the mould by means of the straight edge. The mould and soil was then weighed. The compacted soil specimen was removed from the mould and placed on the mixing tray. The water content of a representative sample of the specimen was determined by

taking some sample on moisture and drying in oven. The remainder of the soil specimen was broken up, rubbed through the 19 mm IS test sieve, and then mixed with the remainder of the original sample. Suitable increments of water was added successively and mixed into the sample, and the above procedure of compaction was repeated for each increment of water added. The step was repeated until there is decrease in weight by increasing moisture content in the sample. At least, five such steps were conducted for each sample such that the optimum moisture content, at which the maximum dry density occurs, is within that range. After determining the dry densities for different moisture contents, curve was plotted to obtain maximum dry density and the respective optimum water content.

Gradation

By passing the sample downward through a series of standard sieves, each of decreasing size openings, the aggregates were separated into several groups, each of which contains aggregates in a particular size range. Amount of materials retained on each sieve were noted. The results of the gradation analysis were recorded graphically on a semi-log graph with particle size as abscissa (log scale) and the percentage smaller than the specified diameter as ordinate.

Dry density

The soil bulk or dry density, $_b$, is the ratio of the mass of the solid phase of the soil (i.e., dried soil) to its total volume (solid and pore volumes together).

The dry density of most soils varies within the range of 1.1-1.6 g/cm^3. In sandy soils, dry density can be as high as 1.6 g/cm^3; in clayey soils and aggregated loams, it can be as low as 1.1 g/cm^3. Dry density depends on the structure of the soil matrix (or its degree of compaction or looseness) and on the soil matrix's swelling/shrinkage characteristics.

The dry (bulk) density ($_b$) of a soil sample was evaluated on the basis of two measured values: (1) M_s, the oven-dried mass of the sample and (2) V_t, the field volume or the total volume of the sample. As stated previously, for the calculation of soil particle density ($_s$), mass (M_s) is measured after drying the sample at 110 ± 5 C until a near constant weight is reached. This laboratory technique directly determines the dry density of a soil sample.

Specific gravity

Specific gravity is the ratio of the weight in air of a given volume of a material at a standard temperature (27°C, Indian Standard) to the weight in air of an equal volume of distilled water at the same stated temperature.

The complete density bottle with stopper was weighed. Few mass of oven dried soil sample passing 2 mm IS sieve was obtained. This sample was transferred to the density bottle, the bottle and contents together with the stopper was weighed. Sufficient air-free distilled water was added so that the soil in the bottle is just covered. The soil in the bottle was stirred carefully by vibrating so that the entrapped air in the soil was removed. The bottle was then completely filled with water ensuring that no void is entrapped and tightened with the stopper. Water on the outer face of bottle was wiped to make the surface dry and weight was taken. The bottle emptied, cleaned and completely filled with air free water and tightened the stopper. After making the outer surface of bottle dry, it was again weighted. By using the provided relation, specific gravity of the given sample was determined.

Unit Weight

The container was calibrated by determining the weight of water required to fill it such that no meniscus is present above the rim of the container. The capacity in liters was obtained by dividing the weight of water in kilograms required to fill the container by the weight.

After calibration, the container was filled about one-third full with thoroughly mixed aggregate and tamped with 25 strokes of the rounded end of the tamping rod. A further similar quantity of aggregate was added and a further tamping of 25 strokes given. The measure was finally filled to over-flowing, tamped 25 times and the surplus aggregate struck off, using the tamping rod as a straightedge. The net weight of the aggregate in the measure was determined and the bulk density/unit weight calculated in kilograms per liter.

Alkali-Aggregate Reactivity

In most concrete, aggregates are more or less chemically inert. However, some aggregates react with the alkali hydroxides in concrete, causing expansion and cracking over a period of many years. Aggregates containing certain forms of silica will react with alkali hydroxide in concrete to

form a gel that swells as it adsorbs water from the surrounding cement paste or the environment. These gels can induce enough expansive pressure to damage concrete.

In the present study, the alkali-aggregate reactivity test was conducted following chemical method for determining the potential reactivity of aggregate with alkalis in cement as indicated by the amount of reaction during 24 hrs at 80^{o}C between 1N sodium hydroxide solution and aggregate that has been crushed and sieved to pass 300 micron sieve and be retained on 150 micron sieve. The test was conducted following ASTM C289-03 standards.

Flakiness Index

Flakiness Index is the percentage by weight of particles in it, whose least dimension (i.e. thickness) is less than three-fifths of its mean dimension. Flaky and elongated particles may have adverse effects on concrete. For instance, flaky and elongated particles tend to lower the workability of concrete mix which may impair the long-term durability.

The sample was sieved as per the specification provided by Indian Standard. Aggregate passing and retained from gauge were weighted to determine the flakiness index.

Annex IV-Schmidt Hammer Test Data

Test site No.: EC (Existing Channel)
Location: N 27^{0}53.925'00"; E 86^{0}54.452'00" and Elv. 5015m
Material type: a boulder of paragneiss in side moraine
Date: 22/10/2014

SN	Test number	Rebound Reading Mpa	Remarks
1	1	220	Psammitic schist boulder
2	2	225	Pegmatite with mica
3	3	210	Pelitic schist
4	4	280	Gneiss
5	5	220	Micaceous Marble
6	6	315	Quartzite
7	7	330	Quartz gneiss
8	8	300	Pegmatite
9	9	280	Gneiss
10	10	200	Pelitic chlorite Schist
Average value		**258**	
Strengthh		**Medium to High**	

1 Kg/cm^2 = 14.22 psi, 1 N/mm^2 = 145 psi

Result: The average field measured strength of the different boulder in the end moraine is medium to high**.**

Test site No.: EC (Existing Channel)
Location: N 27^{0}53.925'00"; E 86^{0}54.452'00" and Elv. 5015m
Material type: a boulder of paragneiss in side moraine
Date: 22/10/2014

SN	Test number	Rebound Reading Mpa	Remarks
1	1	220	Psammitic schist boulder
2	2	225	Pegmatite with mica
3	3	210	Pelitic schist
4	4	280	Gneiss
5	5	220	Micaceous Marble
6	6	315	Quartzite
7	7	330	Quartz gneiss
8	8	300	Pegmatite
9	9	280	Gneiss
10	10	200	Pelitic chlorite Schist
Average value		**258**	
Strengthh		**Medium to High**	

1 Kg/cm^2 = 14.22 psi, 1 N/mm^2 = 145 psi

Result: The average field measured strength of the different boulder in the end moraine is medium to high**.**

Test site No.: L3

Location: N 27^{0}53.934'00"; E 86^{0}54.459'00" and Elv. 5018m
3rd alternative outlet site

Material type: Different boulders of end moraine

Date: 23/10/2014

SN	Test number	Rebound Reading Mpa	Remarks
1	1	200	Granite
2	2	240	Quartz Gneiss
3	3	220	Psammitic schist
4	4	120	Mica schist
5	5	220	Micaceous quartzite
6	6	230	Gneiss
7	7	245	Gneiss
8	8	200	Marble
9	9	235	Pegmatite
10	10	220	Psammitic schist
Average value		**213**	
Strengthh		**Medium**	

1 Kg/cm^2 = 14.22 psi, 1 N/mm^2 = 145 psi

Result: The average field measured strength of the different boulder in the end moraine is medium strong**.**

Test site No.: R1

Location: N 27^{0}53.997'00"; E 86^{0}54.432'00" and Elv. 4984m
at alignment of 1st alternative

Material type: Different boulders of end moraine

Date: 23/10/2014

SN	Test number	Rebound Reading Mpa	Remarks
1	1	400	Gneiss boulder
2	2	415	Ortho gneiss
3	3	410	Fresh pegmatite
4	4	380	Marble
5	5	280	Weathered granite
6	6	375	Psmmatic schist
7	7	370	Psmmatic schist
8	8	325	Green schist
9	9	300	Mica schist
10	10	270	Mica schist (weathered)
Average value		**352.5**	
Strengthh		**Medium to High**	

1 Kg/cm^2 = 14.22 psi, 1 N/mm^2 = 145 psi

Result: The field measured average strength of the verigated boulder in the end moraine is medium to High**.**

Test site No.: R2

Location: N 27^{0}54.048'00"; E 86^{0}54.442'00" and Elv. 5017m at alignment of 2ndalternative

Material type: Different boulders of end moraine

Date: 23/10/2014

SN	Test number	Rebound Reading Mpa	Remarks
1	1	380	Fresh granite boulder
2	2	390	Marble boulder
3	3	420	Granite
4	4	400	Quartzitic pegmatite
5	5	410	Quartziticgneiss
6	6	375	Psmmatic schist
7	7	380	Marble boulder
8	8	370	Psmmatic schist
9	9	360	Gneiss
10	10	300	Psmmatic schist
Average value		**378.5**	
Strengthh		**High**	

1 Kg/cm^2 = 14.22 psi, 1 N/mm^2 = 145 psi

Result: The field measured average strength of the verigated boulder in the end moraine is High**.**

Annex V-Field Permeability Test Data

Observation No.: 1 Location: R1, Fine soil
Radius of the hole, a (cm): 3.5 Map legend: P2 (1)
Soil Type: moraine (silty - clayey layer)
Date: 22/10/2014 42.1

SN	Duration of Time Δt (sec.)	Height of water Δh (cm)	Infiltration volume, $\Delta Q=\pi a^2 \Delta h$ (cm^3)	Infiltration rate Q' (cm^3/sec)	Average Q' (cm3/sec)	Coefficient of permeability (cm/sec) $k = 1.4Q'/\pi\Delta h^2$
1	30	54.0	2077.11	69.24	53.98	**0.0136**
2	30	48.0	1846.32	61.54		
3	30	42.0	1615.53	53.85		
4	30	41.0	1577.07	52.57		
5	30	40.5	1557.83	51.93		
6	30	40.0	1538.60	51.29		
7	30	39.5	1519.37	50.65		
8	30	39.0	1500.14	50.00		
9	30	38.5	1480.90	49.36		
10	30	38.5	1480.90	49.36		

$$k = \frac{1.4Q'}{\pi(dh)^2} \quad with \quad Q' = \frac{\Delta Q}{\Delta t} = \pi a^2 \frac{h_2 - h_1}{t_2 - t_1}$$

h= effective head, cm
where,
Q= consumption of water in one minute,cm ^{3} /sec
k= coefficient of permeability, cm/sec
a= radius of hole (cm)

Result: the soil materials in the moaine is derived as **highly permeable.**

Observation No.: 2 Location: R2, Fine soil
Radius of the hole, a (cm): 3.5 Map legend: P1
Soil Type: end moraine
Date: 22/10/2014 2.905

SN	Duration of Time Δt (sec.)	Height of water Δh (cm)	Infiltration volume, $\Delta Q=\pi a^2 \Delta h$ (cm^3)	Infiltration rate Q' (cm^3/sec)	Average Q' (cm3/sec)	Coefficient of permeability (cm/sec) $k = 1.4Q'/\pi\Delta h^2$
1	60	8.0	307.72	5.13	1.86	**0.0984**
2	60	4.0	153.86	2.56		
3	60	2.5	96.16	1.60		
4	60	2.3	88.47	1.47		
5	60	1.9	73.08	1.22		
6	60	1.8	67.31	1.12		
7	60	1.5	57.70	0.96		
8	60	1.5	57.70	0.96		
9	60	1.5	57.70	0.96		
10	60	1.5	57.70	0.96		
11	60	1.3	50.00	0.83		
12	60	1.3	50.00	0.83		

$$k = \frac{1.4Q'}{\pi(dh)^2} \quad with \quad Q' = \frac{\Delta Q}{\Delta t} = \pi a^2 \frac{h_2 - h_1}{t_2 - t_1}$$

h= effective head, cm
where,
Q= consumption of water in one minute,cm ^{3} /sec
k= coefficient of permeability, cm/sec
a= radius of hole (cm)

Result: the soil materials in the moaine is found as **highly permeable.**

Observation No.: 3 Location: R1, medium grained soil
Radius of the hole, a (cm): 3.5 Map legend: P2 (2)
Soil Type: end moraine
Date: 23/10/2014 70.4

SN	Duration of Time Δt (sec.)	Height of water Δh (cm)	Infiltration volume, $\Delta Q = \pi a^2 \Delta h$ (cm^3)	Infiltration rate Q' (cm^3/sec)	Average Q' (cm3/sec)	Coefficient of permeability (cm/sec) $k = 1.4Q'/\pi \Delta h^2$
1	30	110.0	4231.15	141.04	90.26	**0.0081**
2	30	92.0	3538.78	117.96		
3	30	80.0	3077.20	102.57		
4	30	70.0	2692.55	89.75		
5	30	63.0	2423.30	80.78		
6	30	57.0	2192.51	73.08		
7	30	51.0	1961.72	65.39		
8	30	45.0	1730.93	57.70		
9	30	40.0	1538.60	51.29		
10	30	36.0	1384.74	46.16		
11	30	32.0	1230.88	41.03		
12	30	28.0	1077.02	35.90		

$$k = \frac{1.4Q'}{\pi (dh)^2} \quad with \quad Q' = \frac{\Delta Q}{\Delta t} = \pi a^2 \frac{h_2 - h_1}{t_2 - t_1}$$

h= effective head, cm

where,

Q= consumption of water in one minute,cm ^{3} */sec*

k= coefficient of permeability, cm/sec

a= radius of hole (cm)

Result: the soil materials in the end moaine is found as **highly permeable.**

Observation No.: 4 Location: L1 (L3), Fine soil layer (N 27^{0}53.932'00"; E 86^{0}54.462'00")
Radius of the hole, a (cm): 3.5 Map legend: P2 (2) Elv = 5026m
Soil Type: end moraine
Date: 23/10/2014 1.62

