KSEB
കേരളത്തിന്റെ ഊർജ്ജം

KERALA STATE ELECTRICITY BOARD Ltd
(Incorporated under the Companies Act, 1956)
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ABSTRACT

Standard Operating Procedure (SOP) for investigation of Hydro Electric Projects - "Guidelines for Geological and Geotechnical Investigations of HEPs" - Approved - Orders issued.

CORPORATE OFFICE(SBU-G/C)

BO (DB)No.520/2023(DGC/AEE I/CMD Note/2023) Thiruvananthapuram,Dated: 08.12.2023

Read: 1. Note No. CMD/107/Hydro Power Projects/2023 dated 05.10.2023.
2. Note No. DGC/AEE I/CMD Note/2023 dated 10.11.2023 of the Chairman & Managing Director.
3. Proceedings of 74th meeting of Board of Directors held on 23.11.2023 vide Agenda No. 11-11/2023.

ORDER

Investigations and surveys play a crucial role in the planning, design, and construction of Hydro Electric Projects. Their primary purpose is to gather essential information about the site and its surrounding environment to ensure the successful and sustainable development of the projects. Detailed project report(DPR) is the compilation of all data / information about the terrain, seismic history, construction planning, methodology, ecology, environment and cost of a Hydro Electric Project.

The DPR of Hydro Electric Projects are required to be submitted to the Central Electricity Authority (CEA) for concurrence. All DPRs prepared by Investigation wing of KSEBL for concurrence of DPR approval committee are prepared to meet the guidelines prescribed by CEA to the extent possible. KSEBL has exhibited a commendable capacity in independently conducting numerous investigations for Hydro Electric Projects.

The Chairman & Managing Director, as per note read as 1st above, has directed to formulate a "Standard Operating Procedure" exclusively for the investigation of Hydro Electric Projects within KSEBL.

Based on the said direction, a "Draft Guidelines for Geological and Geotechnical Investigations of HEPs" was prepared by studying guidelines of CWC, CEA GSI & NHPC, various codes of Bureau of Indian Standard Codes related to surface and sub-surface explorations in river valley projects and the experience gained by officials of the investigation wing of KSEBL during the past two to three decades.

"Draft Guidelines for Geological and Geotechnical Investigations of HEPs" was placed before the Board of Directors, as per the note read as 2nd above, for approval.

In the 74th meeting of the Board of Directors held on 23.11.2023, the Chairman & Managing Director informed that the SOP for investigation of Hydro Power Projects was found necessary considering the adverse experience in some of the projects undertaken by KSEBL like

Sengulam Augmentation Scheme and also in the light of Joshimath and various tunnel collapses and people remaining inside tunnel for days.

After detailed discussion, the Board of Directors resolved to approve "Guidelines for Geological and Geotechnical Investigations of HEPs" for implementation in KSEBL.

Resolved further that the corresponding amendments made by the Government of India/NHPC in respect of the guidelines would be adopted in KSEBL from time to time.

Orders are issued accordingly.

By Order of the
Director Board

Sd/-

LEKHA G
Company Secretary

To:

The Chief Engineer (Civil - Investigation & Construction Central)

Copy to: The Company Secretary/ Chief Engineer (IT,CR&CAPS)/ Financial Advisor/ LA&DEO/ Chief Internal Auditor
The TA to the Chairman & Managing Director / Director (Generation-Civil) / Director (Distribution, Safety, SCM & IT) / Director (Transmission, SO & Planning)/ Director (Generation - Electrical, REES, SOURA, Sports & Welfare)
The PA to the Director (Finance & HRM)
The Sr.CA to the Secretary (Administration)
The RCAO/ RAO
Stock File.

Forwarded / By Order

Assistant Executive Engineer

GUIDELINES FOR GEOLOGICAL AND GEOTECHNICAL INVESTIGATIONS OF HYDROELECTRIC PROJECTS

NOVEMBER 2023

PREFACE

As per the statistics in the Central Electricity Authority (CEA) annual publication 'Growth of Electricity Sector in India from 1947-2023', August 2023, though the All India peak deficit and energy deficits of 4.01% and 0.5% respectively for the year 2022-'23, the total energy consumption in India is way below when compared with People Republic of China and the United States. The per capita consumption of India as on 31.03.2023 is 1327 Units which is much below when compared internationally. An important aspect worth mentioning is that among various categories, the share of consumption in Agriculture/Forestry sector in India is much ahead of these Countries. Similarly, the share of electricity consumption in residential sector is much ahead of PRC and comparable with the USA. That is, in Indian scenario power sector have to play a supportive role to these two sectors and hence supply of quality power at affordable rates through sustainable development is crucial. The situation becomes more pronounced in the State of Kerala where the major share of the electricity demand is from the domestic consumers. This demands for more in-house capacity addition and one alternative is by harnessing the power potential from its abundantly rich water resources which are still remaining to be tapped to an optimal level.

Hydro-power potential is available aplenty through various installed capacities ranging from micro to large Hydro-Electric Projects and PSPs. Implementing of Hydro-Electric Projects in a sustainable way without time and cost over-run would definitely beneficial directly to the Kerala State Electricity Board Limited and the State of Kerala in many ways. Development of hydroelectric projects may get marred due to various impeding issues or constraints including geo-technical and geological uncertainties, besides several other factors, resulting in significant time and cost overruns. Facilitating with a detailed project report (DPR) that enlists the prevalent topographical, geological and geotechnical scenarios at all the component locations of the proposed project would definitely help alleviate such concerns stated above and various other scenarios that might encounter in the implementation phase. With such a vision, the need of a Standard Operating Procedure (SOP) with certain set of guidelines in place was sensed of immense help to the Engineering fraternity involved in the investigation, design and implementation of the hydro-electric projects in particular.

The path to this SOP was the result of a guiding inspiration from Dr. Rajan N Khobragade IAS, the Chairman & Managing Director, KSEBL. The analyses of the entire activity flow right from the inception stage till the approval of the DPR is a complex process involving investigations and surveys in specific arenas and the CMD instigated for an SOP in place for the standardisation and guidance to persons involved in the process. Sri. Radhakrishnan G, the Director (Generation-Civil) was a catalyst in fulfilment of preparation of the SOP.

This edition of the SOP involves various aspects, viz., a flow Chart of Activities in Major and Small Hydroelectric Project Development, General Guidelines of Topographical and Geological Investigations for Hydroelectric Projects such as the selection of topographical maps published by Survey of India (SOI), guidelines regarding area of river course to be surveyed at the locations of dam site, reservoir area as well as for the power channel, tunnel, powerhouse and for the layout of project area, Extent and Objectives of geological Exploration, various methods and processes and the selection, how to avail the services of geological survey of India (GSI), deciding various exploratory tests and parameters (of both rock and soil) and depth of exploratory holes required, relevant standards of Bureau of Indian Standards(BSI), Geological Mapping in the component locations, General guidelines for core drilling, exploratory drifting, Guidelines for Geophysical Investigations, its applicability, various tests, selection of methods for various component locations, Guidelines for Exploration of Seismic Aspects of Hydroelectric Projects and approval from National Committee of Seismic Design Parameters (NCSDP) of India, choice of Deterministic as well as Probabilistic approach, geological, seismo-tectonic details and historic earthquake details apart from the other details of information to be submitted to NCSDP, The checklist of various geological inputs, various geological maps to be incorporated in the DPR, the format of progress reporting etc. The major changes introduced in this volume of SOP in exploratory drilling is the increase in depth of drilling into fresh rock and ascertaining 90% core recovery to determine the foundation grade rock for dams and weirs.

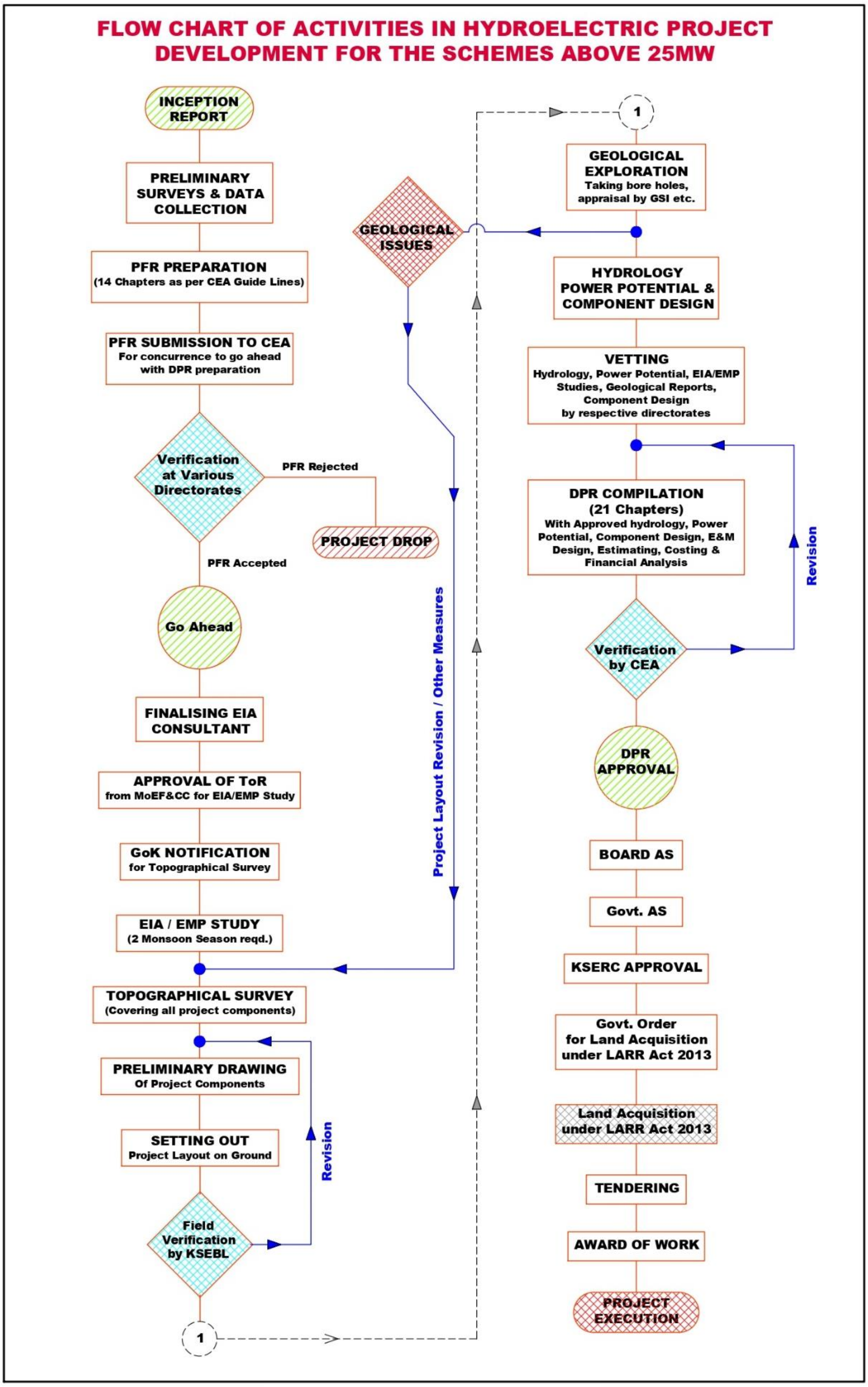
While preparing the SOP, the General Guidelines for Hydroelectric Project Investigation by various agencies in the power development were sought, the guidelines in NHPC was studied in detail, compared with the prevailing practices in KSEBL along with the directions received from the Geological Survey of India before adapting appropriately into this volume of SOP.

