## ANNEX C: Preliminary program of field investigations

Will be updated based on final version of Optimization Study.

GEOTECHNICAL INVESTIGATIONS AND STUDIES

(Hydropower Scheme Sites and Appurtenant Structures, PV Solar Plants Sites)

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# General

A proper assessment of site geologic and geotechnical conditions is one of the most important aspects of a hydropower scheme project design (comprising a dam). Evaluation of the safety of a dam requires, among other things, that its foundation has been adequately examined, explored, and investigated so that it is as fully understood as possible. Foundation explorations should be directed towards obtaining such information which is important to design a hydropower scheme. The exploration program should identify the factors that critically affect the safe performance of the scheme/dam. The following sections of this note briefly identify the methods commonly employed in foundation investigations and are intended to suggest approaches and scopes of investigations which, when properly implemented, should comply with requirements of standards and good practices.

While this note is principally directed toward dams and dam sites, the types of investigations and studies are also applicable to other water retention structures and appurtenant structures of hydropower projects. Within the PIP frame, planned Solar PV plants projects will also require investigations described in the relevant section.

# Purpose and scope

The purpose of this note is to present guidelines for use by the Consultant for determining the appropriateness and level of geotechnical investigations and studies for the main dam, the saddle dams, the water retention and conveyance structures and other appurtenances of the designated **SP2 Hydropower Scheme** located on the St Paul River.

Reports of findings on such investigations and studies will allow to establish the Geotechnical Baseline Report (GBR) which will be utilized along the further development steps of the project, during the detailed design activities, during the construction period and then during the operation of the hydropower scheme.

The scope of this chapter is intended to outline the desirable quantity and quality of those investigations required to support the design of the SP2 hydropower scheme.

An indicative and provisional bill of quantities of proposed site investigation works are presented in Tables 1 and 2 in order to achieve a satisfactory level of geological and geotechnical knowledge for the ground characterization of the various structures’ sites.

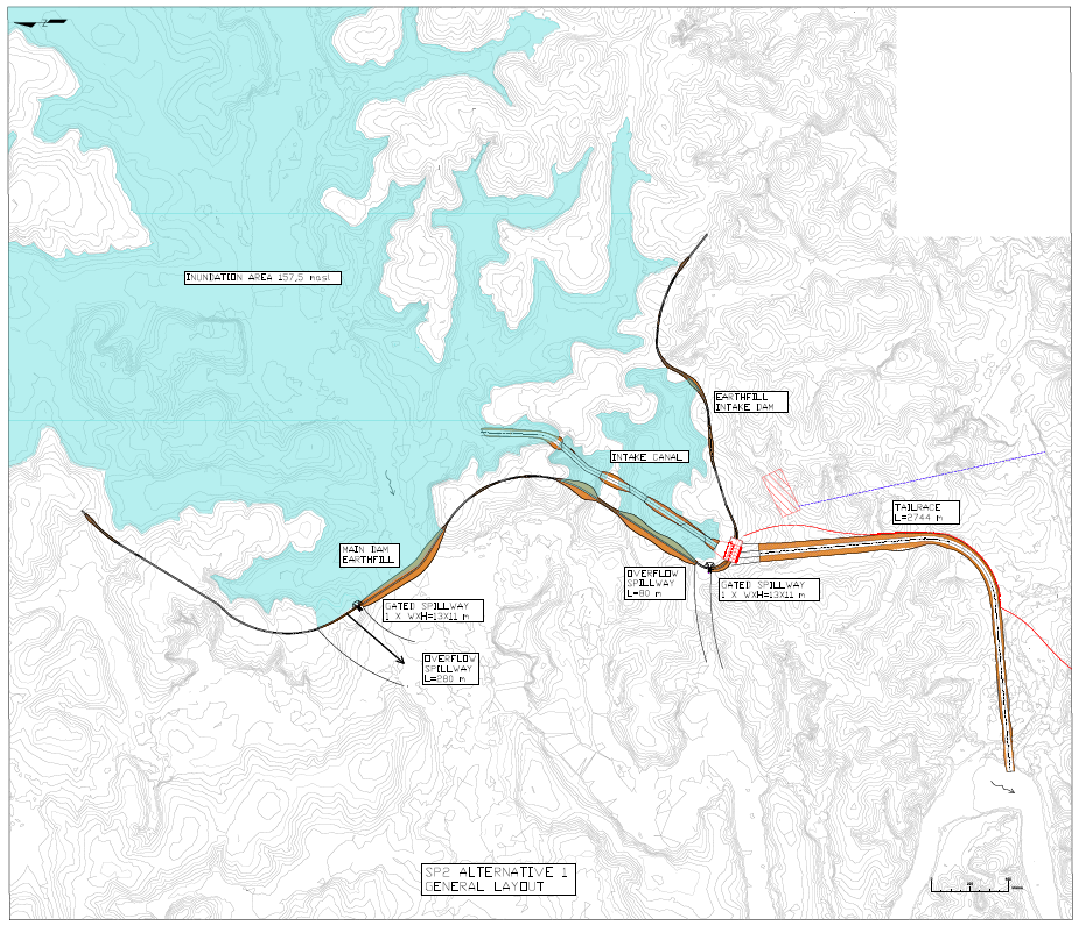
The Consultant is required to provide the unit prices and the overall resulting cost of the investigation campaign as part of the financial proposal. Through the mandatory pre-bid site visit the Consultant will perform his own assessment of the campaign scope and can suggest other types of investigations not listed in the attached table for which he will provide quantities and unit costs. The cost of these other type of investigations will not be part of the amount of his financial offer. At the time of execution of the investigations, there will be possible adjustments of quantities, but the applicable unit prices will be those provided by the Consultant’s in the financial proposal.