SN	Duration of Time Δt (sec.)	Height of water Δh (cm)	Infiltration volume, $\Delta Q = \pi a^2 \Delta h$ (cm^3)	Infiltration rate Q' (cm^3/sec)	Average Q' (cm3/sec)	Coefficient of permeability (cm/sec) $k = 1.4Q'/\pi \Delta h^2$
1	30	4.0	153.86	5.13	2.08	**0.3529**
2	30	3.0	115.40	3.85		
3	30	2.5	96.16	3.21		
4	30	2.0	76.93	2.56		
5	30	1.5	57.70	1.92		
6	30	0.9	34.62	1.15		
7	30	0.8	30.77	1.03		
8	30	0.8	28.85	0.96		
9	30	0.8	28.85	0.96		

$$k = \frac{1.4Q'}{\pi (dh)^2} \quad with \quad Q' = \frac{\Delta Q}{\Delta t} = \pi a^2 \frac{h_2 - h_1}{t_2 - t_1}$$

h= effective head, cm

where,

Q= consumption of water in one minute,cm ^{3} */sec*

k= coefficient of permeability, cm/sec

a= radius of hole (cm)

Result: the soil materials in the end moaine is found as **highly permeable.**

Observation No.: 5 Location: L1, Fine soil layer $(N\ 27^0 53.321'00";\ E\ 86^0 54.001'00")$

Radius of the hole, a (cm): 3.5 Map legend: P4 Elv = 5022m

Soil Type: side moraine

Date: 23/10/2014 141.3

SN	Duration of Time Δt (sec.)	Height of water Δh (cm)	Infiltration volume, $\Delta Q=\pi a^2 \Delta h$ (cm^3)	Infiltration rate Q' (cm^3/sec)	Average Q' (cm3/sec)	Coefficient of permeability (cm/sec) $k = 1.4Q'/\pi \Delta h^2$
1	30	145.0	5577.43	185.91	181.17	**4.05E-03**
2	30	135.0	5192.78	173.09		
3	30	130.0	5000.45	166.68		
4	30	125.0	4808.13	160.27		
5	30	122.0	4692.73	156.42		
6	30	117.0	4500.41	150.01		
7	30	112.0	4308.08	143.60		
8	30	109.0	4192.69	139.76		
9	30	107.0	4115.76	137.19		
10	30	105.0	4038.83	134.63		
11	30	103.0	3961.90	132.06		
12	30	103.0	3961.90	132.06		

$$k = \frac{1.4Q'}{\pi (dh)^2} \quad with \quad Q' = \frac{\Delta Q}{\Delta t} = \pi a^2 \frac{h_2 - h_1}{t_2 - t_1}$$

h= effective head, cm

where,

Q= consumption of water in one minute,cm ^{3} /sec

k= coefficient of permeability, cm/sec

a= radius of hole (cm)

Result: the soil materials in the side moaine is found as **highly permeable.**

Annex VI-Soil Test Data

GRADATION OF SOIL

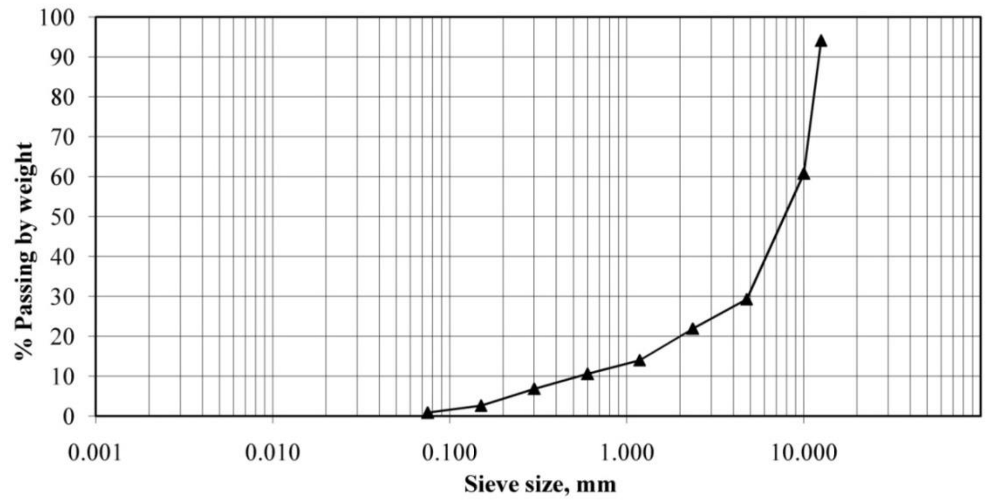
Client/Sample Description: Imza Lake Investigation Project/Coarse sand

Sample: R1 — Testing Standards: IS 2720-4 (1985)

Location: Imza Lake — Date: 10/11/2014

Total Wt. , gm : 1775.00

Sieve Size (mm)	Weight Retained (gm)	Cummulative Weight Retained (gm)	Cummmulative Percentage Retained	Percentage Passing
12.50	104.43	5.88	5.88	94.12
10.00	591.77	33.34	39.22	60.78
4.75	559.27	31.51	70.73	29.27
2.36	131.07	7.38	78.11	21.89
1.18	139.97	7.89	86.00	14.00
0.60	60.41	3.40	89.40	10.60
0.30	66.85	3.77	93.17	6.83
0.15	74.80	4.21	97.38	2.62
0.075	31.18	1.76	99.14	0.86
Pan	15.25	0.86	100.00	0.00



Clay & Silt size = 0.86% — Sand size = 21.03% — Gravel size = 78.11%

GRADATION OF SOIL

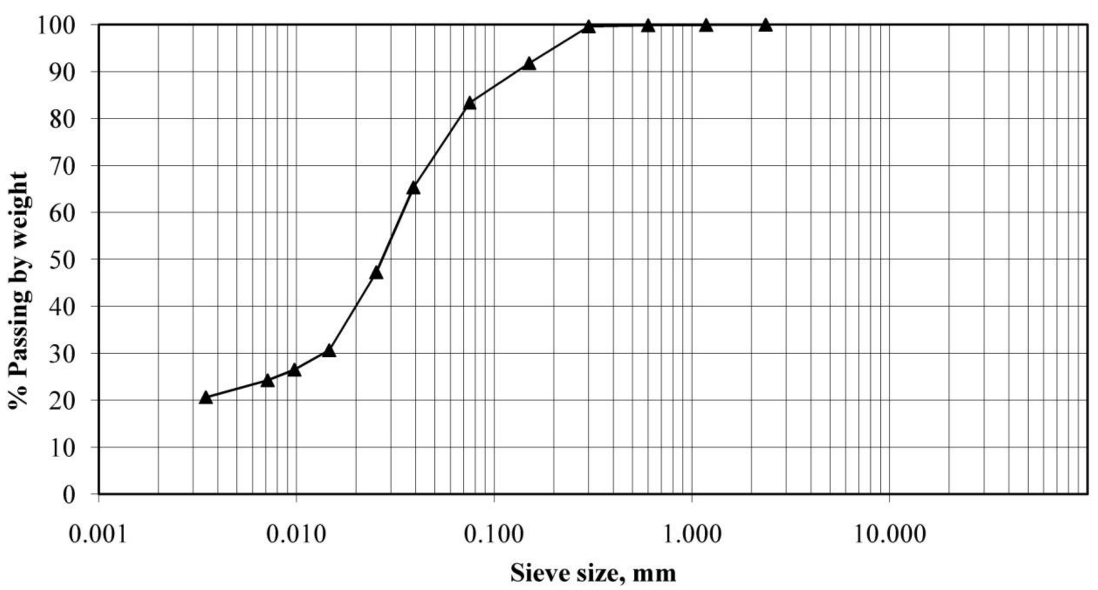
Client/Sample Description: Imza Lake Investigation Project/Silty soil

Sample: R2 — Testing Standards: IS 2720-4 (1985)

Location: Imza Lake — Date: 13/11/2014

Total Wt. , gm : 506.80

Sieve Size (mm)	Weight Retained (gm)	Cummulative Weight Retained (gm)	Cummmulative Percentage Retained	Percentage Passing
10.00	0.00	0.00	0.00	
4.75	0.00	0.00	0.00	
2.36	0.00	0.00	0.00	100.00
1.18	0.60	0.06	0.06	99.94
0.60	0.40	0.04	0.10	99.90
0.30	2.67	0.27	0.37	99.63
0.15	78.20	7.82	8.19	91.81
0.075	84.00	8.40	16.59	83.41
0.039	FROM HYDROMETER ANALYSIS			65.32
0.025				47.28
0.015				30.69
0.010				26.54
0.007				24.28
0.003				20.67



Clay size = 20.67% Silt size = 36.02% Sand size = 16.59% Gravel size = 0.00%

GRADATION OF SOIL

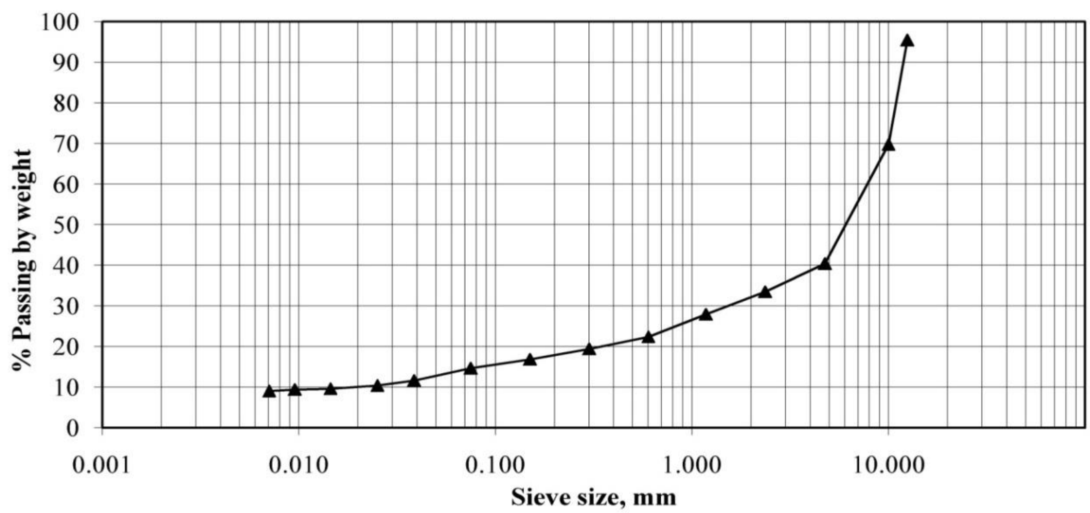
Client/Sample Description: Imza Lake Investigation Project/Silty soil

Sample: E1 Testing Standards: IS 2720-4 (1985)

Location: Imza Lake Date: 10/11/2014

Total Wt. , gm : 3800.00

Sieve Size (mm)	Weight Retained (gm)	Cummulative Weight Retained (gm)	Cummmulative Percentage Retained	Percentage Passing
12.50	172.27	4.53	4.53	95.47
10.00	976.24	25.69	30.22	69.78
4.75	1114.11	29.32	59.54	40.46
2.36	263.93	6.95	66.49	33.51
1.18	211.33	5.56	72.05	27.95
0.60	209.94	5.52	77.57	22.43
0.30	113.26	2.98	80.55	19.45
0.15	98.21	2.58	83.14	16.86
0.075	83.56	2.20	85.34	14.66
0.039	FROM HYDROMETER ANALYSIS			11.62
0.025				10.43
0.014				9.64
0.010				9.44
0.007				9.05



Clay size = 9.05% Silt size =5.61% Sand size = 18.85% Gravel size = 66.49%

GRADATION OF SOIL

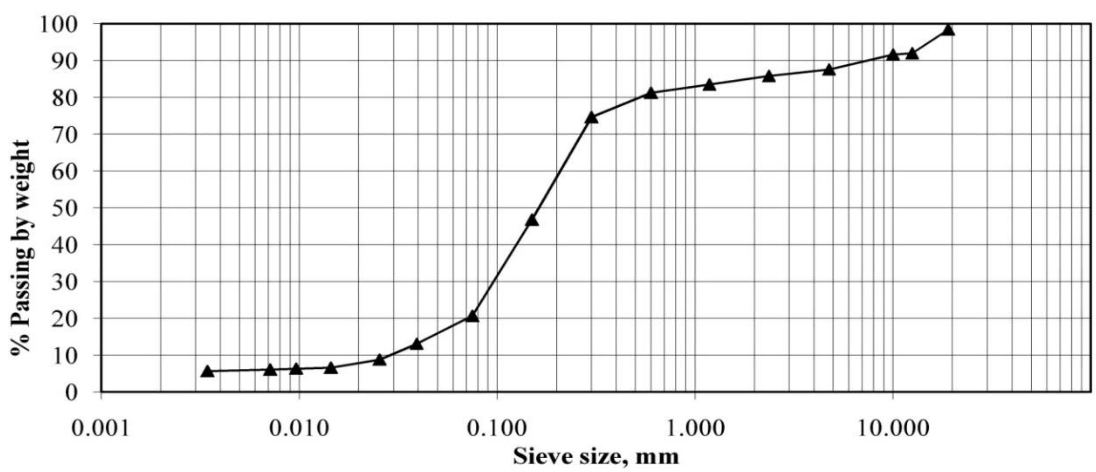
Client/Sample Description: Imza Lake Investigation Project/Silty soil

Sample: L-3 Testing Standards: IS 2720-4 (1985)