I am sure that this venture, the first step towards a sensible cause would be of immense use to the Engineers of KSEBL and other decision makers of the Board. Modifications or amendments, in case required, based on the merits of specific field requirement can be incorporated in the future revision(s), upon decision of the appropriate level of the Board. I whole-heartedly acknowledge my sincere thanks to the CMD of the KSEBL, Director (Generation-Civil) and other Directors of the Board for giving an opportunity in presenting this SOP for effective use in KSEBL. The efforts of Sri. Sunny C D, Assistant Executive Engineer, O/o the Chief Engineer (Civil - Investigation & Construction Central) for the formulation and compilation of this report is duly acknowledged.

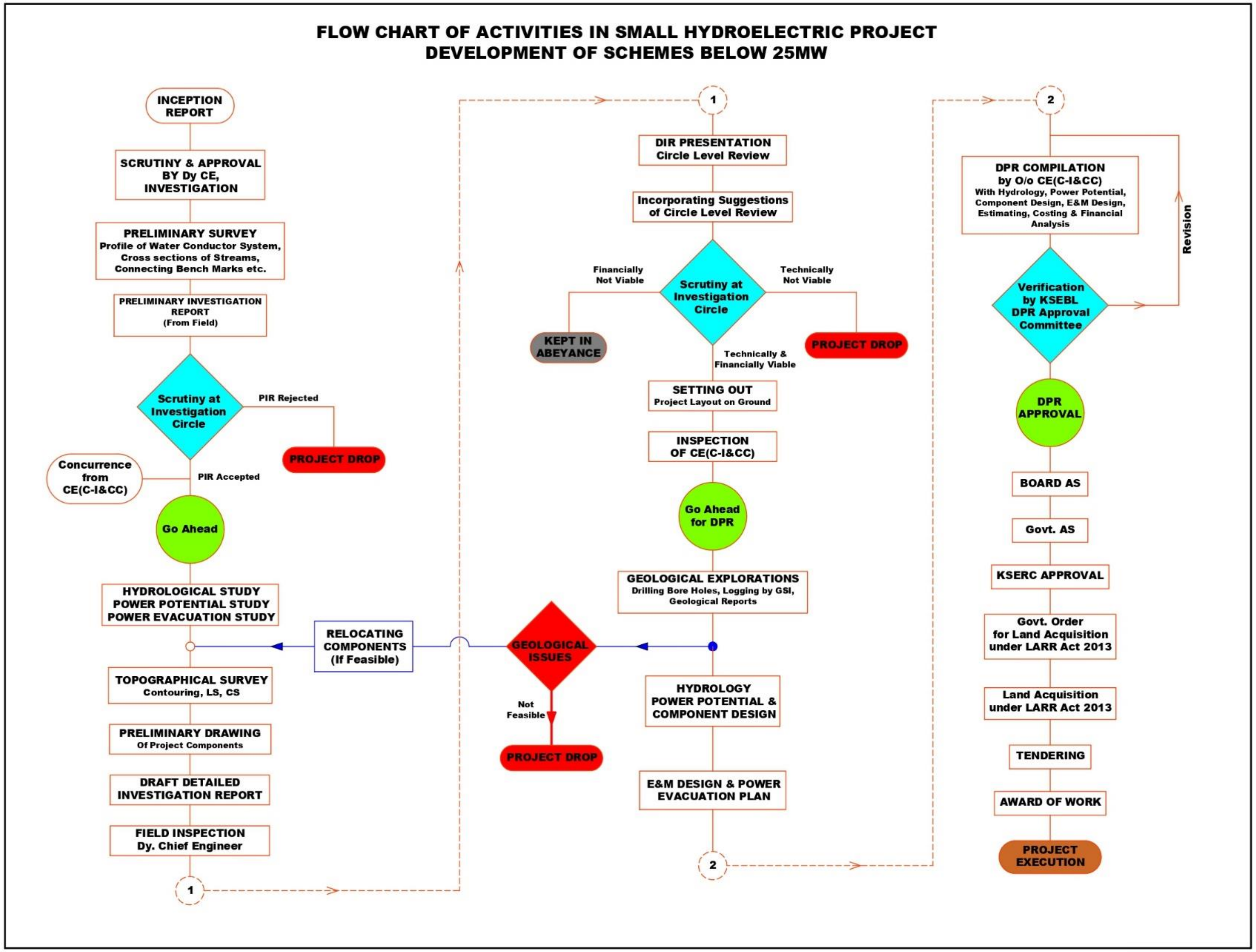
Shanavas A
Chief Engineer (Civil-Investigation & Construction Central)

Contents

1 Flow Chart of Activities in Major Hydroelectric Project Development



2 Flow Chart of Activities in Small Hydroelectric Project Development



3 General Guidelines of Topographical and Geological Investigations for Hydroelectric Projects

3.1 Topographical Survey

(IS 6065 Part -1, CEA document best practices in survey & Investigation)

The Survey of India (SOI) has published topographical maps covering the whole country in 1:2,50,000 and 1:50,000 scale. Besides SOI has also published topographical maps of many parts of the country in 1:25,000 scale.

All new schemes shall be referenced to the open map series of Survey of India based on WGS84 datum. The catchment area and project components shall be marked in the Digital Georeferenced Colour Raster Maps from Survey of India by using GIS technologies.

All the topographical maps during different stages of the project should be preferably made in UTM Coordinate System. *The Universal Transverse Mercator Coordinate system is a substitute for Geographical Lat-Long system for geographical positioning. The Lat-Long system is a spherical angular system with equator as zero plane whereas the UTM is a plane coordinate system with units in metres.*

The service of Survey of India may be adopted for preparing the reservoir maps of Important major HEP’s and PSP’s to the scale of 1:25000 maps or 1:12500 maps.

Following Project specific topographical surveys are required.

3.2 Dam Site

The surveyed area of river course shall be in the following order

Type of Dam	Upstream	Downstream
Small Dams & Weirs of height up to 12m	100m	100m
Intermediate Dams of height between 12m and 30m	250m	250m
Major Dams of height above 30m	500m	500m

(The above distance can also be finalized based on the other important features like height of dam, location of diversion portals, coffer dam and also the work area required on both the u/s and d/s of the dam etc.) extending up to an elevation of top of dam + 1/4 of dam height depending upon the geological requirement and slope stability vis-a-vis abutment stripping.

The contour interval should be 1m to 2m depending on the topographical characteristics of the valley. The dam site survey should also include the area required for diversion arrangement, intake structure, and other appurtenant structures. The scale of the maps may vary from 1:500 to 1:2000 depending upon the size of the area.

The topographical map of the dam site shall be prepared by using Total Station or other modern instruments with the permission of the Engineer-in-Charge.

3.3 Reservoir Area Survey

Survey should cover elevation up to 5m above MWL for all dams below 30m height and 10m above MWL for other dams.

The contour interval generally influenced by the slope characteristics of the terrain. Generally the scale of the map and contour intervals are as follows.

Water Spread Area of Reservoir	Scale of Map	Contour Interval
Up to 200 Ha	1:2000	1m – 2m
200Ha to 1000 Ha	1:5000	2m – 5m
Above 1000 Ha	1:10000	5m

However the Engineer-in-Charge may insist better resolution maps and contour interval as and when required.

The reservoir area may be mapped with the help of total station / DGPS / LiDAR aerial drone mapping. Other modern instruments shall be used with the consent of Engineer-in-Charge.

3.4 Survey for Power Channel

The width of the area considered for contour map/survey shall be as follows.

Towards hillside: Minimum 5m above the uphill side cutting edge of the proposed canal or 75m from the centre line of the canal towards hill side or ridge of the hill whichever is smaller.

Towards valley side: Minimum 10m below the toe edge of the downhill filling edge or 75m from centre line of canal towards downhill side or up to bottom edge of the valley whichever is less.

Scale of Map	Contour Interval
1:1000 to 1:2000	2m

3.5 Survey for tunnel

For detailed studies and layout finalization 200 m to 500m wide strip along the tunnel alignment or extending up to the river in a scale of 1:2000 to 1:5000 with contour interval 2-5m is required.

Survey for Adit portals may be carried out in a scale of 1:200 up to 50 m width on either side of Adit alignment. Adit junctions with main tunnel may be located as far as feasible kept at 90 degree. Adit portal may be located in areas where sufficient space is available for provision of infrastructure facilities for the works.

LiDAR mapping may be adopted for preparing the topographical map of the tunnel route.

3.6 Power house, Surge shaft, Switchyard and other structures:

Detailed Topographical maps of the component structures shall be prepared on a scale of 1:200 to 1:250 with contour interval of 1m.

3.7 Composite Project Layout /Area map:

The scale for the topographical map of the project area is based upon the spread of the project area.

Spread of Project Area	Scale of the Map
Up to 5km	1:5,000
5km to 10km	1:10,000
Above 10km	1:15,000

4 Extent and Objectives of Exploration

The term geological exploration covers all types of explorations, both surface and subsurface to be carried out for determination of the nature and disposition of geological formations and structures at/or near the proposed site of dam and other structures.

The type and extent of exploration should be commensurate with the size and importance of the project and will depend upon the size of the dam and other structures and type of foundation. These should neither be too little, resulting in inadequate data, nor too much, resulting in excessive cost and time for investigation.

All significant geological and structural features affecting the feasibility of structures particularly those which require remedial treatment, should be clearly known in advance, that is, before detailed design and construction.

As such the geological exploration should be focused on highlighting the adverse effects of' geological and structural features with reference to competency of the foundation and abutments. A complete programme of geological exploration should be able to provide required information regarding the following

- Types of lithological units present in the foundation and abutments; their disposition, succession, thickness and areal extent should be shown on the detailed geological maps and sections on specific scales.
- The location, sequence. thickness and areal extent of each soil/rock stratum, including a description and classification of the soil and their structure, stratification in the undisturbed state, significant geological or other structural features, such as fold, faults, shear zones, slide zones, karst/cavity zones buried channels, seams, joints, fissures, mineral and chemical constituents.

- Characteristics of significant geological and structural features such as bedding/foliation, joints, fissures, folds, faults, shear zones, cavities, dykes and their influence on structural instability of the abutments and foundation.
- Extent and thickness of overburden and the type of underlying bedrock, its disposition and depth of weathering.
- Engineering and index properties of the overburden, rock and rock mass.
- Geological attributes and related features contributing to landslide and subsidence hazards.
- Possible instability due to glacial and fluvial material, overburden covered hillslopes etc, should be indicated. In case of dam abutments, structural mapping of hill slopes should be carried out to examine active or potential landslides – debris or rockfall.
- Location of dam in mountainous areas should take into account the possibility of avalanches affecting the stability of structures.
- Identification of tectonic features and active fault.
- The depth to and type of bedrock as well as the location, sequence, thickness, areal extent, attitude, depth of weathering, soundness, description and classification of rock in each rock stratum within the depth of exploration.
- The characteristics of the ground water, including whether the water table is perched or normal, direction of flow of ground water, depth of and pressure in artesian zones, and quantity of dissolved salts present in the ground water.
- Seismo-tectonic set up of the project region.
- In case of tunnels the geological investigations should be carried out to determine:
- Origin and type of rock along the alignment and study of regional geological maps of the area, if available;
- Geological section along the tunnel alignment giving rock types and their disposition; location and attitude of all structural features of rock such as faults, thrusts, joints, dips, strikes and other geological features including pattern, extent and contents of fissures; presence of water in small or large quantities and their probable pressure at tunnel grade, etc.
- Any geological feature which may affect the magnitude of rock pressure to be anticipated along the proposed alignment;
- Cover on the tunnel, position of subsurface rock and overburden contacts;
- Physical, mechanical and strength properties of rock to determine supporting arrangements and also resistance to driving tunnel through rock.

- Hydrological data and information regarding location, type and volume of water and injurious or troublesome gases contained in subsurface strata around tunnel grade.

5 Methods of Geological Investigation/Exploration

The exploration should comprise the following:

a) Surface geotechnical mapping.

b) Exploration by test pits, trenches, drifts and shafts.

c) Exploration by drilling methods.

d) Exploration by geophysical methods including seismic/resistivity surveys, ground penetrating

e) Radar(GPR) Surveys, airborne electromagnetic surveys.

f) Determination of the water table depth and evaluation of field permeability by water percolation tests.

g) Observation of temperature, pressure and discharge of springs met on the surface or in exploratory drillings, trenches, etc.

h) Standard penetration test (SPT) and field density tests in overburden.

i) Laboratory & Insitu Soil Testing

j) Laboratory & Insitu Rock Testing

KSEBL entrust Geological Survey of India for the geological exploration of all hydroelectric project. All activities including location and depth of drill holes, permeability test etc. are conducted with the recommendations / guide lines of GSI. The Executive Engineer of respective Investigation Division shall coordinate the inspections of Engineering Geology Division of Geological Survey of India. The Executive Engineer shall submit a proposal for core drilling / drifting locations duly marked in the topographical map of the scheme to the Chief Engineer (Investigation) with due recommendations of Deputy Chief Engineer (Investigation). In case the drilling / drifting locations are falls under forest area, prior approval shall be obtained from Forest department as per prevailing rules before carrying out the drilling activities.

6 Components Specific Geological Investigation Guidelines

Apart from the general guidelines as discussed above, following are the specifics of investigations to be carried out in different structures based on the IS Codes and other guidelines.

<table>
<tr><td rowspan="3">Concrete Dam
(IS 15662)</td><td>Surface Geological Mapping
The following aspects are for general guidance only.
Dam site should be geologically mapped to scale 1:1000 scale
Contour interval 1m to 5m
Mapping should extend up to 100m above the top of the dam in areas of immature topography and 25m in the area of mature topography.</td></tr>
<tr><td>Core drilling
• The drill hole should be drilled along the proposed axis of the dam at 50-100m interval or less with minimum number of three to five holes in gorge portion and additional two on each abutment parallel to the flow for establishing bed rock.
• At least two more drill holes should be done at the toe of the dam and one hole in the energy dissipation structure immediately after the spillway. Drilling shall be done for a depth of 15m into fresh rock.
• For diversion tunnels, three drill holes may be drilled with one each at the portal and the third one suitably placed along the tunnel alignment depending upon geology and topography.</td></tr>
<tr><td>Drifting
• For a dam up to 50 m height, one drift on either bank with cross cuts should be excavated at or near mid height of the dam. For a dam up to 100 m height, two drifts on either bank with cross cuts are recommended at or near 1/3rd and 2/3rd height of the dam. For a dam more than 100m high, three or more drifts on either bank with crosscuts are recommended. However, the length of the main drift and the cross cuts will depend upon the dimension of the structure (dam section across and along the flow) at that particular elevation, meaning thereby that the length of the main drift and crosscuts will be more near the base and reducing gradually towards the top of the dam. The length of the drift should be decided by the Engineering Geologist as per design requirement, which in tum depend on the height of the dam and quality of the rock mass. These drifts can be utilized for various purposes namely, in-situ testing, inspection, drainage and grouting at a later stage.</td></tr>
</table>

	Rock Mechanics Test These tests are carried out as per the direction of National Institute of Rock Mechanics (NIRM) • In-situ shear test • In-situ Modulus of deformation • Bearing Capacity (if required) • Seismic Wave Velocity
	Laboratory Tests These tests are carried out by the GSI at their labs after collecting samples from core recovery. • Unconfined compressive strength • Modulus of elasticity • Specific gravity and water absorption & other physical properties • Slake durability index • Tensile strength • Shear Parameters Minimum five samples of each rock type are to be tested for UCS, Modulus of elasticity, specific gravity & other physical properties. For tensile strength, minimum 10 samples are to be tested for each rock type. For slake durability 1 or 2 representative samples for each rock type may be used. The mapping should extend up to 100m above the top of the dam in areas of immature topography and 25 m in the area of mature topography. Geological mapping should be extended to assess instability of slopes for providing Special slope treatment. The geological/geotechnical map so prepared should bring out the following: a) Strike extension of various lithological units present in the area. b) Susceptibility to weathering of each unit. c) Structural discontinuities and their characteristics, such as joints, fractures, cleavages, slip planes, shear zones, faults, folds and their permeability characteristics. d) Slope characteristics, such as covered area, creep material, slide/subsidence/collapse features. e) Groundwater characteristics and their range of fluctuation. f) Location of springs, their temperature, discharge, etc. If the area is not easily accessible, maximum information may be collected from stream sections, approachable road sections and through approach paths.

Earth / Rock Fill Dams / Barrages and Weirs (IS 6955, IS 13578)	**Surface Geological Mapping** The sites of dam and its appurtenant structures should be geologically mapped on 1:1000 scale with contour interval of 1m to 5m. Extent of geological mapping should cover an area equal to twice the height of the dam both towards the upstream and the downstream. The mapping should extend up to two times the height of dam or 100m whichever is less from the top of the dam in areas of immature topography and one time the height of dam or 25m whichever is less in the area of mature topography. Geological mapping should be extended to assess instability of slopes for providing special slope treatment. The geological / geotechnical map so prepared should bring out the following: a) Strike extension of various lithological units present in the area. b) Susceptibility to weathering of each unit. c) Structural discontinuities and their characteristics, such as joints, fractures, cleavages, slip planes, shear zones, faults, folds and their permeability characteristics. d) Slope characteristics, such as covered area, creep material, slide/subsidence/collapse features. e) Groundwater characteristics and their range of fluctuation. f) Location of springs, their temperature, discharge, etc. If the area is not easily accessible, maximum information may be collected from stream sections, approachable road sections and through approach paths.
	Choice of Methods For dams up to 30m height exploration by trial pits, trenches and drill holes are sufficient. Some field test on permeability and penetration resistance would also be necessary. For dams up to 100m, in addition drifts and shafts may be required depending on geological complexity of site. Spacing of Test pit or drill holes For dams less than 30 m in height, exploration by pits at a spacing of 250 m to 300 m depending upon the nature of the foundation material may be necessary. For dams over 30 m in height, the spacing between drill holes may be decided so as to have minimum 5 numbers of drill holes with particular attention being given for adequate coverage to deeper sections. In between drill hole locations, trial pits or auger holes would be sufficient. **Location** Exploratory holes, pits and augur holes may be located along the axis of dam for dams up to 100m height. For dams greater than 100m however, additional line of holes may be necessary depending on geological conditions.