Location: Imza Lake Date: 13/11/2014

Total Wt. , gm : 500.80

Sieve Size (mm)	Weight Retained (gm)	Cummulative Weight Retained (gm)	Cummmulative Percentage Retained	Percentage Passing
19.00	7.80	1.56	1.56	98.44
12.50	32.10	6.41	7.97	92.03
10.00	1.60	0.32	8.29	91.71
4.75	20.40	4.07	12.36	87.64
2.36	8.80	1.76	14.12	85.88
1.18	11.70	2.34	16.45	83.55
0.60	11.30	2.26	18.71	81.29
0.30	33.00	6.59	25.30	74.70
0.15	139.50	27.86	53.15	46.85
0.075	130.90	26.14	79.29	20.71
0.039	FROM HYDROMETER ANALYSIS			13.12
0.025				8.83
0.014				6.62
0.010				6.36
0.007				6.11
0.003				5.72

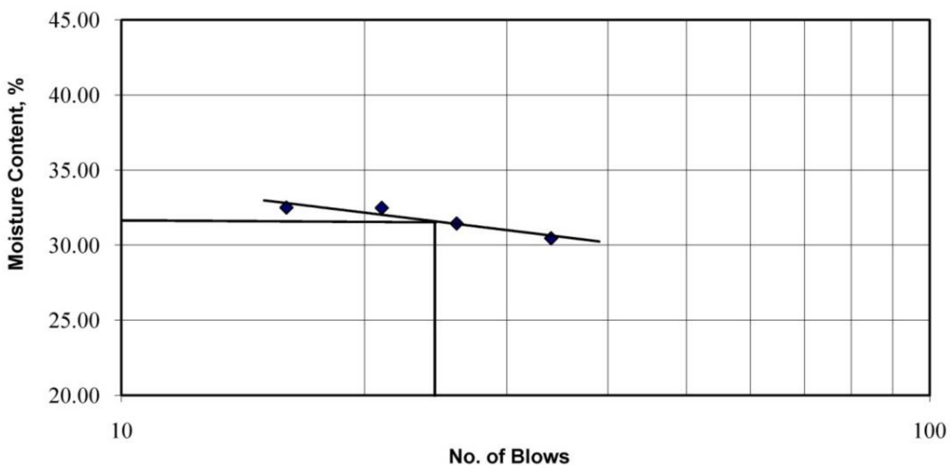


Clay size = 5.72% Silt size = 14.99% Sand size = 65.17% Gravel size = 14.12%

ATTERBERG LIMITS TEST

Client/Sample Description : Imza Lake Investigation Project/Silty soil
Sample : R-2
Location/Chainage :
Sample received on : Sample tested on: 13/11/2014
Lab Reference No. Testing Standard: IS 2720-5 (1985)

S.No.	Specimen no		Liquid Limit				Plastic Limit
			AR	S	A	AI	
1	No. of blows		34	26	21	16	No Plastic Limit
2	Wt. Of Container + Wet Soil	gms	23.08	29.1	22.04	31.26	
3	Wt. Of Container + Dry Soil	gms	20.13	25.99	18.59	28.08	
4	Wt. Of Water	gms	2.95	3.11	3.45	3.18	
5	Wt. Of Empty Container	gms	10.45	16.1	7.97	18.3	
6	Wt. Of Dry Soil	gms	9.68	9.89	10.62	9.78	
7	Moisture Content	%	30.48	31.45	32.49	32.52	



Liquid Limit (%)	31.53	Plastic Limit	0.00	Plasticity Index	31.53

SHRINKAGE LIMIT TEST

Client/Sample Description: Imza Lake Investigation
Sample received on: Testing Standard: IS 2720-6 (1972)
Location: Imza Lake Test No. :
Sample: R-2 Sample tested on: 17/11/2014

Observation and Calculations:

1	Container No.		1	2	Average
2	Mass of dish+wet soil	gm	79.44	79.93	
3	Mass of dish+dry soil	gm	69.24	69.71	
4	Mass of dish, M_d	gm	38.87	38.87	
5	Mass of dry soil, M_s	gm	30.37	30.84	
6	Mass of water, M_w	gm	10.20	10.22	
7	Initial water content, ω_o	%	33.59	33.14	

Data for volume of soil cake

Wet cake volume (initial)

8	Mass of Dish + Hg, M_{dm}	gm	328.26	328.26	
9	Mass of Coated Dish, M_d	gm	38.87	38.87	
10	Volume of Shrink Dish, $V_o=(M_{dm}-M_d)/\rho$	cc	21.363	21.363	

Dry cake volume (final)

11	Wt. of Volume cup + Hg, M_{vcm}	gm	714.66	714.21	
12	Wt. of Volume cup + Hg - Soil, M_{vcms}	gm	438.74	434.93	
13	Wt. displaced Hg	gm	275.92	279.28	
14	Volume of Soil Cake, V_f	cc	20.369	20.617	

Shrinkage Limit, $\omega_s = (\omega_o-(V_o-V_f)/M_s)*100 =$	30.31	30.72	
Average Shrinkage Limit =	30.52		

SHRINKAGE LIMIT TEST

Client/Sample Description: Imza Lake Investigation
Sample received on: Testing Standard: IS 2720-6 (1972)
Location: Imza Lake Test No. :
Sample: R-2 Sample tested on: 17/11/2014

Observation and Calculations:

1	Container No.		1	2	Average
2	Mass of dish+wet soil	gm	79.44	79.93	
3	Mass of dish+dry soil	gm	69.24	69.71	
4	Mass of dish, M_d	gm	38.87	38.87	
5	Mass of dry soil, M_s	gm	30.37	30.84	
6	Mass of water, M_w	gm	10.20	10.22	
7	Initial water content, ω_o	%	33.59	33.14	

Data for volume of soil cake

Wet cake volume (initial)

8	Mass of Dish + Hg, M_{dm}	gm	328.26	328.26	
9	Mass of Coated Dish, M_d	gm	38.87	38.87	
10	Volume of Shrink Dish, $V_o=(M_{dm}-M_d)/\rho$	cc	21.363	21.363	

Dry cake volume (final)

11	Wt. of Volume cup + Hg, M_{vcm}	gm	714.66	714.21	
12	Wt. of Volume cup + Hg - Soil, M_{vcms}	gm	438.74	434.93	
13	Wt. displaced Hg	gm	275.92	279.28	
14	Volume of Soil Cake, V_f	cc	20.369	20.617	

Shrinkage Limit, ω_s = $(\omega_o-(V_o-V_f)/M_s)*100$ =	30.31	30.72	
Average Shrinkage Limit =	30.52		

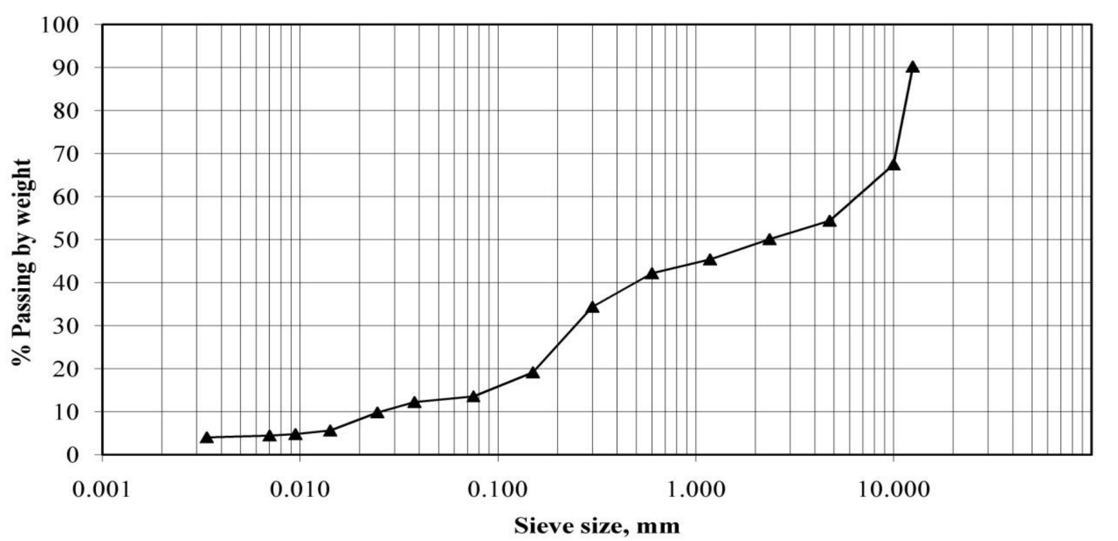
Annex VII-Construction Material Test Data

GRADATION OF SOIL

Client/Sample Description: Imza Lake Investigation Project/Silty soil
Sample: CM-2
Location: Imza Lake
Total Wt. , gm : 1000.00

Testing Standards: IS 2720-4 (1985)
Date: 10/11/2014

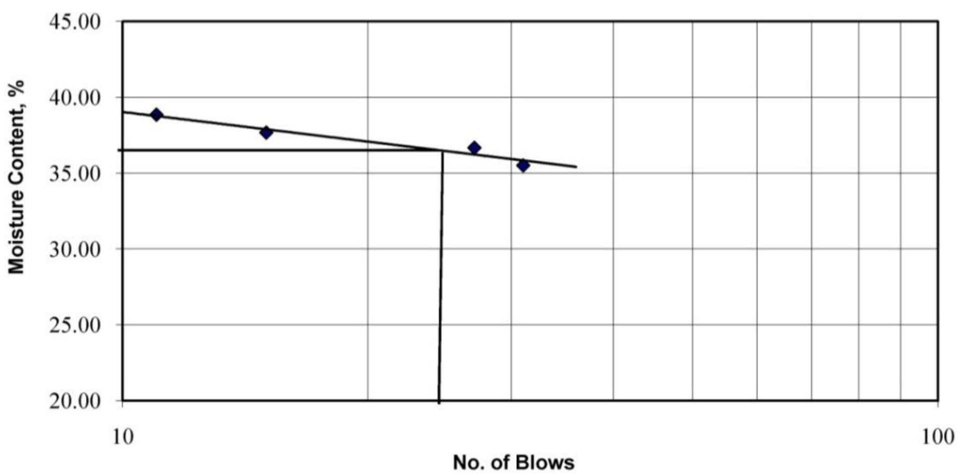
Sieve Size (mm)	Weight Retained (gm)	Cummulative Weight Retained (gm)	Cummmulative Percentage Retained	Percentage Passing
12.50	97.47	9.75	9.75	90.25
10.00	227.41	22.74	32.49	67.51
4.75	131.16	13.12	45.60	54.40
2.36	42.96	4.30	49.90	50.10
1.18	47.12	4.71	54.61	45.39
0.60	31.81	3.18	57.79	42.21
0.30	78.32	7.83	65.63	34.38
0.15	152.18	15.22	80.84	19.16
0.075	55.86	5.59	86.43	13.57
0.038	FROM HYDROMETER ANALYSIS			12.25
0.025				9.82
0.014				5.64
0.009				4.79
0.007				4.46
0.003				4.03



ATTERBERG LIMITS TEST

Client/Sample Description : Imza Lake Investigation Project/Sandy silt
Sample : CM-2
Location/Chainage :
Sample received on : Sample tested on: 13/11/2014
Lab Reference No. Testing Standard: IS 2720-5 (1985)

S.No.	Specimen no		Liquid Limit				Plastic Limit
			AF	AB	AH	K	
1	No. of blows		31	27	15	11	No Plastic Limit
2	Wt. Of Container + Wet Soil	gms	22.89	30.53	31.96	28.65	
3	Wt. Of Container + Dry Soil	gms	20.67	26.94	26.82	24.32	
4	Wt. Of Water	gms	2.22	3.59	5.14	4.33	
5	Wt. Of Empty Container	gms	14.42	17.15	13.18	13.18	
6	Wt. Of Dry Soil	gms	6.25	9.79	13.64	11.14	
7	Moisture Content	%	35.52	36.67	37.68	38.87	



Liquid Limit (%)	36.45	Plastic Limit	0.00	Plasticity Index	36.45

SHRINKAGE LIMIT TEST

Client/Sample Description: Imza Lake Investigation
Sample received on: Testing Standard: IS 2720-6 (1972)
Location: Imza Lake Test No. :
Sample: R-3 Sample tested on: 14/11/2014

Observation and Calculations:

1	Container No.		1	2	Average
2	Mass of dish+wet soil	gm	74.84	75.02	
3	Mass of dish+dry soil	gm	63.80	64.03	
4	Mass of dish, M_d	gm	38.89	38.89	
5	Mass of dry soil, M_s	gm	24.91	25.14	
6	Mass of water, M_w	gm	11.04	10.99	
7	Initial water content, ω_o	%	44.32	43.72	

Data for volume of soil cake

Wet cake volume (initial)

8	Mass of Dish + Hg, M_{dm}	gm	328.26	328.26	
9	Mass of Coated Dish, M_d	gm	38.89	38.89	
10	Volume of Shrink Dish, $V_o=(M_{dm}-M_d)/\rho$	cc	21.362	21.362	

Dry cake volume (final)

11	Wt. of Volume cup + Hg, M_{vcm}	gm	715.56	716.86	
12	Wt. of Volume cup + Hg - Soil, M_{vcms}	gm	469.12	471.73	
13	Wt. displaced Hg	gm	246.44	245.13	
14	Volume of Soil Cake, V_f	cc	18.193	18.096	
Shrinkage Limit, $\omega_s = (\omega_o-(V_o-V_f) /M_s)*100 =$			31.60	30.73	
Average Shrinkage Limit =			31.16		

DETERMINATION OF SPECIFIC GRAVITY

Client/Description of sample: Imza Lake Investigation — Testing Standard: IS:2386 (Part III) 1963