	Depth of Exploration In general, the depth up to which explorations should be made depends upon the following factors: • Depth of overburden and depth up to which weathering of bed rock has progressed. Exploration should be carried to a depth to locate all weak and compressible or otherwise undesirable layers in the foundation, such as buried channels. • The depth would be generally guided by the permeability characteristics of the strata. It may be sufficient to explore up to a depth of 1/ 3 or 1/2 of the hydraulic head at the location of the dam if rock is found at shallow depths or less than 1/3 to 1/ 2 of the hydraulic head. If the depth to rock is larger than 1/3 or 1/2 of the hydraulic head, one or two drill holes may be taken down to 10m into the in-situ rock. Further, while carrying out detailed explorations for DPR: • For dams less than 30 m in height. one additional line of holes (in addition to those indicated earlier) as per design considerations may be necessary. The holes should be suitably staggered to provide information at 30 m intervals. The depth of 1/3 of these holes may be kept equal to the hydraulic head of the dam. • For dams 30 m to 100 m in height. two additional rows of holes would be required. The spacing between drill holes may be 1/10th of the length of the portion with particular attention being given for adequate coverage to deeper sections. Half the number of holes should be taken to depths equal to the hydraulic head and the remaining to half the hydraulic head or to a depth to prove a continuous impervious soil or rock or such strata that can be rendered impervious by treatment. The depths to which exploration should be continued in the impervious medium or medium that can be rendered impervious by treatment should be decided on the basis of design considerations. • For dams above 100 m in height, three lines of holes should be drilled at locations as per design considerations. The depth of these holes should be equal to the hydraulic head. In addition, trenches to explore the foundation sequence in the river bed section and for collection of undisturbed samples may be required. • The grout ability of foundation through trial grouting of the specific section in a set pattern, should also be tested during detailed exploration.
	Drifting • For a dam up to 50 m height, one drift on either bank with cross cuts should be excavated at or near mid height of the dam. For a dam up to 100 m height, two drifts on either bank

	with cross cuts are recommended at or near 1/3rd and 2/3rd height of the dam. For a dam more than 100m high, three or more drifts on either bank with crosscuts are recommended. However, the length of the main drift and the cross cuts will depend upon the dimension of the structure (dam section across and along the flow) at that particular elevation, meaning thereby that the length of the main drift and crosscuts will be more near the base and reducing gradually towards the top of the dam. The length of the drift should be decided by the Engineering Geologist as per design requirement, which in tum depend on the height of the dam and quality of the rock mass. These drifts can be utilized for various purposes namely, in-situ testing, inspection, drainage and grouting at a later stage.
	Soil Mechanics Testing (In-situ) • Strength tests -Deep Penetration Tests (Static & Dynamic Penetration Tests) • Shear tests (Vane Shear Test, Large Shear Test) • Measurement of density of foundation material, • Permeability tests, and • Blasting tests (Blasting test is often performed in foundations of saturated loose non-cohesive soils mainly for assessment of the likely chances of liquefaction and settlement in the event of earthquake, and also as prototype test for studying the efficacy of blasting as means of compaction of non-cohesive soils, where compaction is considered necessary or desirable) **Laboratory Soil Tests** The various tests that are usually necessary are given: • **Visual and Manual Examination** This would give general description of the soil or rock in terms of colour, consistency, structure • **Natural Moisture Content** It helps in assessment of foundation pore pressures [see IS 2720 (Part 2). • **Liquid and Plastic Limits** Liquid and plastic limits are semi quantitative measures of water absorption qualities of clay. They give an indication of the cohesiveness of the soils, and are also useful in soil classification. [see IS 2720 (Part 5)]. • **Specific Gravity** Specific gravity indicates a basic characteristic of the soil and is useful in calculating several of the soil parameters.

- **Particle Size Distribution**

  Knowledge of particle size distribution is of use for soil classification in understanding the foundation features, such as density, permeability and susceptibility to liquefaction [see IS 2720 (Part 4)]. Material must be well graded for dam construction and have a grain size distribution depending upon rock strength and tendency to breakage.

- **Bulk Density**

  Knowledge of bulk density is essential for computing stability.

- **Permeability**

  Knowledge of permeability of different foundation strata is essential for estimating general seepage loss, piping danger and grouting requirements. It is also essential for the design of under seepage control measures. Ratio of horizontal to vertical permeability can indicate the degree of homogeneity and isotropy of the granular foundation material.

- **Consolidation Characteristics**

  These are required for estimating the magnitude and rate of settlement due to consolidation of soil and for assessment of pore pressure development during construction.

- **Swelling Tests**

  Swelling tests are useful for clays particularly those of montmorillonite family to assess likely pressures the clay would exert on saturation. These tests should be conducted at the lowest moisture content that may be obtained in the field.

- **Strength Characteristics**

  Strength characteristics of soil may be determined by unconfined compression test [see IS 2720 (Part 10)], direct shear test [see IS 2720 (Part 13)] and triaxial shear test. Unconfined compression test is generally suitable for rock samples for determination of foundation strength. Strength characteristics of undisturbed soil samples from foundations are usually determined by triaxial shear test or direct shear test.

- **Compaction Test**
- **Density Index (Relative Density)**

  For cohesionless soil to assess the degree of compaction of the soil in-situ [see IS 2720 (Part 14)].

- **Mineralogical Composition:**

  By differential and X-ray diffraction studies. May be required for expansive soils combined with low height dams.

	• **Chemical Analysis:** Chemical tests may be performed on one or two typical soil samples to determine soluble salt content [IS 2720 (Part 21)], calcium carbonate content [IS 2720 (Part 23)] and organic matter content [see IS 2720 (Part 22)]. • **Dispersive Test:** Presence of dispersive clays leads to disperse or flocculation in the presence of water which becomes turbid as dispersion progresses. Soil classes have to be evolved on this and necessary precautions undertaken for use of the same material. **Tests for Rock** • **Petrographic Study:** Petrographic study of the rock done by helps to evaluate the stability of the constituent minerals under conditions of prolonged saturation of the foundation material (IS 1123). These may be required in special cases. • **Shear Strength Tests:** Shear strength tests may be required in the case of weak and layered rock foundations. • **Specific Gravity and Porosity:** This would indicate the state of denseness of the rock (IS 1122). • **Water Absorption:** This test determines the capacity of rock for absorbing water (IS 1124). • **Chemical Analysis:** Chemical tests may be performed on one or two typical rock samples to determine soluble salt content, calcium carbonate content and organic matter content.
Water Conductor System including HRT, Intake and Desilting Chamber (IS 17833)	**Surface Geological Mapping**: • Tunnel /Channel area to be mapped on 1: 2000 to 1:10000 scale at 5m contour interval. For short lengths of tunnel/channel mapping at 1:1000 and 1: 2000 scale may be carried out. • Adit portals to be mapped on 1: 500 scale at 1m interval. • Critical areas in open channel to be mapped on 1:1000 scale at 1 m contour interval. • Geological section along major nallas crossing the HRT. If the area is not easily accessible, maximum information may be collected from stream sections, approachable road sections and through approach paths. Important features like orientation of tunnel with respect to regional strike and weak zones of rock formation, maximum and

	minimum cover over tunnel alignment, joint sets, low and high cover zones, weak/shear/fault zones etc. are to be picked up. In case tunnel is situated within a folded sequence or other discontinuity plane like thrust or fault, lineament then orientation of tunnel w.r.t structural features is to be seen. Presence of hot water springs, karstic zones also need to be picked up during geological Mapping.
	Core drilling • Minimum one drill hole at Intake. • Exploratory drill holes at tunnel alignment at low cover zones, major nalla crossings, lithological contacts, tectonic contacts and where major shear/thrusts are anticipated based on geological mapping. These drill holes should be drilled up to the tunnel grade. • At least one hole at Adit portals where rock is not exposed
	Drifting • One drift in intake area. • One drift in Desilting Chamber either by extending the drift at Intake or a separate drift covering preferably the entire length of Desilting Chamber or at least half of it. • Exploratory drill holes at tunnel alignment at low cover zones, major nalla crossings, lithological contacts, tectonic contacts and where major shear/thrusts are anticipated based on geological mapping. • 30-50m long drifts at Adit portal
	Rock Mechanics Test • Insitu Stress Measurements in Desilting Chamber. • Insitu Deformability Tests in Desilting Chamber. • Minimum five samples of each rock type encountered in HRT, Desilting Chamber and Adits are to be tested in Lab for UCS, Young's Modulus & Poisson's Ratio, Tensile Strength, Cohesion & Friction Angle and Physical Properties
Surge Shaft and Pressure Shaft	**Surface Geological Mapping:** Geological mapping on 1:500 to 1:1000 scale at 1m contour interval. If the area is not easily accessible, maximum information may be collected from stream sections, approachable road sections and through approach paths. Important features like orientation of structure with respect to regional strike and weak zones of rock formation, maximum and minimum cover over structure, joint sets, low and high cover zones, weak/shear/fault zones etc. are to be picked up. In case structure is situated within a folded sequence or other discontinuity plane like thrust or fault, lineament then orientation of structure w.r.t structural features is to be seen. Presence of hot

	water springs, karstic zones also need to be picked up during geological Mapping.
	Core drilling: • One drill hole down to the full depth of proposed surge shaft. • One additional drill hole for surge shaft cut slope if it involves high open cut. • 2-3 drill holes along pressure shaft alignment extending up to the tunnel grade in case of inclined pressure shafts.
	Drifting • Exploratory drift extending up to the bottom of surge shaft in case of open to sky surge shaft or to the top of underground surge shaft.
	Rock Mechanics Test Minimum five samples of each rock type are to be tested in Lab for UCS, Young's Modulus & Poisson's Ratio, Tensile Strength, Cohesion & Friction Angle and Physical Properties
Surface Powerhouse IS 10060	**Surface Geological Mapping:** Geological mapping on 1:1000 scale at 1-2m contour interval.
	Subsurface exploration • Minimum two drill holes along length of powerhouse. • Drill holes if required on the hill side involving high cut slope. • Exploration by test pits/trenches in case of shallow overburden. • Ascertaining the groutability of foundation through trial grouting if required.
	Drifting One drift for assessing rock mass of powerhouse back slope, if required.
	Rock/Soil Mechanics Testing **Lab Tests:** UCS and Shear parameters, Young's Modulus and Poisson's Ratio in case of rock. Lab tests on representative samples and undisturbed soil samples for determining engineering properties of overburden material. Tests such as Gradation analysis, Atterberg Limits, Relative density, Odeometer tests, Young's Modulus, Poisson's ratio, Void ratio, Proctor compaction etc. may be conducted.
	In-situ Tests: Plate load or plate bearing test, Shear strength Parameters (c, Ø), SPT/CPT in boreholes in case the powerhouse is to be founded on overburden.

Underground Powerhouse IS 10060	**Surface Geological Mapping**: Geological mapping on 1:1000 to 1:2000 scale at 1-2m contour interval. If the area is not easily accessible, maximum information may be collected from stream sections, approachable road sections and through approach paths. Important features like orientation of structure with respect to regional strike and weak zones of rock formation, maximum and minimum cover over structure, joint sets, low and high cover zones, weak/shear/fault zones etc. are to be picked up. In case structure is situated within a folded sequence or other discontinuity plane like thrust or fault, lineament then orientation of structure w.r.t structural features is to be seen. Presence of hot water springs, karstic zones also need to be picked up during geological Mapping.
	Exploratory Drilling Exploratory drill holes one or two as per requirement may be taken up from surface extending to PH level
	Exploratory Drifting: One exploratory drift along the entire length of proposed PH Cavern having at least three crosscuts on either side of the powerhouse axis and extending up to the powerhouse walls. Drift may preferably be kept at haunch level of the roof arch.
	Rock Mechanics Testing: **Lab Tests**: Uniaxial Compressive Strength, Traixial Shear Parameters, Young's Modulus, Poisson's Ratio and physical properties. **In-situ Tests**: Deformability Test, Direct Shear Test for R/R interface, Insitu Stress Measurements by hydrofracturing/ overcoring method.
Tail Race Tunnel/ Channel (IS 17883)	**Surface Geological Mapping:** Tunnel length/ Channel area to be mapped 1:1000 to 1:5000 scale at 1-5m contour interval depending on length. Portals to be mapped on 1:500 scale at 1m contour interval for 50m on either side of the centreline of proposed portal. If the area is not easily accessible, maximum information may be collected from stream sections, approachable road sections and through approach paths. Important features like orientation of structure with respect to regional strike and weak zones of rock formation, maximum and minimum cover over structure, joint sets, low and high cover zones, weak/shear/fault zones etc. are to be picked up. In case structure is situated within a folded sequence or other

	discontinuity plane like thrust or fault, lineament then orientation of structure w.r.t structural features is to be seen. Presence of hot water springs, karstic zones also need to be picked up during geological mapping.
	Exploratory Drilling Exploratory drill holes at tunnel alignment at low cover zones, major nalla crossings, lithological contacts, tectonic contacts and where major shear/thrusts are anticipated based on geological mapping. These drill holes should be drilled up to the tunnel grade. For short TRT (upto 1km) provision of 1-2 drill holes and for longer TRT’s 3-4 drill holes. One drill hole at adit /outlet portal in case the bedrock is not exposed in the area.
	Exploratory Drifting: About 30-50m drifts in outlet portal and at adit /portals in case the bedrock is not exposed.
	Rock Mechanics Test Minimum five samples of each rock type to be encountered in TRT, to be tested in Lab for UCS, Young’s Modulus & Poisson’s Ratio, Tensile Strength, Cohesion & Friction Angle and Physical Properties

7 General Guidelines for Core drilling

a) Drill holes should generally be of Nx size and double tube core barrels should be used. In weak, fractured rock and shear zones, triple tube core barrels should be used. Where rock is soluble in nature face discharge drill bits should be used so that rock does not come in contact with drilling water.

b) Holes should be drilled at least up to 15m in fresh bedrock and up to 20m in bedrock where the area comprises of big boulders.

c) Core recovery of more than 90% should be ensured, except in case of overburden. Rock cores should be generally free from mechanical breakage and stored with proper markings in standard core boxes as per IS 4078.

d) Colour photographs of all the cores properly stacked in core boxes with separation pieces indicating the depth in natural light along with core box indicating name of project, drill hole no. and core box no. should be taken and appended with geological log of the drill hole to be prepared in the format given in IS 4464.

e) Drilling data is to be recorded in drillers log sheet as per IS 5313.

f) Permeability/water pressure testing in all is to be carried out both in overburden and bedrock preferably in descending order as per IS 5529 (Part- 1& 2) with daily water table measurement prior to start of drilling as per procedures detailed in IS 6955. Water pressure test should always be done with clean water.

g) For water pressure testing a centrifugal pump of minimum capacity 500L/min capable of producing pressure up to the maximum pressure suggested in the work schedule.

h) Generally double packer water pressure test is carried out in drill holes with 2kg/cm², 4kg/cm², 6kg/cm² both ascending and descending order. The pressure range may varies as per the recommendations in preliminary stage geological inspection by GSI team.

i) Core drilling geological information should be supplemented with information of bore hole cameras and geophysical logging.

j) All the cores are to be protected and properly stored and kept in a core library. This core library should be used exclusively only for storing drill cores.

8 General Guidelines for Exploratory Drifting

a) Standard size of exploratory drift is 1.5 m(W)x2.2m(H). Length varies depending on the requirement.

b) 3D Geological logging of the drift in standard format on 1: 100 or 1: 50 scale.

c) Portions of the drifts which are enlarged for carrying out Insitu Testing should also be properly logged.

d) The drift prior to logging should be properly cleaned with high pressure water jet so that the rock surface and joints are clearly visible. The responsibility of drift cleaning should rest with the contractor who is excavating the drift.

e) 3D Geological log should also contain lithological and structural details along with other characteristics essential for rock mass classification.

9 Guidelines for Geophysical Investigations of Hydroelectric Projects

In order to accelerate the subsurface investigation program, keeping in view the restricted time-frame and finance, indirect techniques of Geophysics plays a vital role. Geophysical methods are rapid and economic indirect exploration techniques for determining in-situ physical properties of subsurface materials and locating underground geological features. While direct exploration provides detail information of the underground at specific location, the indirect techniques of geophysics furnish information over larger area, generating continuous profile of the subsurface and reducing thereby the risk of overlooking critical zones.

Few drill holes or other direct subsurface explorations are needed for calibration of the geophysical data towards obtaining good results. Geophysical techniques are of great value when performed early in the field exploration program in combination with limited direct and semi-direct explorations. These studies are to be carried out on the requirements as recommended by the geologists/designers. The prime engineering geophysical techniques utilized for investigation of engineering projects are detailed hereunder:

Geophysical techniques shall be used for all major projects and Pumped Storage projects of capacity 25MW and above. This exploration shall be carried out after the preliminary exploratory drilling work. The choice of geophysical explorations in SHP development is as per the discretion of the Engineer-in-charge or specific recommendation by GSI Team.

9.1 Seismic Refraction Technique

Seismic Refraction Technique is widely applied geophysical technique and is utilized for determination of subsurface information in terms of seismic compressional wave velocity. This technique is applied for delineation of overburden stratification, estimation of depth-to-bedrock & its disposition, delineation of zones of weaknesses, demarcation of buried channel as well as in assessment of rock mass quality/condition (IS15681,2006).

Since seismic wave velocity is controlled by the fundamental parameters of elastic strength and density, it serves as an index of rock mass quality. In association with shear wave velocity, it facilitates computation of dynamic elastic parameters of the soil/rock. It has also applicability in profiling across river channels under calm flow conditions.

9.2 Resistivity Imaging

Resistance is a basic physical property of any earth material and resistivity methods utilizes this fundamental property to scan the subsurface in terms of resistivity of the medium. Resistivity technique measures variations in the electrical resistivity of the ground, by applying electric currents across arrays of ground electrodes. Initially, this method was able to provide point information below the surface in one-dimension only and had very limited application in field investigations. With the advancement of technology, development of resistivity surveying techniques has been very rapid in the last few decades and has tremendously increased the practical applicability to utilize this technique for producing the image of the subsurface in terms of resistivity values of the material under investigation in two-dimensional/three-dimension space (IS15736-2007,2012).

Data is processed using advanced software based on finite element or finite difference methods. This technique is very helpful in detecting shear zones/cavities where the conventional seismic refraction technique has limitations.

Moreover, it is to submit that investigation of HRT in general is carried out through geological mapping based on the available outcrops and sometimes limited drilling along the tunnel stretch. Resistivity Imaging can be effectively utilized to scan the entire length of HRT and other underground works for better understanding of rock mass characterization. Further, even if the penetration through this technique up to the requisite structure level is not achieved, still it can provide insight of the probable weak zones which may have extension up to the structures which are not visible on surface and may pose problem during construction.