Sample: CM-1 — Sample tested on: 19/11/2014

A. Coarse Aggregate (> 4.75 mm Sieve)

Specimen No.		1	2	Average
Weight of Basket + Sample in water	gm	2154.4	2196.2	
Weight of Basket in water	gm	1328.7	1328.7	
Weight of Sample in Water (C)	gm	825.7	867.5	
Weight of Sample Saturated Surface Dry (B)	gm	1322.7	1385.3	
Weight of Sample Oven Dry (A)	gm	1311.4	1375	
Water Absorption = 100 (B - A)/A	%	0.86	0.75	
Apparent Specific Gravity = A/(A - C)		2.70	2.71	**2.70**
Specific Gravity Saturated Surface Dry = B/(B - C)		2.66	2.68	**2.67**

DETERMINATION OF SPECIFIC GRAVITY

Client/Description of sample: Imza Lake Investigation — Testing Standard: IS:2386 (Part III) 1963

Sample: CM-1 — Sample tested on: 19/11/2014

A. Coarse Aggregate (> 4.75 mm Sieve)

Specimen No.		1	2	Average
Weight of Basket + Sample in water	gm	2154.4	2196.2	
Weight of Basket in water	gm	1328.7	1328.7	
Weight of Sample in Water (C)	gm	825.7	867.5	
Weight of Sample Saturated Surface Dry (B)	gm	1322.7	1385.3	
Weight of Sample Oven Dry (A)	gm	1311.4	1375	
Water Absorption = 100 (B - A)/A	%	0.86	0.75	
Apparent Specific Gravity = A/(A - C)		2.70	2.71	**2.70**
Specific Gravity Saturated Surface Dry = B/(B - C)		2.66	2.68	**2.67**

DETERMINATION OF SPECIFIC GRAVITY

Client/Description of sample: Imza Lake Investigation — Testing Standard: IS:2386 (Part III) 1963

Sample: CM-3 — Sample tested on: 19/11/2014

A. Coarse Aggregate (> 4.75 mm Sieve)

Specimen No.		1	2	Average
Weight of Basket + Sample in water	gm	2570.3	2381.6	
Weight of Basket in water	gm	1328.7	1328.7	
Weight of Sample in Water (C)	gm	1241.6	1052.9	
Weight of Sample Saturated Surface Dry (B)	gm	1997.3	1705.6	
Weight of Sample Oven Dry (A)	gm	1981.1	1689.2	
Water Absorption = 100 (B - A)/A	%	0.82	0.97	
Apparent Specific Gravity = A/(A - C)		2.68	2.65	**2.67**
Specific Gravity Saturated Surface Dry = B/(B - C)		2.64	2.61	**2.63**

DETERMINATION OF SPECIFIC GRAVITY

Client/Description of sample: Imza Lake Investigation — Testing Standard: IS:2386 (Part III) 1963

Sample: CM-2 — Sample tested on: 20/11/2014

A. Coarse Aggregate (> 4.75 mm Sieve)

Specimen No.		1	2	Average
Weight of Basket + Sample in water	gm	2295.2	2354.7	
Weight of Basket in water	gm	1328.7	1328.7	
Weight of Sample in Water (C)	gm	966.5	1026	
Weight of Sample Saturated Surface Dry (B)	gm	1543.5	1629.6	
Weight of Sample Oven Dry (A)	gm	1529.7	1619.2	
Water Absorption = 100 (B - A)/A	%	0.90	0.64	
Apparent Specific Gravity = A/(A - C)		2.72	2.73	**2.72**
Specific Gravity Saturated Surface Dry = B/(B - C)		2.68	2.70	**2.69**

DETERMINATION OF BULK DENSITY/UNIT WEIGHT AND WATER ABSORPTION

Client/Description of sample: Imza Lake Investigation — Testing Standard: IS 2386-3 (1990)

Sample : CM-1 — Sample tested on: 12/11/2014

Sample received on: — Lab temperature: 20°C

A. Calibration of Apparatus

Trial No.		1	2	Average
Weight of empty measue + glass sheet	kg	3.48	3.48	
Weight of water + measure + glass sheet	kg	6.49	6.49	
Weight of water only	kg	3.01	3.01	
Density of water at lab temperature	kg/lit	0.9982	0.9982	
Volume of water required to fill the measure	lit	3.015	3.015	3.015

B. Test Procedure

Specimen No.		1	2	3
Weight of measure filled with aggregate with glass	kg	8.63	8.78	8.67
Net weight of aggregate	kg	5.15	5.30	5.19
Unit weight/Bulk density of aggregate, r	kg/lit	1.708	1.758	1.721
Specific Gravity of aggregate, Gs				
Percentage voids				

% Voids = 100*(Gs - r)/Gs

Unit weight/Bulk density of aggregate, r **1.73** **kg/lit** UNRODDED

Specimen No.		1	2	3
Weight of measure filled with aggregate with glass	kg	9.19	9.28	9.30
Net weight of aggregate	kg	5.71	5.80	5.82
Unit weight/Bulk density of aggregate, r	kg/lit	1.894	1.923	1.930
Specific Gravity of aggregate, Gs				
Percentage voids				

% Voids = 100*(Gs - r)/Gs

Unit weight/Bulk density of aggregate, r **1.92** **kg/lit** RODDED

DETERMINATION OF BULK DENSITY/UNIT WEIGHT AND WATER ABSORPTION

Client/Description of sample: Imza Lake Investigation — Testing Standard: IS 2386-3 (1990)

Sample : CM-3 — Sample tested on: 19/11/2014

Sample received on: — Lab temperature: 20°C

A. Calibration of Apparatus

Trial No.		1	2	Average
Weight of empty measue + glass sheet	kg	3.48	3.48	
Weight of water + measure + glass sheet	kg	6.49	6.49	
Weight of water only	kg	3.01	3.01	
Density of water at lab temperature	kg/lit	0.9982	0.9982	
Volume of water required to fill the measure	lit	3.015	3.015	3.015

B. Test Procedure

Specimen No.		1	2	3
Weight of measure filled with aggregate with glass	kg	8.32	8.30	8.3
Net weight of aggregate	kg	4.84	4.82	4.82
Unit weight/Bulk density of aggregate, r	kg/lit	1.605	1.598	1.598
Specific Gravity of aggregate, Gs				
Percentage voids				

% Voids = 100*(Gs - r)/Gs

Unit weight/Bulk density of aggregate, r **1.60** **kg/lit** UNRODDED

Specimen No.		1	2	3
Weight of measure filled with aggregate with glass	kg	8.88	9.00	8.98
Net weight of aggregate	kg	5.40	5.52	5.50
Unit weight/Bulk density of aggregate, r	kg/lit	1.791	1.831	1.824
Specific Gravity of aggregate, Gs				
Percentage voids				

% Voids = 100*(Gs - r)/Gs

Unit weight/Bulk density of aggregate, r **1.82** **kg/lit** RODDED

DETERMINATION OF BULK DENSITY/UNIT WEIGHT AND WATER ABSORPTION

Client/Description of sample: Imza Lake Investigation — Testing Standard: IS 2386-3 (1990)

Sample : CM-2 — Sample tested on: 20/11/2014

Sample received on: — Lab temperature: 20^{o}C

A. Calibration of Apparatus

Trial No.		1	2	Average
Weight of empty measue + glass sheet	kg	3.48	3.48	
Weight of water + measure + glass sheet	kg	6.49	6.49	
Weight of water only	kg	3.01	3.01	
Density of water at lab temperature	kg/lit	0.9982	0.9982	
Volume of water required to fill the measure	lit	3.015	3.015	3.015

B. Test Procedure

Specimen No.		1	2	3
Weight of measure filled with aggregate with glass	kg	8.36	8.36	8.38
Net weight of aggregate	kg	4.88	4.88	4.9
Unit weight/Bulk density of aggregate, r	kg/lit	1.618	1.618	1.625
Specific Gravity of aggregate, Gs				
Percentage voids				

% Voids = 100*(Gs - r)/Gs

Unit weight/Bulk density of aggregate, r **1.62** **kg/lit** UNRODDED

Specimen No.		1	2	3
Weight of measure filled with aggregate with glass	kg	8.80	8.78	8.80
Net weight of aggregate	kg	5.32	5.30	5.32
Unit weight/Bulk density of aggregate, r	kg/lit	1.764	1.758	1.764
Specific Gravity of aggregate, Gs				
Percentage voids				

% Voids = 100*(Gs - r)/Gs

Unit weight/Bulk density of aggregate, r **1.76** **kg/lit** RODDED

FLAKINESS AND ELONGATION INDICES

Client/Sample Description : MEH /GEOS JV

Source :

Location/Chainage : Imza Lake Investigation Project

Sample received on : Sample Tested on: 10/11/2014

Sample Name : CM-1 Test Standard: IS 2386-1963

	Flakiness			Elongation		
Sieve Size (mm)	Weight Retained (gm)	Weight Passing (gm)	Total Weight (gm)	Weight Retained (gm)	Weight Passing (gm)	Total Weight (gm)
63 ~ 50						
50 ~ 40						
40 ~ 31.5	76.2	-				
31.5 ~ 25	460.9	118.9				
25 ~ 20	578.8	271.7				
20 ~ 16	293.0	151.0				
16 ~ 12.5	230.2	144.8				
12.5 ~ 10	227.0	118.2				
10 ~ 6.3	108.1	47.6				
Total Weight	1974.2	852.2				

Flakiness Index (%)= $\frac{\text{Total weight passing thickness gauges x 100 \%}}{\text{Total weight of test sample}}$

= 30.15%

FLAKINESS AND ELONGATION INDICES

Client/Sample Description : MEH /GEOS JV
Source :
Location/Chainage : Imza Lake Investigation Project
Sample received on : Sample Tested on: 11/11/2014
Sample Name : CM-3 Test Standard: IS 2386-1963

	Flakiness			Elongation		
Sieve Size (mm)	Weight Retained (gm)	Weight Passing (gm)	Total Weight (gm)	Weight Retained (gm)	Weight Passing (gm)	Total Weight (gm)
63 ~ 50						
50 ~ 40	137.7	-				
40 ~ 31.5	-	51.5				
31.5 ~ 25	144.9	161.3				
25 ~ 20	352.1	180.0				
20 ~ 16	163.8	84.6				
16 ~ 12.5	264.2	190.3				
12.5 ~ 10	93.1	54.4				
10 ~ 6.3	81.0	58.8				
Total Weight	1236.7	780.8				

Flakiness Index (%)= $\frac{\text{Total weight passing thickness gauges}}{\text{Total weight of test sample}}$ x 100 %

= 38.70%

FLAKINESS AND ELONGATION INDICES

Client/Sample Description : MEH /GEOS JV
Source :
Location/Chainage : Imza Lake Investigation Project
Sample received on : Sample Tested on: 19/11/2014
Sample Name : RB Test Standard: IS 2386-1963

	Flakiness			Elongation		
Sieve Size (mm)	Weight Retained (gm)	Weight Passing (gm)	Total Weight (gm)	Weight Retained (gm)	Weight Passing (gm)	Total Weight (gm)
63 ~ 50						
50 ~ 40	-	-				
40 ~ 31.5	74.4	-				
31.5 ~ 25	110.0	-				
25 ~ 20	207.3	167.0				
20 ~ 16	197.3	101.1				
16 ~ 12.5	129.5	182.1				
12.5 ~ 10	202.8	147.5				
10 ~ 6.3	119.1	93.6				
Total Weight	1040.4	691.3				

Flakiness Index (%)= $\frac{\text{Total weight passing thickness gauges}}{\text{Total weight of test sample}}$ x 100 %

= 39.92%

Client/Sample Description : Imza Lake Investigation
Source :
Location/Chainage: Imza Lake
Sample received on: Sample tested on: 10/11/2014
Sample No.: CM-1 Testing Standard: IS 2386-4

AGGREGATE IMPACT VALUE (AIV)

S.No.	Details	Trial Number		Remarks
		1	2	
1	Total weight of aggregates sample + cylindrical measure (gm), W1	1215.4	1218.2	
2	Weight of the cylindrical measure (gm), W2	866.3	866.3	
3	Total weight of aggregates sample (gm), W3 = (W1-W2)	349.1	351.9	
4	Weight of the aggregates retained on 2.36 mm sieve after the test (gm), W4	268.7	269.9	
5	Weight of the aggregates passing 2.36 mm sieve after the test (gm), W5 = W3-W4	80.4	82.1	
6	Aggregate Impact Value (%) = W5/W3*100	23.03%	23.32%	
7	Average	23.17%		

Los Angeles Abrashion value = 1.45*AIV
= 33.60 %

Client/Sample Description : Imza Lake Investigation
Source :
Location/Chainage: Imza Lake
Sample received on: Sample tested on: 10/11/2014
Sample No.: CM-3 Testing Standard: IS 2386-4

AGGREGATE IMPACT VALUE (AIV)

S.No.	Details	Trial Number		Remarks
		1	2	
1	Total weight of aggregates sample + cylindrical measure (gm), W1	1214.5	1211.9	
2	Weight of the cylindrical measure (gm), W2	866.3	866.3	
3	Total weight of aggregates sample (gm), W3 = (W1-W2)	348.2	345.6	
4	Weight of the aggregates retained on 2.36 mm sieve after the test (gm), W4	281.7	281.1	
5	Weight of the aggregates passing 2.36 mm sieve after the test (gm), W5 = W3-	66.5	64.5	
6	Aggregate Impact Value (%) = W5/W3*100	19.10%	18.66%	
7	Average	18.88%		

Los Angeles Abrashion value = 1.45*AIV
= 27.38 %

Client/Sample Description : Imza Lake Investigation
Source :
Location/Chainage: Imza Lake
Sample received on: Sample tested on: 19/11/2014
Sample No.: RB Testing Standard: IS 2386-4

AGGREGATE IMPACT VALUE (AIV)

S.No.	Details	Trial Number		Remarks
		1	2	
1	Total weight of aggregates sample +	1216.3	1220.1	
2	Weight of the cylindrical measure (gm),	866.3	866.3	
3	Total weight of aggregates sample (gm),	350.0	353.8	
4	Weight of the aggregates retained on	288.4	290.6	
5	Weight of the aggregates passing 2.36	61.6	63.2	
6	Aggregate Impact Value (%) =	17.60%	17.86%	
7	Average	17.73%		

Los Angeles Abrashion value = 1.45*AIV

= 25.71 %

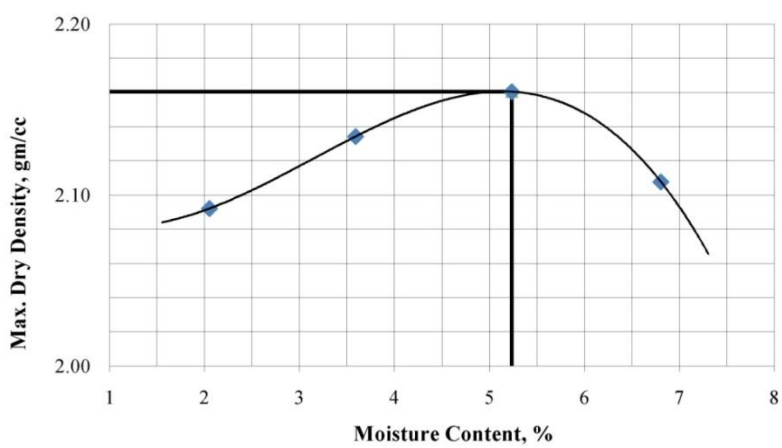
COMPACTION TEST: DRY DENSITY MOISTURE CONTENT RELATIONSHIP

Client/Sample Description: Imza Lake Investigation Project/Sandy soil | Testing Standard: IS 2720-8 (1983)
Sample/Location: CM-1 | Mould Volume, cc: 2239
Sample received on: | Sample tested on: 10/11/2014
Lab Reference No.

Test number	1	2	3	4	5
Wt. of mould+base+compacted specimen, W2	15180	15350	15490	15440	
Wt. of mould+base, W1	10400	10400	10400	10400	
Wt. of compacted specimen, W2-W1	4780	4950	5090	5040	
Bulk density, γ =(W2-W1)/V, gm/cc	2.14	2.21	2.27	2.25	
Moisture content, ω	2.051	3.592	5.236	6.806	
Dry density, $\gamma d = \gamma/(1+\omega)$	2.09	2.13	2.16	2.11	

Moisture Content Determination

Sample No.		1		2		3		4		5	
Container no.		22	36	16	19	28	31	4	38		
Wt. Container+Wet Soil (A)	gm	161.1	185.7	205.6	195.5	189.3	217.6	165.3	181.9		
Wt. Container + Dry Soil (B)	gm	158.3	182.7	199.6	189.8	180.9	208.8	157.1	171.9		
Wt. Of water ww = (A-B)	gm	2.79	2.94	6.02	5.71	8.44	8.86	8.28	9.93		
Wt. Of empty container (C)	gm	29.43	30.98	30.99	31.85	28.76	28.77	31.77	30.1		
Wt. Of dry soil wd = (B-C)	gm	128.9	151.7	168.6	158	152.1	180	125.3	141.8		
M.C. = (ww/wd)x100	%	2.165	1.938	3.57	3.615	5.549	4.922	6.609	7.002		
Avg. Moisture Content, ω	%	2.051		3.592		5.236		6.806			



Optimum Moisture Content, % = 5.236
Maximum Dry Density, g/cc = 2.16

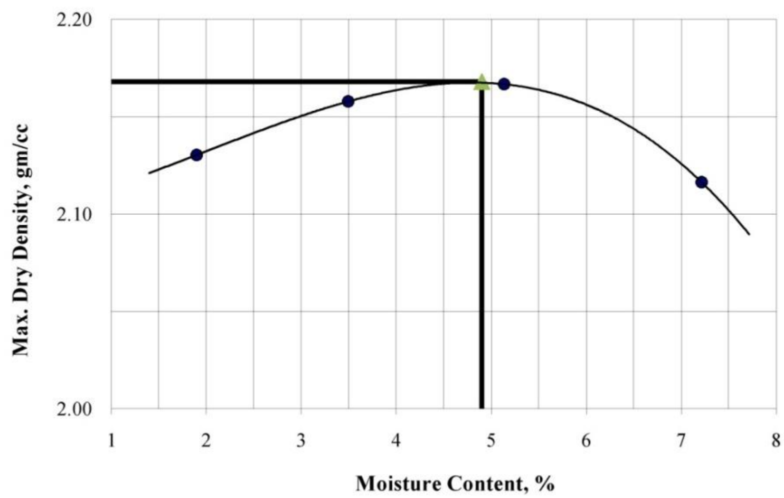
COMPACTION TEST: DRY DENSITY MOISTURE CONTENT RELATIONSHIP

Client/Sample Description: Imza Lake Investigation Project/Sandy soil — Testing Standard: IS 2720-8 (1983)
Sample/Location: CM-3 — Mould Volume, cc: 2239
Sample received on: — Sample tested on: 18/11/2014
Lab Reference No.

Test number	1	2	3	4	5
Wt. of mould+base+compacted specimen, W2	15260	15400	15500	15480	
Wt. of mould+base, W1	10400	10400	10400	10400	
Wt. of compacted specimen, W2-W1	4860	5000	5100	5080	
Bulk density,γ =(W2-W1)/V, gm/cc	2.17	2.23	2.28	2.27	
Moisture content, ω	1.896	3.494	5.134	7.215	
Dry density, γd = γ/(1+ω)	2.13	2.16	2.17	2.12	

Moisture Content Determination

Sample No.		1		2		3		4			
Container no.		5	13	8	29	32	30	12	15		
Wt. Container+Wet Soil (A)	gm	175.3	189.5	186.5	193	241	202.1	191.6	209.6		
Wt. Container + Dry Soil (B)	gm	172.6	186.6	181.2	187.4	230.2	194.1	181.1	197.3		
Wt. Of water ww = (A-B)	gm	2.68	2.87	5.25	5.60	10.84	8.04	10.51	12.24		
Wt. Of empty container (C)	gm	33.69	32.53	31.92	26.05	27.11	30.98	31.6	31.93		
Wt. Of dry soil wd = (B-C)	gm	138.9	154.1	149.3	161.3	203.1	163.1	149.5	165.4		
M.C. = (ww/wd)x100	%	1.929	1.863	3.516	3.472	5.338	4.929	7.03	7.401		
Avg. Moisture Content,ω	%	1.896		3.494		5.134		7.215			



Optimum Moisture Content, % = 4.90
Maximum Dry Density, g/cc = 2.17

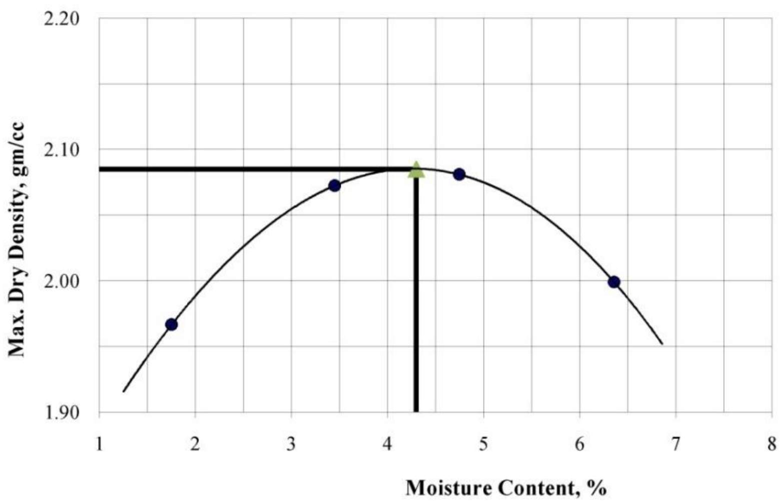
COMPACTION TEST: DRY DENSITY MOISTURE CONTENT RELATIONSHIP

Client/Sample Description: Imza Lake Investigation Project/Sandy soil
Testing Standard: IS 2720-8 (1983)
Sample/Location: RB
Mould Volume, cc: 2239
Sample received on:
Sample tested on: 21/11/2014
Lab Reference No.

Test number	1	2	3	4	5
Wt. of mould+base+compacted specimen, W2	14880	15200	15280	15160	
Wt. of mould+base, W1	10400	10400	10400	10400	
Wt. of compacted specimen, W2-W1	4480	4800	4880	4760	
Bulk density, $\gamma = (W2-W1)/V$, gm/cc	2.00	2.14	2.18	2.13	
Moisture content, ω	1.753	3.450	4.745	6.357	
Dry density, $\gamma d = \gamma/(1+\omega)$	1.97	2.07	2.08	2.00	

Moisture Content Determination

Sample No.		1		2		3		4		5	
Container no.		22	36	37	27	36	32	21	26		
Wt. Container+Wet Soil (A)	gm	224.2	176.5	246.7	201.1	264.5	278.6	196.4	226.1		
Wt. Container + Dry Soil (B)	gm	220.7	174.1	239.5	195.3	254.3	266.8	186.3	214.5		
Wt. Of water ww = (A-B)	gm	3.50	2.40	7.20	5.80	10.18	11.82	10.10	11.60		
Wt. Of empty container (C)	gm	29.43	30.98	28.4	29.07	30.98	27.11	30.12	28.8		
Wt. Of dry soil wd = (B-C)	gm	191.3	143.1	211.1	166.2	223.3	239.7	156.2	185.7		
M.C. = (ww/wd)x100	%	1.83	1.677	3.411	3.489	4.558	4.931	6.467	6.247		
Avg. Moisture Content, ω	%	1.753		3.450		4.745		6.357			



Optimum Moisture Content, % = 4.30
Maximum Dry Density, g/cc = 2.08

COMPACTION TEST: DRY DENSITY MOISTURE CONTENT RELATIONSHIP

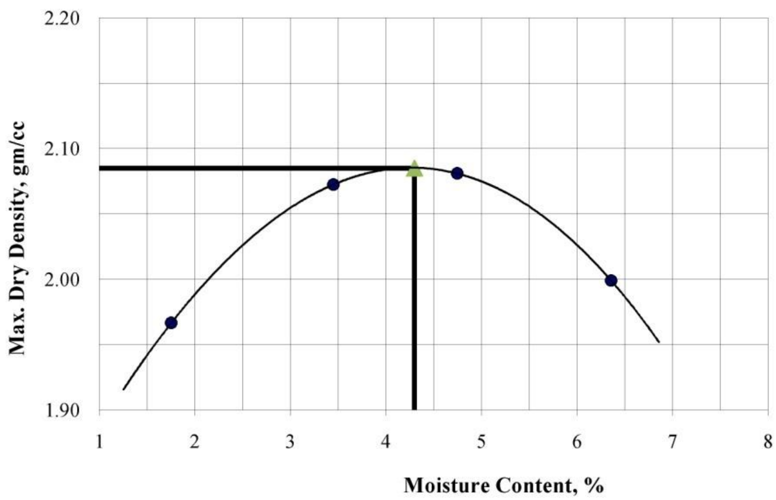
Client/Sample Description: Imza Lake Investigation Project/Sandy soil
Sample/Location: CM-2
Sample received on:
Lab Reference No.

Testing Standard: IS 2720-8 (1983)
Mould Volume, cc: 2239
Sample tested on: 21/11/2014

Test number	1	2	3	4	5
Wt. of mould+base+compacted specimen, W2	14880	15200	15280	15160	
Wt. of mould+base, W1	10400	10400	10400	10400	
Wt. of compacted specimen, W2-W1	4480	4800	4880	4760	
Bulk density,γ =(W2-W1)/V, gm/cc	2.00	2.14	2.18	2.13	
Moisture content, ω	1.753	3.450	4.745	6.357	
Dry density, γd = γ/(1+ω)	1.97	2.07	2.08	2.00	

Moisture Content Determination

Sample No.		1		2		3		4		5	
Container no.		22	36	37	27	36	32	21	26		
Wt. Container+Wet Soil (A)	gm	224.2	176.5	246.7	201.1	264.5	278.6	196.4	226.1		
Wt. Container + Dry Soil (B)	gm	220.7	174.1	239.5	195.3	254.3	266.8	186.3	214.5		
Wt. Of water ww = (A-B)	gm	3.50	2.40	7.20	5.80	10.18	11.82	10.10	11.60		
Wt. Of empty container (C)	gm	29.43	30.98	28.4	29.07	30.98	27.11	30.12	28.8		
Wt. Of dry soil wd = (B-C)	gm	191.3	143.1	211.1	166.2	223.3	239.7	156.2	185.7		
M.C. = (ww/wd)x100	%	1.83	1.677	3.411	3.489	4.558	4.931	6.467	6.247		
Avg. Moisture Content,ω	%	1.753		3.450		4.745		6.357			



Optimum Moisture Content, % = 4.30
Maximum Dry Density, g/cc = 2.08

FLAKINESS AND ELONGATION INDICES

Client/Sample Description : MEH /GEOS JV

Source :

Location/Chainage : Imza Lake Investigation Project

Sample received on : Sample Tested on: 19/11/2014

Sample Name : CM-2 Test Standard: IS 2386-1963

	Flakiness			Elongation		
Sieve Size (mm)	Weight Retained (gm)	Weight Passing (gm)	Total Weight (gm)	Weight Retained (gm)	Weight Passing (gm)	Total Weight (gm)
63 ~ 50						
50 ~ 40	-	-				
40 ~ 31.5	74.4	-				
31.5 ~ 25	110.0	-				
25 ~ 20	207.3	167.0				
20 ~ 16	197.3	101.1				
16 ~ 12.5	129.5	182.1				
12.5 ~ 10	202.8	147.5				
10 ~ 6.3	119.1	93.6				
Total Weight	1040.4	691.3				