9.3 Seismic Tomography:

Seismic tomography has been studied and developed extensively to improve abilities to map the mother Earth. Its original idea came from the well-known CAT scan utilized in medical science. The word tomography is derived from the Greek tomos meaning cut or slice and it literally means "graphing slices of an object". As a geophysical method, the goal of tomography is to obtain the precise two/three dimensional image of the subsurface in terms of seismic velocities. In practical application, the seismic waves are initiated at one end of the medium under investigation utilizing especially designed source & received at other end by highly sensitive receivers and further recorded through engineering seismograph. This recording is carried out for various source receiver combinations for achieving high grade scan of the media.

This tool can be utilized to scan the rockmass characterization to delineate geological structures, map cavities, weak zones and for evaluating engineering parameters of rockmass. As a general practice during investigation stage, dam area is explored with 2 to 3 drill holes, surface and drift logging. In this mode of investigation, zone in between the drillholes remain unexplored and sometimes causes problem during construction. Such lacuna in investigation can be handled with effective utilization of Seismic Tomography to scan the complete dam seat area with optimized drilling of holes.

Grouting is carried out in initial stage of dam construction within a rockmass with the intent of filling rock mass discontinuities for consolidation to control water leakage in dam constructions. Successful implementation of a consolidation grouting program can be very well checked by carrying out seismic tomography in primary holes. This practice is now followed internationally for checking the efficacy of grouting and optimization of drilling.

Further, this study can help us to target those areas in dam seat where secondary grouting is required and drilling secondary/tertiary holes can accordingly be reduced.

9.4 MASW Technique:

The Multichannel Analysis of Surface Waves (MASW) technique is a surface wave measurement study for determination of subsurface information in terms of seismic shear wave velocity. The field layout for MASW data acquisition comprises a mechanical source (hammer/weigh drop) for generating the seismic wave and a linear array of receivers (4Hz/10Hz vertical geophones) at short inter-spacing connected to a multi-channel seismograph recorder. In data acquisition, the source off-set is set according to the depth of probing while the receiver spacing is decided on the basis of the resolution desired. The data processing involves transformation of the raw data from time domain to frequency domain by Fourier analysis. The 'Energy accumulation pattern recognition technique' is employed to extract the fundamental mode Rayleigh wave for generating the dispersion curve. Finally, the extracted dispersion curve is used as a reference to back calculate Vs variations with depth through least square iterative inversion process. The result of MASW study is presented either in the form of 1-D or 2-D image for visualizing the detailed status of the underground.

The technique has prime application in estimation of Vs(30) for site specific seismic design parameters, delineation of subsurface stratification in high resolution 1-D & 2-D forms and also in evaluation of Shear Wave velocity based liquefaction potential assessment. During DPR stage of the project development, detailed geophysical investigation is carried out for finalization of the sites and designing of diversion, powerhouse and other appurtenant structures of the projects for TEC and other routine obligatory clearances. Therefore, in this stage the preferable alternative selected during the project feasibility study needs thoroughly investigated for generating a bankable DPR. Besides optimizing the drilling program, the purpose of geophysical survey at this stage would be towards detailed study of the subsurface condition so as to minimize the grey areas and enhance the level of confidence in project development. Accordingly, during this stage, it would be appropriate to carry out a detailed seismic refraction profiling and resistivity imaging at the requisite sites. The state-of-the-art MASW study need be undertaken at this stage for determination of Vs(30) towards site specific seismic design parameters as well as in high resolution shear wave velocity scanning. As per the site requirement, the technique can be advantageously utilized for evaluation of liquefaction potential assessment. Other techniques, specific to the problems, which are utilized during this stage, include seismic tomography for scanning adverse underground features and critical zones.

10 Components Specific Geophysical Investigation Guidelines

Component	Geophysical Studies Required
Dam / Barrage	**Seismic Refraction Profiling:** The planning of profile layout should be done keeping in view the ground condition and expected subsurface status. Generally, profile length is kept 115m under medium bedrock depth (<25m) and profile length is 230m under deeper bedrock conditions (25-75m). The Geophone spacing should be 5-10m based on the required resolution. Number of profiles in dam area is site specific. Hydrophones can also be used across the river channel for determining overburden thickness and estimating bedrock disposition. **Seismic Tomography:** Seismic tomography study should be carried out across the river channel for scanning the subsurface towards delineating the rock mass character. The application should be based on the river channel width and abutment conditions. The holes utilized for seismic tomography should be PVC cased. As per site requirements, the number of holes can be utilized for the purpose for generating 2-D/3-D seismic tomograms. Non-destructive mechanical/sparker source should generally be used in the boreholes for effective utility. **Resistivity Imaging:** Resistivity imaging may be planned and conducted under specific circumstances in order to access the subsurface conditions. The inter-electrode spacing and number of electrodes should be chosen keeping in view the required resolution and depth of penetration. **MASW Test:** The test is required for delineation of in-situ shear wave velocity in 1-D and 2-D forms. This provides weighted average of shear wave velocity down to 30m depth Vs(30) for site specific seismic design parameters, in delineation of low velocity layers in subsurface and it is useful in assessment of liquefaction potential assessment. **Ultrasonic Pulse Method:** In case of specific requirement, ultrasonic pulse test may be carried out on rock core samples for determining dynamic elastic parameters utilizing P & S wave pulse technique. In-situ test can possibly be conducted under the circumstance when the rock exposure is adequately smooth to allow proper propagation of ultrasonic pulse.

Component	Geophysical Studies Required
Coffer Dam	**Seismic Refraction Profiling:** The planning of the profile layout should be done keeping in view the ground conditions as the application is site specific. **Resistivity Imaging:** Resistivity imaging may be planned and conducted under specific circumstances in order to access the subsurface conditions. The inter-electrode spacing and number of electrodes should be chosen keeping in view the required resolution and depth of penetration.
Intake / Diversion Channel / Tunnel & Related Structures	**Seismic Refraction Profiling:** The technique can be planned and utilized in the proposed intake / adit portal sites for determining the overburden thickness and bedrock disposition under congenial site conditions. **Resistivity Imaging:** Resistivity imaging may be planned and conducted under specific circumstances in order to access the subsurface conditions in near the intake channel/tunnel/portal areas. The inter-electrode spacing and number of electrodes should be choosen keeping in view the required resolution and depth of penetration. **Seismic Tomography:** Seismic tomography study may be carried out as per specific requirements at intake area and other adits /portals towards delineating weak zones and the rock mass character. The holes utilized for seismic tomography should be PVC cased. As per site requirements, the number of holes can be utilized for the purpose for generating 2-D/3-D seismic tomograms. Non-destructive mechanical/sparker source should generally be used in the boreholes for effective utility. **MASW Test:** The test is required for delineation of in-situ shear wave velocity in 1-D and 2-D forms. It may be used for high resolution subsurface scanning of shear wave velocity for the area.
Water Conductor System	**Seismic Refraction Profiling:** Seismic Refraction Profiling may be carried out for determining the overburden conditions and bedrock depth. The application is site specific. **Resistivity Imaging:** Resistivity Imaging can be effectively utilized to scan the entire length of HRT and other underground works for better understanding of rock mass characterization. Further, even if the penetration through this technique up to the requisite structure level is not achieved, still it can provide insight of the probable

Component	Geophysical Studies Required
	weak zones which may have extension up to the structures which are not visible on surface and may pose problem during construction of underground structures.
Surge Shaft / Pressure Shaft Areas	**Seismic Refraction Profiling:** Seismic Refraction Profiling may be carried out for determining the overburden conditions and bedrock depth. The application is site specific. **Seismic Tomography:** Under specific circumstances, the Seismic tomography study may be carried out for scanning the subsurface towards delineating the rock mass character. The holes utilized for seismic tomography should be PVC cased. As per site requirements, the number of holes can be utilized for the purpose for generating 2-D/3-D seismic tomograms. Non-destructive mechanical/sparker source should generally be used in the boreholes for effective utility **Resistivity Imaging:** Resistivity Imaging can be effectively utilized to scan the surge shaft/pressure shaft and other underground works for better understanding of rock mass characterization. Further, even if the penetration through this technique up to the requisite structure level is not achieved, still it can provide insight of the probable weak zones which may have extension up to the structures which are not visible on surface and may pose problem during construction of underground structures.
Power House & Switch Yard Area	**Seismic Refraction Profiling:** Seismic Refraction Profiling should be carried out for determining the overburden thickness and bedrock disposition, including rock quality evaluation, under congenial circumstances. The planning of the profile layout should be done keeping in view the ground condition and expected subsurface status. **Seismic Tomography:** Seismic tomography study should be carried out scanning the subsurface towards delineating the rock mass character. The holes utilized for seismic tomography should be PVC cased. As per underground powerhouse site requirements, the number of holes can be utilized for the purpose for generating 2-D/3-D seismic tomograms. Non-destructive mechanical/sparker source should generally be used in the boreholes for effective utility. **Resistivity Imaging:** Resistivity imaging should be planned and conducted in the proposed powerhouse, machine halls and switchyard areas

Component	Geophysical Studies Required
	keeping in view the prevailing ground conditions. The technique should be utilized for optimization of earth mat design of various electrical structures to be installed in Powerhouse, Machine Hall and Switchyard areas. **MASW Test:** The test is required for delineation of in-situ shear wave velocity in 1-D and 2-D forms. This provides weighted average of shear wave velocity down to 30m depth Vs(30) for site specific seismic design parameters, in delineation of low velocity layers in subsurface and it is useful in assessment of liquefaction potential assessment (in case of surface powerhouse). **Ultrasonic Pulse Method:** In case of specific requirement, ultrasonic pulse test may be carried out on rock core samples for determining dynamic elastic parameters utilizing P & S wave pulse technique. In-situ test can possibly be conducted under the circumstance when the rock exposure is adequately smooth to allow propagation of ultrasonic pulse.
Reservoir Area	**Seismic Refraction Profiling:** The technique can be planned and utilized in the proposed dyke site for determining the overburden thickness and bedrock disposition under congenial site conditions. **Resistivity Imaging:** Resistivity imaging may be planned and conducted under specific circumstances in order to access the subsurface conditions in reservoir rim area. The inter-electrode spacing and number of electrodes should be chosen keeping in view the required resolution and depth of penetration.
Other Applications	**Seismic Refraction Profiling:** Seismic Refraction Profiling may be carried out in terrace/shoal areas for broad quantification of construction material. The seismic profiles should be planned according to site conditions and study requirements. **Resistivity Imaging:** Under specific requirement, resistivity sounding and imaging survey may be undertaken for groundwater prospecting and designing earth mat. The resistivity survey should be planned according to site conditions and study requirement. **Vibration Monitoring Studies:** Under specific requirement, vibration monitoring studies can be undertaken at specific site for establishing controlled blasting criteria for safety of different structures at the time of excavation of different project components.