Flakiness Index (%)= $\frac{\text{Total weight passing thickness gauges}}{\text{Total weight of test sample}}$ x 100 %

= 39.92%

GRADATION OF SOIL

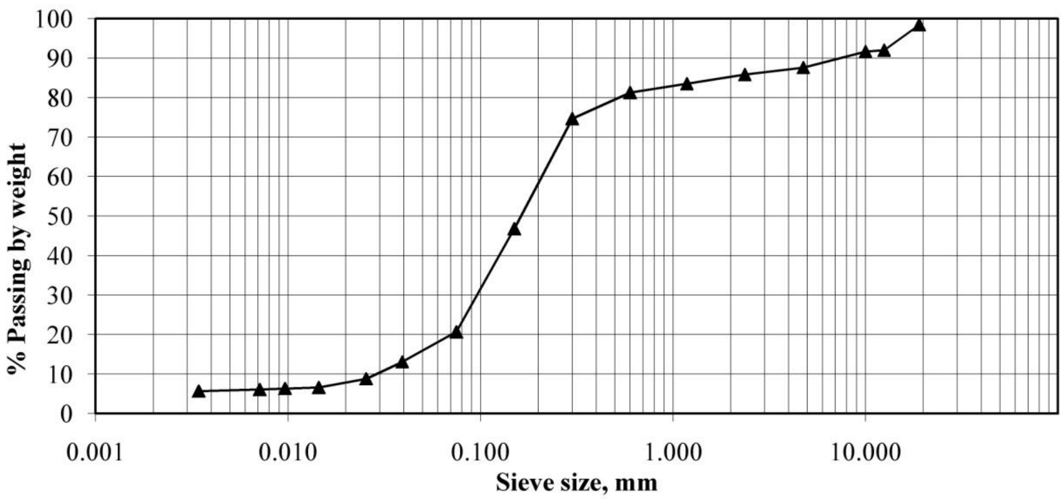
Client/Sample Description: Imza Lake Investigation Project/Silty soil

Sample: L-1 | Testing Standards: IS 2720-4 (1985)

Location: Imza Lake | Date: 13/11/2014

Total Wt. , gm : 500.80

Sieve Size (mm)	Weight Retained (gm)	Cummulative Weight Retained (gm)	Cummmulative Percentage Retained	Percentage Passing
19.00	7.80	1.56	1.56	98.44
12.50	32.10	6.41	7.97	92.03
10.00	1.60	0.32	8.29	91.71
4.75	20.40	4.07	12.36	87.64
2.36	8.80	1.76	14.12	85.88
1.18	11.70	2.34	16.45	83.55
0.60	11.30	2.26	18.71	81.29
0.30	33.00	6.59	25.30	74.70
0.15	139.50	27.86	53.15	46.85
0.075	130.90	26.14	79.29	20.71
0.039	FROM HYDROMETER ANALYSIS			13.12
0.025				8.83
0.014				6.62
0.010				6.36
0.007				6.11
0.003				5.72



Clay size = 5.72% Silt size = 14.99% Sand size = 65.17% Gravel size = 14.12%

Client/Sample Description : Imza Lake Investigation
Source :
Location/Chainage: Imza Lake
Sample received on: Sample tested on: 19/11/2014
Sample No.: CM-2 Testing Standard: IS 2386-4

AGGREGATE IMPACT VALUE (AIV)

S.No.	Details	Trial Number		Remarks
		1	2	
1	Total weight of aggregates sample +	1216.3	1220.1	
2	Weight of the cylindrical measure (gm),	866.3	866.3	
3	Total weight of aggregates sample (gm),	350.0	353.8	
4	Weight of the aggregates retained on	288.4	290.6	
5	Weight of the aggregates passing 2.36	61.6	63.2	
6	Aggregate Impact Value (%) =	17.60%	17.86%	
7	Average	17.73%		

Los Angeles Abrashion value = 1.45*AIV
= 25.71 %

ATTERBERG LIMITS TEST

Client/Sample Description : Imza Lake Investigation Project/Sandy silt
Sample : R-3
Location/Chainage :
Sample received on : Sample tested on: 13/11/2014
Lab Reference No. Testing Standard: IS 2720-5 (1985)

S.No.	Specimen no		Liquid Limit				Plastic Limit
			AF	AB	AH	K	
1	No. of blows		31	27	15	11	No Plastic Limit
2	Wt. Of Container + Wet Soil	gms	22.89	30.53	31.96	28.65	
3	Wt. Of Container + Dry Soil	gms	20.67	26.94	26.82	24.32	
4	Wt. Of Water	gms	2.22	3.59	5.14	4.33	
5	Wt. Of Empty Container	gms	14.42	17.15	13.18	13.18	
6	Wt. Of Dry Soil	gms	6.25	9.79	13.64	11.14	
7	Moisture Content	%	35.52	36.67	37.68	38.87	

Liquid Limit (%)	36.45	Plastic Limit	0.00	Plasticity Index	36.45

Annex VIII-ERT Field data

Profile ERT-1

sn	c2	c1	p1	p2	n	rho	K	a	A Res	X
1	0	1	2	3	1	65.7	188.5714	10	12389.14	15
2	0	1	3	4	2	17.25	754.2857	10	13011.43	20
3	1	2	3	4	1	42.1	188.5714	10	7938.857	25
4	1	2	4	5	2	7.15	754.2857	10	5393.143	30
5	2	3	4	5	1	34.3	188.5714	10	6468	35
6	2	3	5	6	2	8.33	754.2857	10	6283.2	40
7	3	4	5	6	1	33.8	188.5714	10	6373.714	45
8	3	4	6	7	2	7.42	754.2857	10	5596.8	50
9	4	5	6	7	1	32	188.5714	10	6034.286	55
10	4	5	7	8	2	4.5	754.2857	10	3394.286	60
11	5	6	7	8	1	19.89	188.5714	10	3750.686	65
12	5	6	8	9	2	6.7	754.2857	10	5053.714	70
13	6	7	8	9	1	38.4	188.5714	10	7241.143	75
14	6	7	9	10	2	10.55	754.2857	10	7957.714	80
15	7	8	9	10	1	33.7	188.5714	10	6354.857	85
16	7	8	10	11	2	11.26	754.2857	10	8493.257	90
17	8	9	10	11	1	46	188.5714	10	8674.286	95
18	8	9	11	12	2	17.34	754.2857	10	13079.31	100
19	9	10	11	12	1	60	188.5714	10	11314.29	105
20	9	10	12	13	2	32.1	754.2857	10	24212.57	110
21	10	11	12	13	1	85.7	188.5714	10	16160.57	115
22	10	11	13	14	2	13.82	754.2857	10	10424.23	120
23	11	12	13	14	1	54.1	188.5714	10	10201.71	125
24	11	12	14	15	2	42.5	754.2857	10	32057.14	130
25	12	13	14	15	1	131	188.5714	10	24702.86	135
26	12	13	15	16	2	31.2	754.2857	10	23533.71	140
27	13	14	15	16	1	36.8	188.5714	10	6939.429	145
28	13	14	16	17	2	37	754.2857	10	27908.57	150
29	14	15	16	17	1	114	188.5714	10	21497.14	155
30	14	15	17	18	2	8.5	754.2857	10	6411.429	160
31	15	16	17	18	1	4.5	188.5714	10	848.5714	165
32	15	16	18	19	2	12	754.2857	10	9051.429	170
33	16	17	18	19	1	69.5	188.5714	10	13105.71	175
34	16	17	19	20	2	10.32	754.2857	10	7784.229	180
35	17	18	19	20	1	26.3	188.5714	10	4959.429	185

Profile ERT-2

sn	c2	sn	c2	c1	p1	p2	n	rho	K	a	A Res	X
1	0	1	0	1	2	3	1	135	188.6	10	25457	15
2	0	2	0	1	3	4	2	98.4	754.3	10	74222	20
3	1	3	1	2	3	4	1	153	188.6	10	28851	25
4	1	4	1	2	4	5	2	28.1	754.3	10	21195	30
5	2	5	2	3	4	5	1	43	188.6	10	8108.6	35
6	2	6	2	3	5	6	2	50.1	754.3	10	37790	40
7	3	7	3	4	5	6	1	158	188.6	10	29794	45
8	3	8	3	4	6	7	2	27	754.3	10	20366	50
9	4	9	4	5	6	7	1	48.1	188.6	10	9070.3	55
10	4	10	4	5	7	8	2	17.48	754.3	10	13185	60
11	5	11	5	6	7	8	1	39.2	188.6	10	7392	65
12	5	12	5	6	8	9	2	113	754.3	10	85234	70
13	6	13	6	7	8	9	1	263	188.6	10	49594	75
14	6	14	6	7	9	10	2	45	754.3	10	33943	80
15	7	15	7	8	9	10	1	28.8	188.6	10	5430.9	85
16	7	16	7	8	10	11	2	46	754.3	10	34697	90
17	8	17	8	9	10	11	1	46.5	188.6	10	8768.6	95
18	8	18	8	9	11	12	2	11.5	754.3	10	8674.3	100
19	9	19	9	10	11	12	1	89.2	188.6	10	16821	105
20	9	20	9	10	12	13	2	66	754.3	10	49783	110
21	10	21	10	11	12	13	1	47.5	188.6	10	8957.1	115
22	10	22	10	11	13	14	2	59.7	754.3	10	45031	120
23	11	23	11	12	13	14	1	83.5	188.6	10	15746	125
24	11	24	11	12	14	15	2	13.72	754.3	10	10349	130
25	12	25	12	13	14	15	1	39.5	188.6	10	7448.6	135
26	12	26	12	13	15	16	2	35	754.3	10	26400	140
27	13	27	13	14	15	16	1	44	188.6	10	8297.1	145
28	13	28	13	14	16	17	2	17	754.3	10	12823	150
29	14	29	14	15	16	17	1	98	188.6	10	18480	155
30	14	30	14	15	17	18	2	33.3	754.3	10	25118	160
31	15	31	15	16	17	18	1	52.9	188.6	10	9975.4	165
32	15	32	15	16	18	19	2	21.7	754.3	10	16368	170
33	16	33	16	17	18	19	1	51.7	188.6	10	9749.1	175
34	16	34	16	17	19	20	2	15.71	754.3	10	11850	180
35	17	35	17	18	19	20	1	54.9	188.6	10	10353	185
36	17	36	17	18	20	21	2	21.5	754.3	10	16217	190
37	18	37	18	19	20	21	1	54.1	188.6	10	10202	195
38	18	38	18	19	21	22	2	7.74	754.3	10	5838.2	200
39	19	39	19	20	21	22	1	19.42	188.6	10	3662.1	205
40	19	40	19	20	22	23	2	10.37	754.3	10	7821.9	210

41	20	41	20	21	22	23	1	47.2	188.6	10	8900.6	215
42	20	42	20	21	23	24	2	5.23	754.3	10	3944.9	220
43	21	43	21	22	23	24	1	18.5	188.6	10	3488.6	225
44	21	44	21	22	24	25	2	9	754.3	10	6788.6	230
45	22	45	22	23	24	25	1	23.7	188.6	10	4469.1	235
46	22	46	22	23	25	26	2	9	754.3	10	6788.6	240
45	23	45	23	24	25	26	1	35.6	188.6	10	6713.1	245
46	23	46	23	24	26	27	2	7.5	754.3	10	5657.1	250
47	24	47	24	25	26	27	1	29	188.6	10	5468.6	255
48	24	48	24	25	27	28	2	16	754.3	10	12069	260
49	25	49	25	26	27	28	1	35	188.6	10	6600	265
50	25	50	25	26	28	29	2	9.5	754.3	10	7165.7	270
51	26	51	26	27	28	29	1	56.3	188.6	10	10617	275
52	26	52	26	27	29	30	2	25.8	754.3	10	19461	280
53	27	53	27	28	29	30	1	64.8	188.6	10	12219	285
54	25	54	25	26	29	30	3	5.7	1886	10	10749	275
55	24	55	24	25	28	29	3	9.6	1886	10	18103	265
56	23	56	23	24	27	28	3	4	1886	10	7542.9	255
57	22	57	22	23	26	27	3	5	1886	10	9428.6	245
58	21	58	21	22	25	26	3	8	1886	10	15086	235
59	20	59	20	21	24	25	3	6.3	1886	10	11880	225
60	19	60	19	20	23	24	3	5	1886	10	9428.6	215
61	18	61	18	19	22	23	3	9.1	1886	10	17160	205
62	17	62	17	18	21	22	3	5.4	1886	10	10183	195
63	16	63	16	17	20	21	3	9	1886	10	16971	185
64	15	64	15	16	19	20	3	16.5	1886	10	31114	175
65	14	65	14	15	18	19	3	10.5	1886	10	19800	165
66	13	66	13	14	17	18	3	4.3	1886	10	8108.6	155
67	12	67	12	13	16	17	3	6.2	1886	10	11691	145
68	11	68	11	12	15	16	3	10	1886	10	18857	135
69	10	69	10	11	14	15	3	5.5	1886	10	10371	125
70	9	70	9	10	13	14	3	4	1886	10	7542.9	115
71	8	71	8	9	12	13	3	6.8	1886	10	12823	105
72	7	72	7	8	11	12	3	8.5	1886	10	16029	95
73	6	73	6	7	10	11	3	6.1	1886	10	11503	85
74	5	74	5	6	9	10	3	3.9	1886	10	7354.3	75
75	4	75	4	5	8	9	3	9.5	1886	10	17914	65
76	3	76	3	4	7	8	3	7.9	1886	10	14897	55
77	2	77	2	3	6	7	3	7.8	1886	10	14709	45
78	1	78	1	2	5	6	3	16.9	1886	10	31869	35

Profile ERT-3

sn	c2	c1	p1	p2	n	rho	K	a	A Res	X
1	0	1	2	3	1	28.7	188.6	10	5412	15
2	0	1	3	4	2	15.43	754.3	10	11639	20
3	1	2	3	4	1	43.2	188.6	10	8146.3	25
4	1	2	4	5	2	10.26	754.3	10	7739	30
5	2	3	4	5	1	43.5	188.6	10	8202.9	35
6	2	3	5	6	2	11.24	754.3	10	8478.2	40
7	3	4	5	6	1	53.3	188.6	10	10051	45
8	3	4	6	7	2	7.13	754.3	10	5378.1	50
9	4	5	6	7	1	25.5	188.6	10	4808.6	55
10	4	5	7	8	2	7.42	754.3	10	5596.8	60
11	5	6	7	8	1	46.1	188.6	10	8693.1	65
12	5	6	8	9	2	8.15	754.3	10	6147.4	70
13	6	7	8	9	1	33.4	188.6	10	6298.3	75
14	6	7	9	10	2	4.56	754.3	10	3439.5	80
15	7	8	9	10	1	22.8	188.6	10	4299.4	85
16	7	8	10	11	2	5.71	754.3	10	4307	90
17	8	9	10	11	1	40.6	188.6	10	7656	95
18	8	9	11	12	2	42	754.3	10	31680	100
19	9	10	11	12	1	104.4	188.6	10	19687	105
20	9	10	12	13	2	11.43	754.3	10	8621.5	110
21	10	11	12	13	1	35	188.6	10	6600	115
22	10	11	13	14	2	14.29	754.3	10	10779	120
23	11	12	13	14	1	76.6	188.6	10	14445	125
24	11	12	14	15	2	14.88	754.3	10	11224	130
25	12	13	14	15	1	35.5	188.6	10	6694.3	135
26	12	13	15	16	2	12.44	754.3	10	9383.3	140
27	13	14	15	16	1	66.4	188.6	10	12521	145
28	13	14	16	17	2	19.83	754.3	10	14957	150
29	14	15	16	17	1	40.9	188.6	10	7712.6	155
30	14	15	17	18	2	14.81	754.3	10	11171	160
31	15	16	17	18	1	52.4	188.6	10	9881.1	165
32	15	16	18	19	2	15.59	754.3	10	11759	170

33	16	17	18	19	1	61	188.6	10	11503	175
34	16	17	19	20	2	25.4	754.3	10	19159	180
35	17	18	19	20	1	51.8	188.6	10	9768	185
36	15	16	19	20	3	22.8	1886	10	42994	175
36	14	15	18	19	3	4.87	1886	10	9183.4	165
37	13	14	17	18	3	8.1	1886	10	15274	155
38	12	13	16	17	3	6.64	1886	10	12521	145
39	11	12	15	16	3	9.52	1886	10	17952	135
40	10	11	14	15	3	3.08	1886	10	5808	125
41	9	10	13	14	3	5.12	1886	10	9654.9	115
42	8	9	12	13	3	5.33	1886	10	10051	105
43	7	8	11	12	3	4.04	1886	10	7618.3	95
44	6	7	10	11	3	1.86	1886	10	3507.4	85
45	5	6	9	10	3	2.6	1886	10	4902.9	75
46	4	5	8	9	3	2.4	1886	10	4525.7	65
47	3	4	7	8	3	2.22	1886	10	4186.3	55
48	2	3	6	7	3	2.4	1886	10	4525.7	45
49	1	2	5	6	3	3.2	1886	10	6034.3	35
50	0	1	4	5	3	5.1	1886	10	9617.1	25
51	0	1	5	6	4	2.73	3771	10	10296	30
52	1	2	6	7	4	1.239	3771	10	4672.8	40
53	2	3	7	8	4	1.422	3771	10	5363	50
54	3	4	8	9	4	1.723	3771	10	6498.2	60
55	4	5	9	10	4	1.103	3771	10	4159.9	70
56	5	6	10	11	4	1.56	3771	10	5883.4	80
57	6	7	11	12	4	1.76	3771	10	6637.7	90
58	7	8	12	13	4	1.927	3771	10	7267.5	100
59	8	9	13	14	4	3.06	3771	10	11541	110
60	9	10	14	15	4	1.922	3771	10	7248.7	120
61	10	11	15	16	4	2.42	3771	10	9126.9	130
62	11	12	16	17	4	5.48	3771	10	20667	140
63	12	13	17	18	4	3.78	3771	10	14256	150
64	13	14	18	19	4	3.81	3771	10	14369	160
65	14	15	19	20	4	12.11	3771	10	45672	170

Profile ERT-4

sn	c2	c1	p1	p2	n	rho	K	a	A Res	X
1	0	1	2	3	1	28.4	188.57	10	5355.4	15
2	0	1	3	4	2	4.62	754.29	10	3484.8	20
3	1	2	3	4	1	22.9	188.57	10	4318.3	25
4	1	2	4	5	2	5.42	754.29	10	4088.2	30
5	2	3	4	5	1	26.1	188.57	10	4921.7	35
6	2	3	5	6	2	11.57	754.29	10	8727.1	40
7	3	4	5	6	1	20.6	188.57	10	3884.6	45
8	3	4	6	7	2	5.38	754.29	10	4058.1	50
9	4	5	6	7	1	70.6	188.57	10	13313	55
10	4	5	7	8	2	14.79	754.29	10	11156	60
11	5	6	7	8	1	46.7	188.57	10	8806.3	65
12	5	6	8	9	2	4.48	754.29	10	3379.2	70
13	6	7	8	9	1	19.59	188.57	10	3694.1	75
14	6	7	9	10	2	9.58	754.29	10	7226.1	80
15	7	8	9	10	1	26.2	188.57	10	4940.6	85
16	7	8	10	11	2	6.9	754.29	10	5204.6	90
17	8	9	10	11	1	24.7	188.57	10	4657.7	95
18	8	9	11	12	2	15.56	754.29	10	11737	100
19	9	10	11	12	1	25.6	188.57	10	4827.4	105
20	9	10	12	13	2	12.97	754.29	10	9783.1	110
21	10	11	12	13	1	25.5	188.57	10	4808.6	115
22	10	11	13	14	2	6.73	754.29	10	5076.3	120
23	11	12	13	14	1	34.9	188.57	10	6581.1	125
24	11	12	14	15	2	10.28	754.29	10	7754.1	130
25	12	13	14	15	1	50.7	188.57	10	9560.6	135
26	12	13	15	16	2	19.88	754.29	10	14995	140
27	13	14	15	16	1	74.3	188.57	10	14011	145
28	11	12	15	16	3	10.55	1885.7	10	19894	135
29	10	11	14	15	3	3.95	1885.7	10	7448.6	125
30	9	10	13	14	3	3.75	1885.7	10	7071.4	115
31	8	9	12	13	3	10.24	1885.7	10	19310	105
32	7	8	11	12	3	2.69	1885.7	10	5072.6	95
33	6	7	10	11	3	4.27	1885.7	10	8052	85
34	5	6	9	10	3	4.11	1885.7	10	7750.3	75
35	4	5	8	9	3	3.16	1885.7	10	5958.9	65
36	3	4	7	8	3	4.36	1885.7	10	8221.7	55
37	2	3	6	7	3	2.8	1885.7	10	5280	45
38	1	2	5	6	3	1.687	1885.7	10	3181.2	35
39	0	1	4	5	3	2.4	1885.7	10	4525.7	25
40	0	1	5	6	4	1.133	3771.4	10	4273	30
41	1	2	6	7	4	1.621	3771.4	10	6113.5	40
42	2	3	7	8	4	2.91	3771.4	10	10975	50
43	3	4	8	9	4	0.843	3771.4	10	3179.3	60
44	4	5	9	10	4	6.64	3771.4	10	25042	70
45	5	6	10	11	4	2.5	3771.4	10	9428.6	80
46	6	7	11	12	4	2.77	3771.4	10	10447	90
47	7	8	12	13	4	4.39	3771.4	10	16557	100
48	8	9	13	14	4	8.04	3771.4	10	30322	110
49	9	10	14	15	4	4.62	3771.4	10	17424	120
50	10	11	15	16	4	5.67	3771.4	10	21384	130

Profile ERT-5

sn	c2	c1	p1	p2	n	rho	K	a	A Res	X
1	0	1	2	3	1	64.5	188.57	10	12163	15
2	0	1	3	4	2	33.1	754.29	10	24967	20
3	1	2	3	4	1	41.5	188.57	10	7825.7	25
4	1	2	4	5	2	8.47	754.29	10	6388.8	30
5	2	3	4	5	1	30.2	188.57	10	5694.9	35
6	2	3	5	6	2	26.6	754.29	10	20064	40
7	3	4	5	6	1	26.7	188.57	10	5034.9	45
8	3	4	6	7	2	17.87	754.29	10	13479	50
9	4	5	6	7	1	81	188.57	10	15274	55
10	4	5	7	8	2	17.13	754.29	10	12921	60
11	5	6	7	8	1	45.8	188.57	10	8636.6	65
12	5	6	8	9	2	18.13	754.29	10	13675	70
13	6	7	8	9	1	67.6	188.57	10	12747	75
14	6	7	9	10	2	10.15	754.29	10	7656	80
15	7	8	9	10	1	13	188.57	10	2451.4	85
16	7	8	10	11	2	68.4	754.29	10	51593	90
17	8	9	10	11	1	14.58	188.57	10	2749.4	95
18	8	9	11	12	2	33.3	754.29	10	25118	100
19	9	10	11	12	1	27.2	188.57	10	5129.1	105
20	9	10	12	13	2	8.5	754.29	10	6411.4	110
21	10	11	12	13	1	28.4	188.57	10	5355.4	115
22	10	11	13	14	2	17.44	754.29	10	13155	120
23	11	12	13	14	1	57.2	188.57	10	10786	125
24	11	12	14	15	2	7.38	754.29	10	5566.6	130
25	12	13	14	15	1	24.9	188.57	10	4695.4	135
26	12	13	15	16	2	37.3	754.29	10	28135	140
27	13	14	15	16	1	18.66	188.57	10	3518.7	145
28	11	12	15	16	3	11.38	1885.7	10	21459	135
29	10	11	14	15	3	5.06	1885.7	10	9541.7	125
30	9	10	13	14	3	7.08	1885.7	10	13351	115
31	8	9	12	13	3	4.64	1885.7	10	8749.7	105
32	7	8	11	12	3	5.32	1885.7	10	10032	95
33	6	7	10	11	3	5.66	1885.7	10	10673	85
34	5	6	9	10	3	4.37	1885.7	10	8240.6	75
35	4	5	8	9	3	6.21	1885.7	10	11710	65
36	3	4	7	8	3	3.26	1885.7	10	6147.4	55
37	2	3	6	7	3	10.73	1885.7	10	20234	45
38	1	2	5	6	3	2.23	1885.7	10	4205.1	35
39	0	1	4	5	3	3.19	1885.7	10	6015.4	25
40	0	1	5	6	4	2.28	3771.4	10	8598.9	30
41	1	2	6	7	4	1.162	3771.4	10	4382.4	40
42	2	3	7	8	4	3.99	3771.4	10	15048	50
43	3	4	8	9	4	2.22	3771.4	10	8372.6	60
44	4	5	9	10	4	1.988	3771.4	10	7497.6	70
45	5	6	10	11	4	1.06	3771.4	10	3997.7	80
46	6	7	11	12	4	2.96	3771.4	10	11163	90
47	7	8	12	13	4	2.39	3771.4	10	9013.7	100
48	8	9	13	14	4	5.93	3771.4	10	22365	110
49	9	10	14	15	4	1.863	3771.4	10	7026.2	120
50	10	11	15	16	4	2.64	3771.4	10	9956.6	130