11 Guidelines for Exploration of Seismic Aspects of Hydroelectric Projects

The site specific seismic study for a river valley project requires an understanding of the seismic scenario with regard to dam site, which includes geological setting of the area, tectonic features and the history of earthquake occurrence in the region. The study enables evaluation of design ground motion based on identifiable seismic source zones and appropriate ground motion attenuation laws.

The site specific seismic studies need to be carried out and submitted for the approval of the National Committee of Seismic Design Parameters (NCSDP) of India in respect of all such river valley project/dams that are classified under 'high' or 'extreme' hazard potential categories. However, the uniform hazard potential categorization criteria for dams in India are yet to be formulated and approved by the 'National Committee on Dam Safety'. Till such time the hazard categorization criteria is not in place, it will be mandatory, for the large dams that fall in seismic zone III, IV or V to get the approval of NCSDP for site specific seismic studies for the assessment of design earthquake parameters. However, for the projects in seismic zone II, the approval of NCSDP for the site specific seismic studies will be mandatory for such dams that are more than 30 meters in height.

The site specific studies for determination of design earthquake parameters shall have to be carried out by Deterministic as well as Probabilistic approach. However, where the available data on past seismicity is scanty, and even the data on tectonic features and geological processes are inadequate to have any meaningful application of probabilistic analysis, the deterministic analysis only shall be carried out by recording the proper justification for not adopting the probabilistic approach for analysis. The details required for preparation of site specific seismic design parameter report are:

A seismotectonic map of 1:1000,000 or comparable scale, depicting geology, structures (with emphasis on nature and extent of major faults, shear zones etc) and seismicity for an area about 300 km radius from dam site should be used (i.e., about 60 latitude x 60 longitude with the dam site at the centre). Location and description of faults and shear zones and assessment of the capability of faults to generate earthquakes should be furnished. This should include documentation on the existence of or the lack of historical or pre-historical activity (paleoseismicity) for each major fault.

At least one regional seismotectonic section through the dam and across the major tectonic trend (based on para above under Seismotectonic map) of the region should be prepared. The section covering a minimum 50 km reach on either side of the dam should clearly show (if necessary, by vertical exaggeration) the subsurface disposition of the major faults and earthquake hypocenters.

11.1 Seismic History

The earthquake catalogue should contain information about origin time (date/ time), location (latitude/ longitude/ depth), and size (magnitude / type of magnitude /

intensity) of earthquake from the historical time to present time for an area of about 300 km radius from dam site. This data may be obtained from IMD and updated on the basis of other authentic sources. To the extent possible, information on focal mechanism, felt area, accompanying surface effects, known or estimated intensity of ground motion induced at the dam site, and the source of data and its reliability, should also be presented for all major events.

For dams exceeding the height of 100 m, the details of micro earthquake data recordings around the dam site within a radius of 50 km should be provided incorporating full catalogue information for a period of at least six months. Such data should be observed /collected by the project authorities. 3.3 Local Geologic Setting

For dams higher than 200m and located in seismic zone IV or V (as per IS 1893 Part 1 (2002) a geological map (based on photo-geology/imagery studies and ground mapping) on 1:50,000 to 1:60,000 scales should be prepared for an area of 50 km radius from the dam site with special emphasis on gross lithological (or stratigraphical/tectono-stratigraphic) domains, structural details like faults, folds, shear zones, master joints, structural trend lines and lineaments etc. Geomorphic and/or evidence from Quaternary Geology (if any) within the influence area indicating presence of active fault should be documented. Geological evidences wherever available on the nature of movement along the fault vis-à-vis the age of such movement should be indicated. A short descriptive account on the various litho-stratigraphic units and structural elements should be included.

Apart from geological, seismotectonic details and historic earthquake catalogue, the details should include a section/chapter giving the following information for submission to NCSDP for clearance:

- Comparison of target response spectra obtained from Deterministic as well as Probabilistic approach for MCE and DBE conditions along with final target response spectra selected with justification.
- Compatible acceleration time histories for MCE & DBE target response spectra
- Computed response spectra for different damping values i.e., 2%, 3%,5%,10% and 15% at least.
- Site specific horizontal and vertical Seismic coefficients.

The project authorities will make a PowerPoint presentation of the study report before NCSDP, and answer to the queries of the members of the Committee. The presentation should cover:

(i) details of the project;
(ii) regional geological & seismotectonic setting;
(iii) seismic history;
(iv) local geological setting;
(v) study methodology and deviation, if any, from the recommended approach;
(vi) evaluated parameters of the site specific seismic study; and
(vii) recommendations on design approach.

12 Checklist for Geological Inputs in DPR

12.1 Reservoir

- ✓ Geological study based on existing regional geological maps and Remote Sensing data.
- ✓ Reservoir competency study

12.2 Dam Complex

- ✓ Geological mapping of dam/barrage area
- ✓ Sub surface explorations through drill holes
- ✓ Sub surface explorations through drift
- ✓ Sub surface explorations through geophysical survey
- ✓ In-situ tests
- ✓ Laboratory tests
- ✓ Analysis of Geological Structural Data

12.3 River Diversion Arrangement

- ✓ Geological mapping along both cofferdam axes and diversion tunnel
- ✓ Explorations through bore holes
- ✓ Sub surface explorations through geophysical survey
- ✓ Analysis of Geological Structural Data

12.4 Intake and Desilting Chambers

- ✓ Geological mapping of Intake (s)
- ✓ Geological mapping of Desilting Chamber (s)
- ✓ Geological mapping of adits, Silt Flushing Tunnel
- ✓ Sub surface explorations through drill holes
- ✓ Sub surface explorations through drift
- ✓ Sub surface explorations through geophysical survey
- ✓ Insitu tests
- ✓ Laboratory tests

12.5 Head Race Tunnel

- ✓ Geological mapping of HRT
- ✓ Geological mapping of construction adits
- ✓ Sub surface explorations through drill holes
- ✓ Sub surface explorations through drift
- ✓ Sub surface explorations through geophysical survey
- ✓ In-situ tests
- ✓ Laboratory tests
- ✓ Analysis of Geological Structural Data

12.6 Powerhouse Complex

- ✓ Geological mapping of surge shaft
- ✓ Geological mapping of pressure shaft / penstock alignment
- ✓ Geological mapping of power house
- ✓ Geological mapping of construction adits, MAT, Cable Tunnel, etc
- ✓ Sub surface explorations through drill holes
- ✓ Sub surface explorations through drift
- ✓ Sub surface explorations through geophysical survey
- ✓ In-situ tests
- ✓ Laboratory tests
- ✓ Analysis of Geological Structural Data

12.7 Construction Material

- ✓ Geological maps of quarry areas

13 Maps to be incorporated in the geological volume of DPR:

1. A river basin map showing locations of existing and all identified hydro projects immediately upstream and downstream of the present proposed project.
2. Catchment area map.
3. Regional Geological and Seismotectonic map.
4. Project layout plan showing all alternative layouts including the finally selected layout.
5. Lineament and Geomorphological Map.
6. A geological map containing entire layout of proposed project
7. Diversion Structure Complex
    - Geological map of dam/barrage area, coffer dams, river diversion structure and
    - intake portals with location of explorations proposed and carried out.
    - Geological sections across the river at dam axis, dam toe, bucket and plunge pool
    - area incorporating subsurface exploration data.
    - Geological sections across u/s cofferdam, dam/diversion structure and d/s cofferdam
    - incorporating subsurface exploration data.
    - Geological sections across dam axis along left abutment and right abutment.
    - 3D geological logs of drifts and geological logs of boreholes.
    - Geological section across the river, along dam axis, showing discontinuities and
    - slope of dam abutments.
8. River Diversion Arrangement
    - Geological plan and sections along both cofferdam axes with locations of explorations carried out.
    - Geological plan and section along diversion tunnel (if more than one DT, then sections of all DTs).
9. Stereographic projections of structural data showing angle of internal friction, orientation of the project components to determine vulnerable wedges and planes likely to develop for both the banks along dam axis, tunnels and adits.
10. Water Conducting System
    - Geological plan and sections along and across proposed intake(s)
    - Detailed geological map of the proposed area, showing the layout of scheme along with sections (L and X) of desilting chambers.
    - Geological longitudinal section of construction adits to DC, SFT (including portals).

- Layout plan of the HRT in geological map showing construction adits (portal and alignment), topographic contours, cross drainages, etc.
- Geological longitudinal section of HRT and construction adits (including portals) to HRT. The sections should indicate sheared/fractured/ weak zones, low cover/high cover zones, kinks in alignment etc.
- Geological longitudinal section of construction adits (including portals) to HRT (if any).