Profile ERT-6

sn	c2	c1	p1	p2	n	rho	K	a	A Res	X
1	0	1	2	3	1	150	188.5714286	10	28285.71429	15
2	0	1	3	4	2	41	754.2857143	10	30925.71429	20
3	1	2	3	4	1	110	188.5714286	10	20742.85714	25
4	1	2	4	5	2	38	754.2857143	10	28662.85714	30
5	2	3	4	5	1	113.2	188.5714286	10	21346.28571	35
6	2	3	5	6	2	45.7	754.2857143	10	34470.85714	40
7	3	4	5	6	1	94.3	188.5714286	10	17782.28571	45
8	3	4	6	7	2	15	754.2857143	10	11314.28571	50
9	4	5	6	7	1	115	188.5714286	10	21685.71429	55
10	4	5	7	8	2	27	754.2857143	10	20365.71429	60
11	5	6	7	8	1	113	188.5714286	10	21308.57143	65
12	5	6	8	9	2	29	754.2857143	10	21874.28571	70
13	6	7	8	9	1	76	188.5714286	10	14331.42857	75
14	6	7	9	10	2	18.6	754.2857143	10	14029.71429	80
15	7	8	9	10	1	90.6	188.5714286	10	17084.57143	85
16	7	8	10	11	2	32.9	754.2857143	10	24816	90
17	8	9	10	11	1	123	188.5714286	10	23194.28571	95
18	8	9	11	12	2	22.7	754.2857143	10	17122.28571	100
19	9	10	11	12	1	128.9	188.5714286	10	24306.85714	105
20	9	10	12	13	2	23.8	754.2857143	10	17952	110
21	10	11	12	13	1	124	188.5714286	10	23382.85714	115
22	10	11	13	14	2	27	754.2857143	10	20365.71429	120
23	11	12	13	14	1	62	188.5714286	10	11691.42857	125
24	11	12	14	15	2	12.42	754.2857143	10	9368.228571	130
25	12	13	14	15	1	109	188.5714286	10	20554.28571	135
26	12	13	15	16	2	23	754.2857143	10	17348.57143	140
27	13	14	15	16	1	78	188.5714286	10	14708.57143	145
28	11	12	15	16	3	12.91	1885.714286	10	10371.42857	135
29	10	11	14	15	3	28.2	1885.714286	10	14425.71429	125
30	9	10	13	14	3	8.57	1885.714286	10	20460	115
31	8	9	12	13	3	13.7	1885.714286	10	17801.14286	105
32	7	8	11	12	3	22.4	1885.714286	10	14953.71429	95
33	6	7	10	11	3	12.9	1885.714286	10	16160.57143	85
34	5	6	9	10	3	5.5	1885.714286	10	24344.57143	75
35	4	5	8	9	3	7.65	1885.714286	10	53177.14286	65
36	3	4	7	8	3	10.85	1885.714286	10	16160.57143	55
37	2	3	6	7	3	9.44	1885.714286	10	25834.28571	45
38	1	2	5	6	3	7.93	1885.714286	10	42240	35
39	0	1	4	5	3	8.57	1885.714286	10	24325.71429	25
40	0	1	5	6	4	7.53	3771.428571	10	67093.71429	30
41	1	2	6	7	4	1.11	3771.428571	10	66754.28571	40
42	2	3	7	8	4	2.34	3771.428571	10	24061.71429	50
43	3	4	8	9	4	6.91	3771.428571	10	26060.57143	60
44	4	5	9	10	4	17.55	3771.428571	10	66188.57143	70
45	5	6	10	11	4	10.39	3771.428571	10	39185.14286	80
46	6	7	11	12	4	3.29	3771.428571	10	12408	90
47	7	8	12	13	4	5.75	3771.428571	10	21685.71429	100
48	8	9	13	14	4	17.79	3771.428571	10	28398.85714	110
49	9	10	14	15	4	17.7	3771.428571	10	4186.285714	120
50	10	11	15	16	4	6.38	3771.428571	10	8825.142857	130

Profile ERT-7

sn	c2	c1	p1	p2	n	rho	K	a	A Res	X
1	0	1	2	3	1	4.23	188.57	10	797.66	15
2	0	1	3	4	2	2.44	754.29	10	1840.5	20
3	1	2	3	4	1	49.6	188.57	10	9353.1	25
4	1	2	4	5	2	14.06	754.29	10	10605	30
5	2	3	4	5	1	20.3	188.57	10	3828	35
6	2	3	5	6	2	24	754.29	10	18103	40
7	3	4	5	6	1	46.8	188.57	10	8825.1	45
8	3	4	6	7	2	6.93	754.29	10	5227.2	50
9	4	5	6	7	1	31.6	188.57	10	5958.9	55
10	4	5	7	8	2	10.15	754.29	10	7656	60
11	5	6	7	8	1	11.1	188.57	10	2093.1	65
12	5	6	8	9	2	6.13	754.29	10	4623.8	70
13	6	7	8	9	1	10.91	188.57	10	2057.3	75
14	6	7	9	10	2	3.79	754.29	10	2858.7	80
15	7	8	9	10	1	20.4	188.57	10	3846.9	85
16	7	8	10	11	2	6.32	754.29	10	4767.1	90
17	8	9	10	11	1	15.54	188.57	10	2930.4	95
18	8	9	11	12	2	5.64	754.29	10	4254.2	100
19	9	10	11	12	1	41.9	188.57	10	7901.1	105
20	9	10	12	13	2	17.61	754.29	10	13283	110
21	10	11	12	13	1	45.5	188.57	10	8580	115
22	10	11	13	14	2	51.6	754.29	10	38921	120
23	11	12	13	14	1	117.8	188.57	10	22214	125
24	11	12	14	15	2	30.6	754.29	10	23081	130
25	12	13	14	15	1	136.5	188.57	10	25740	135
26	12	13	15	16	2	49.5	754.29	10	37337	140
27	13	14	15	16	1	73.8	188.57	10	13917	145
28	11	12	15	16	3	37.8	1885.7	10	71280	135
29	10	11	14	15	3	11.39	1885.7	10	21478	125
30	9	10	13	14	3	32.2	1885.7	10	60720	115
31	8	9	12	13	3	3.79	1885.7	10	7146.9	105
32	7	8	11	12	3	2.09	1885.7	10	3941.1	95
33	6	7	10	11	3	3.61	1885.7	10	6807.4	85
34	5	6	9	10	3	2.26	1885.7	10	4261.7	75
35	4	5	8	9	3	2.41	1885.7	10	4544.6	65
36	3	4	7	8	3	4.86	1885.7	10	9164.6	55
37	2	3	6	7	3	2.91	1885.7	10	5487.4	45
38	1	2	5	6	3	7.85	1885.7	10	14803	35
39	0	1	4	5	3	1.433	1885.7	10	2702.2	25
40	0	1	5	6	4	1.57	3771.4	10	5921.1	30
41	1	2	6	7	4	2.62	3771.4	10	9881.1	40
42	2	3	7	8	4	2.16	3771.4	10	8146.3	50
43	3	4	8	9	4	1.46	3771.4	10	5506.3	60
44	4	5	9	10	4	0.84	3771.4	10	3168	70
45	5	6	10	11	4	2.69	3771.4	10	10145	80
46	6	7	11	12	4	1.2	3771.4	10	4525.7	90
47	7	8	12	13	4	1.785	3771.4	10	6732	100
48	8	9	13	14	4	1.927	3771.4	10	7267.5	110
49	9	10	14	15	4	8.67	3771.4	10	32698	120
50	10	11	15	16	4	2.19	3771.4	10	8259.4	130

Profile ERT-8

sn	c2	c1	p1	p2	n	rho	K	a	A Res	X
1	0	1	2	3	1	47.3	188.57	10	8919.4	15
2	0	1	3	4	2	14.15	754.29	10	10673	20
3	1	2	3	4	1	75.9	188.57	10	14313	25
4	1	2	4	5	2	14.43	754.29	10	10884	30
5	2	3	4	5	1	40.2	188.57	10	7580.6	35
6	2	3	5	6	2	7.44	754.29	10	5611.9	40
7	3	4	5	6	1	53.2	188.57	10	10032	45
8	3	4	6	7	2	21.1	754.29	10	15915	50
9	4	5	6	7	1	49.6	188.57	10	9353.1	55
10	4	5	7	8	2	34.5	754.29	10	26023	60
11	5	6	7	8	1	22.4	188.57	10	4224	65
12	5	6	8	9	2	27.7	754.29	10	20894	70
13	6	7	8	9	1	29.1	188.57	10	5487.4	75
14	6	7	9	10	2	50.3	754.29	10	37941	80
15	7	8	9	10	1	25.3	188.57	10	4770.9	85
16	7	8	10	11	2	12	754.29	10	9051.4	90
17	8	9	10	11	1	30	188.57	10	5657.1	95
18	8	9	11	12	2	25	754.29	10	18857	100
19	9	10	11	12	1	25.3	188.57	10	4770.9	105
20	9	10	12	13	2	11	754.29	10	8297.1	110
21	10	11	12	13	1	23.3	188.57	10	4393.7	115
22	10	11	13	14	2	11	754.29	10	8297.1	120
23	11	12	13	14	1	26.6	188.57	10	5016	125
24	11	12	14	15	2	21.3	754.29	10	16066	130
25	12	13	14	15	1	18.4	188.57	10	3469.7	135
26	12	13	15	16	2	16.8	754.29	10	12672	140
27	13	14	15	16	1	12.1	188.57	10	2281.7	145
28	13	14	16	17	2	24	754.29	10	18103	150
29	14	15	16	17	1	25	188.57	10	4714.3	155
30	14	15	17	18	2	20	754.29	10	15086	160
31	15	16	17	18	1	27	188.57	10	5091.4	165
32	15	16	18	19	2	30	754.29	10	22629	170
33	16	17	18	19	1	18	188.57	10	3394.3	175
34	16	17	19	20	2	37	754.29	10	27909	180
35	17	18	19	20	1	23	188.57	10	4337.1	185

Profile ERT-9

sn	c2	c1	p1	p2	n	rho	K	a	A Res	X
1	0	1	2	3	1	93.7	188.57	10	17669	15
2	0	1	3	4	2	16	754.29	10	12069	20
3	1	2	3	4	1	80.6	188.57	10	15199	25
4	1	2	4	5	2	29.1	754.29	10	21950	30
5	2	3	4	5	1	78.8	188.57	10	14859	35
6	2	3	5	6	2	26.3	754.29	10	19838	40
7	3	4	5	6	1	45.4	188.57	10	8561.1	45
8	3	4	6	7	2	18.9	754.29	10	14256	50
9	4	5	6	7	1	33.1	188.57	10	6241.7	55
10	4	5	7	8	2	20.1	754.29	10	15161	60
11	5	6	7	8	1	133.2	188.57	10	25118	65
12	5	6	8	9	2	82.6	754.29	10	62304	70
13	6	7	8	9	1	58.5	188.57	10	11031	75
14	6	7	9	10	2	20.7	754.29	10	15614	80
15	7	8	9	10	1	81.1	188.57	10	15293	85
16	5	6	9	10	3	38.2	1885.7	10	72034	75
17	4	5	8	9	3	6.5	1885.7	10	12257	65
18	3	4	7	8	3	7	1885.7	10	13200	55
19	2	3	6	7	3	12.31	1885.7	10	23213	45
20	1	2	5	6	3	22.1	1885.7	10	41674	35
21	0	1	4	5	3	6.7	1885.7	10	12634	25
22	0	1	5	6	4	5.07	3771.4	10	19121	30
23	1	2	6	7	4	4.7	3771.4	10	17726	40
24	2	3	7	8	4	6.58	3771.4	10	24816	50
25	3	4	8	9	4	8.4	3771.4	10	31680	60
26	4	5	9	10	4	3.5	3771.4	10	13200	70

Profile ERT-10

sn	c2	c1	p1	p2	n	rho	K	a	A Res	X
1	0	1	2	3	1	160.8	188.57	10	30322	15
2	0	1	3	4	2	33.6	754.29	10	25344	20
3	1	2	3	4	1	93.3	188.57	10	17594	25
4	1	2	4	5	2	18.7	754.29	10	14105	30
5	2	3	4	5	1	113.2	188.57	10	21346	35
6	2	3	5	6	2	45.7	754.29	10	34471	40
7	3	4	5	6	1	94.3	188.57	10	17782	45
8	3	4	6	7	2	21.5	754.29	10	16217	50
9	4	5	6	7	1	125.6	188.57	10	23685	55
10	4	5	7	8	2	32.7	754.29	10	24665	60
11	5	6	7	8	1	90.8	188.57	10	17122	65
12	5	6	8	9	2	37.5	754.29	10	28286	70
13	6	7	8	9	1	76	188.57	10	14331	75
14	6	7	9	10	2	18.6	754.29	10	14030	80
15	7	8	9	10	1	90.6	188.57	10	17085	85
16	7	8	10	11	2	32.9	754.29	10	24816	90
17	8	9	10	11	1	168.4	188.57	10	31755	95
18	8	9	11	12	2	22.7	754.29	10	17122	100
19	9	10	11	12	1	128.9	188.57	10	24307	105
20	9	10	12	13	2	23.8	754.29	10	17952	110
21	10	11	12	13	1	139.9	188.57	10	26381	115
22	10	11	13	14	2	15.61	754.29	10	11774	120
23	11	12	13	14	1	54.3	188.57	10	10239	125
24	11	12	14	15	2	12.42	754.29	10	9368.2	130
25	12	13	14	15	1	91.6	188.57	10	17273	135
26	12	13	15	16	2	17.17	754.29	10	12951	140
27	13	14	15	16	1	25.7	188.57	10	4846.3	145
28	11	12	15	16	3	5.5	1885.7	10	10371	135
29	10	11	14	15	3	7.65	1885.7	10	14426	125
30	9	10	13	14	3	10.85	1885.7	10	20460	115
31	8	9	12	13	3	9.44	1885.7	10	17801	105
32	7	8	11	12	3	7.93	1885.7	10	14954	95
33	6	7	10	11	3	8.57	1885.7	10	16161	85
34	5	6	9	10	3	12.91	1885.7	10	24345	75
35	4	5	8	9	3	28.2	1885.7	10	53177	65
36	3	4	7	8	3	8.57	1885.7	10	16161	55
37	2	3	6	7	3	13.7	1885.7	10	25834	45
38	1	2	5	6	3	22.4	1885.7	10	42240	35
39	0	1	4	5	3	12.9	1885.7	10	24326	25
40	0	1	5	6	4	17.79	3771.4	10	67094	30
41	1	2	6	7	4	17.7	3771.4	10	66754	40
42	2	3	7	8	4	6.38	3771.4	10	24062	50
43	3	4	8	9	4	6.91	3771.4	10	26061	60
44	4	5	9	10	4	17.55	3771.4	10	66189	70
45	5	6	10	11	4	10.39	3771.4	10	39185	80
46	6	7	11	12	4	3.29	3771.4	10	12408	90
47	7	8	12	13	4	5.75	3771.4	10	21686	100
48	8	9	13	14	4	7.53	3771.4	10	28399	110
49	9	10	14	15	4	1.11	3771.4	10	4186.3	120
50	10	11	15	16	4	2.34	3771.4	10	8825.1	130