11 Powerhouse Complex
- Geological map of power house complex
- Geological sections of surge shaft showing vertical and lateral cover (minimum and maximum)
- Geological section along surge shaft- pressure shaft -power house-tailrace
- L- and X-section of powerhouse (including machine hall, transformer cavern)
- Geological longitudinal sections of construction adits, MAT, Cable Tunnel, etc (in case of u/g ph)
- 3D geological log along power house drift (in case of u/g ph)
- Geological sections (L- and cross) of TRT/TRC

12 Reservoir
- Geological, Geomorphological, Lineament, Landuse–Land cover map, indicating locations of existing landslides in reservoir area, if any.

13 Construction Material
- Location plan of quarries identified for construction material
- Geological plan and cross sections of quarries for construction material

14 Photographs

Photographs of locations of important geological features, exploratory drifts and any other important informative features.

14 Status Reporting Format for Major Hydroelectric Project Development

Sl. No.	Name of Scheme	
	Installed Capacity	
	Annual Generation	
	Activities	**% Progress**
1	**Inception Report**	
1.1	Google Earth Studies	
1.2	GIS Studies	
1.3	Field Visit & GPS positioning	
1.4	Reservoir Capacity Assessment	
1.5	Preliminary Layout Preparation	
1.6	Preliminary Design	
1.7	Power Potential Assessment	
1.8	Draft Inception Report	
1.9	Scrutiny at Investigation Circle	
1.10'	Verification by CE(C-I&CC)	
1.11	Reporting to Director (Gen-Civil)	
2	**Approval from Board**	
2.1	Decision for Internal DPR Preparation / EPC	
2.2	Forming Sub Division for DPR Preparation	
2.3	Tendering & Awarding of EPC Contract	
2.4	Name of Agency	
3	**Preliminary Surveys & Data Collection**	
3.1	Profile of Water Conductor System	
3.2	Cross Sections of Streams	
3.3	Connecting Bench Marks	
3.4	Hydrological Study	
3.5	Power Potential Study	
4	**Draft Feasibility Report**	
5	**Approval of Feasibility Report by Board**	
6	**PFR Preparation (Pre DPR Chapters 14 Nos)**	
7	**PFR Submission to CEA**	
8	**PFR Verification at Various Directorates of CEA & CWC**	
8.1	PFR Rejected	
8.2	Go Ahead	
9	**Finalising EIA Consultant**	
9.1	Approval of ToR from MoEF&CC for EIA/EMP Study	

Sl. No.	Name of Scheme	
	Installed Capacity	
	Annual Generation	
	Activities	**% Progress**
10	**Topographical Survey**	
11	**Preliminary Drawing of Project Component**	
12	**Setting out Project Layout**	
13	**Field Verification by KSEBL**	
13.1	Revision	
13.2	Go Ahead	
14	**Geological Exploration**	
14.1	Preliminary Geological Inspection	
14.2	Taking Drill Holes, Drifts, Trial Pits etc.	
14.3	Logging	
14.4	Geological Appraisal & Report	
14.4.1	Revise Scheme Layout	
14.4.2	Go Ahead	
15	**Detailed Design & Studies**	
15.1	Hydrological Study	
15.2	Power Potential Study	
15.3	Component Design	
15.4	E&M Design	
15.5	Power Evacuation Plan	
15.6	Estimating & Costing	
15.7	Financial Analysis	
16	**Vetting of Studies & Reports by directorates**	
17	**DPR Compilation (21 Chapters with approved study reports)**	
18	**Verification by CEA**	
19	**DPR Approval**	
20	**Board AS**	
21	**Government AS**	
22	**KSERC Approval**	
23	**Government Order for Land Acquisition**	
24	**Land Acquisition under LARR Act 2013**	
25	**Tendering**	
26	**Award of Work**	

15 Status Reporting Format for Small Hydroelectric Project Development

Sl. No.	Name of Scheme	
	Installed Capacity	
	Annual Generation	
	Activities	% Progress
1	**Inception Report**	
2	**Scrutiny & Approval by Dy. CE (Investigation)**	
3	**Preliminary Survey**	
3.1	Profile of Water Conductor System	
3.2	Cross Sections of Streams	
3.3	Connecting Bench Marks	
4	**Preliminary Investigation Report from Field**	
5	**Scrutiny at Investigation Circle**	
5.1	Not Feasible - Project Drop	
5.2	Concurrence from CE(C-I&CC) - Go Ahead	
6	**Detailed Studies**	
6.1	Hydrological Study	
6.2	Power Potential Study	
6.3	Power Evacuation Study	
7	**Topographical Surveys**	
7.1	Establishing Control points by DGPS / Total Station Traversing	
7.2	Contouring	
7.3	Longitudinal Section	
8	**Preliminary Drawings**	
8.1	Detailed Survey Drawings	
8.2	Components Layout	
9	**Draft Detailed Investigation Report**	
10	**Field Inspection by Dy. CE (Investigation)**	
11	**DIR Presentation & Review**	
12	**Incorporating Suggestions of Circle Level Review**	
13	**Scrutiny of DIR at Investigation Circle**	
13.1	Technically Not Viable - Project Drop	
13.2	Financially Not Viable - Kept in Abeyance	
13.3	Found Viable - Report to CE(C-I&CC)	
14	**Setting Out Project Layout on Ground**	
15	**Field Inspection by CE(C-I&CC)**	

Sl. No.	Name of Scheme	
	Installed Capacity	
	Annual Generation	
	Activities	% Progress
16	**Go Ahead with DPR Preparation**	
17	**Geological Explorations**	
17.1	Preliminary Inspection of Geologists	
17.2	Finalising Drill Hole Locations	
17.3	Approval of Drill Hole Locations from CE(C-I&CC)	
17.4	Estimate Preparation for Drill Holes	
17.5	Tendering for Drill Holes	
17.6	Taking Drill Holes	
17.7	Logging of Core Samples by GSI	
17.8	Geological Report from GSI	
17.9	Taking Additional Holes (if any)	
17.10'	Relocating Components on Geological grounds	
17.11	Abandoning Project due to Geological Reasons	
18	**DPR Stage Studies**	
18.1	Hydrology	
18.2	Power Potential	
18.3	Component Design	
19	**Electro Mechanical**	
19.1	E&M Design	
19.2	Power Evacuation Plan	
20	**DPR Drawings**	
21	**Estimating & Costing**	
22	**Financial Analysis**	
23	**Draft DPR Compilation**	
24	**Verification by KSEBL DPR Approval Committee**	
25	**DPR Approval**	
26	**Board AS**	
27	**Government AS**	
28	**KSERC Approval**	
29	**Government Order for Land Acquisition**	
30	**Land Acquisition under LARR Act 2013**	
31	**Tendering**	
32	**Award of Work**	

16 List of Relevant IS Codes for Investigation

Sl. No	IS Code No.	Title
1	IS 4078: 1980	Code of practice for indexing and storage of drill cores (First revision)
2	IS 4453:1980	Code of practice for exploration of pits, trenches, drifts and shafts (First revision)
3	IS 4464:1985	Code of practice for presentation of drilling information and core description in foundation investigation (First revision)
4	IS 5313:1980	Guide for core drilling observations (First revision)
5	IS 5313:1980	Guide for topographical surveys for river valley projects (First revision)
6	IS 5529 (Part 1): 1985	Code of practice for in-situ permeability test: Part 1 Test in overburden (First revision)
7	IS 5529 (Part 2): 1985	Code of practice for in-situ permeability test: Part 2 Test in bedrock (First revision)
8	IS 6066:1994	Recommendations for pressure grouting of rock foundations in river valley projects
9	IS 6926:1996	Diamond core drilling for site investigation for river valley projects – Code of practice (First revision)
10	IS 6935:1973	Method for determination of water level in a bore hole
11	IS 6955:2008	Code of practice for subsurface exploration for earth and rock fill dams
12	IS 7422(Part 1): 1974	Symbols and abbreviations for use in geological maps, sections and subsurface exploratory logs: Part 1 Abbreviations
13	IS 7422(Part 2): 1974	Symbols and abbreviations for use in geological maps, sections and subsurface exploratory logs: Part 2 Igneous rocks
14	IS 7422(Part 3): 1974	Symbols and abbreviations for use in geological maps, sections and subsurface exploratory logs: Part 3 Sedimentary rocks
15	IS 7422(Part 4): 1985	Symbols and abbreviations for use in geological maps, sections and subsurface exploratory logs: Part 4 Metamorphic rocks
16	IS 7422(PT 5): 1992	Symbols and abbreviations for use in geological maps, sections and subsurface exploratory logs: Part 5 Line

Sl. No	IS Code No.	Title
		symbols for formation contacts and structural features
17	IS 10060: 2013	Code of practice for subsurface investigation for power house sites
18	IS 10290:1982	Code of practice for photogeological interpretation and mapping of river valley project site
19	IS 11385:1985	Code of practice for subsurface exploration for canals and cross drainage works
20	IS 13216:1991	Code of practice for geological exploration for reservoir sites
21	IS 13578:1992	Subsurface exploration for barrages and weirs-code of practice
22	IS 14330:1996	Groundwater investigation for hydraulic structures-Guidelines
23	IS 15662: 2006	Code of practice for subsurface exploration for Gravity Dams and overflow structures
24	IS 15681:2006	Geological Exploration by Geophysical Method (Seismic Refraction) - Code of Practice
25	IS 15686: 2006	Recommendations for the preparation of geological and geotechnical maps for river valley projects (Superseding IS 6065 Part 1: 1985)
26	IS 15736: 2007	Geological Exploration by Geophysical Method (Electrical Resistivity) - Code of Practice
27	IS 17833: 2022	Geological Exploration for Tunnels — Guidelines
28	IS 1893 (Part 1): 2016	Criteria for Earthquake Resistant Design of Structures - Part 1: General Provisions and Buildings (Including Amendment No. 1 & 2)