# Intended conceptual design of the SP2 hydropower scheme

An Optimization Study (OS) performed by a Consultant has identified the possible location of the SP2 hydropower scheme along the St Paul River. A reconnaissance site visit was performed with visual inspection and a broad assessment of the physical environment but no geotechnical investigations as such. The sites were assessed appropriate for the construction of a hydropower scheme contingent to findings of proper additional surveys and investigations for optimizing the location, capacities and design of the scheme.

# Conceptual design general layout

The following sketch illustrates the general layout of the SP2 HP Scheme (for the FSL 157.5 m asl alternative.) established during the OS, showing the main infrastructures, their provisional locations and their indicative dimensions.



# Indicative locations of investigations and tests areas

The map above is only indicative, however, the very flat topography requires the construction of long dykes and levées for closing the downstream reservoir rim. When developing the more detailed layout, based on the data of the LIDAR survey and other design and optimization parameters, the Consultant will determine the location of these dykes, levées, the location of the spillways (gated and/or overflow), the axis of the main dam(s), the location of the power house and switchyard and all appurtenant infrastructures, access roads, service buildings, warehouses, storage yards and temporary installations during the construction.

# Intensity of investigations

The extent of required investigations should be dictated by hazard classification assessed during reconnaissance of the sites and analysis of available information and documents, nature of structures, and quantity of data already available.

Geotechnical investigations for proposed sites should be generally divided into three separate phases to minimize costs and for developing the necessary data at each stage of the approval, design, and construction of the project:

Generally, the 3 phases are:

* Preliminary Investigations resulting in information to justify site selection, conceptual design and preliminary cost estimates;
* Initial Design Investigations resulting in Information necessary to obtain regulatory approvals, refine cost estimates, and develop engineering and environmental data;
* Final Design Investigations resulting in information necessary for developing plans and specifications for preparing the tender dossier for obtaining bids for constructing the project.

## Preliminary Investigations

**Output**: information to justify site selection and preliminarycost estimates.

These investigations will provide a first general impression of the engineering and geological aspects of the proposed sites and should determine the extend of further study of the sites. The field work generally would include preliminary field geologic mapping, some preliminary hand auger holes for soil and overburden sampling, a limited number of core holes into rock and possibly some preliminary seismic refraction traverses. The data would also be used to plan the type, location, and amount of explorations and laboratory testing required for future, more detailed investigations.

## Initial Design Investigations

**Output**: information necessary to obtain regulatory approvals,refine cost estimates, and develop engineering and environmental data.

These investigations will be undertaken to provide more detailed information on foundation characteristics on a particular site or several sites, and to provide data for preliminary considerations of the design requirements and construction methods. This type of information will be developed for inclusion in reports providing conceptual analyses of the project structures. This phase of field investigation will include surface and subsurface exploration and sampling through borings, test pits, test trenches, material testing, geologic mapping, and additional geophysical surveys to supplement drilling. Data developed from these activities will be used to compare alternative sites, to analyze different types of structures that might serve the same purpose, and to develop economic evaluations of the sites.

## Final Design Investigations

**Output**: Information necessary for developing plans and specifications, preparation of the tender dossier for obtaining bids for constructing the project.

These investigations will be primarily composed of detailed drilling, sampling, and testing concentrated on specific features at the selected project site; and will be specifically planned to provide the Consultant with information that is necessary to design structures, estimate quantities, determine rates of construction progress, develop cost estimates, prepare plans and specifications for including in the further tender dossier for obtaining bids.

# Quantities

The tables below list the various types of investigations and tests suggested to be performed by the Consultant.

Quantities shall be proposed by the Consultant after having assessed the conditions of the site during the pre-bid site visit and further to the consultation of documents and reports made available to prequalified bidders.

The table must be filled for the 3 suggested steps of investigations, namely: i) Preliminary investigations, ii) Initial Design investigations and iii) Final Design investigations.

For the geophysical investigations, the profiles/traverses along axis and perpendicular to the said axis (designated A-B, C-D etc…) are indicative only. The Consultant will detail the location and number of such profiles/traverses on an map of appropriate scale.

## For the Hydropower Scheme (SP2)

**Table 1 : Type and quantities of investigations and tests for the SP2 HPP sites**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Table to be filled for the 3 different steps of investigations for applicable items.** | | | | | |
| **Nº** | **Description** | **Unit** | **Provisional**  **quantity** | **Unit Price** | **Total** |
|  | **(a)** | **(b)** | **(c)** | **(d)** | **(e) = (c x d)** |
| **1.** | **Mobilization and management of activities** |  |  |  |  |
| **1.1** | Mobilization, including access to the site, transport and put in operation of equipment, local camp and facilities, catering for staff, desk work and reporting activities etc. | **LS** |  |  |  |
| **1.2** | Demobilization | **LS** |  |  |  |
| **2** | **Geophysical investigations** |  |  |  |  |
| **2.1** | **Seismic refraction along de dam axis (120m long profiles)** |  |  |  |  |
| **2.1.1** | Along the dam axis A-B | **Nb.Profile** |  |  |  |
| **2.1.2** | Along the dam axis C-D | **Nb.Profile** |  |  |  |
| **2.1.3** | Along the dam axis G-H | **Nb.Profile** |  |  |  |
| **2.1.4** | Along the dam selected axis | **Nb.Profile** |  |  |  |
| **2.2** | **Seismic refraction along spillway axis (120m long profiles)** |  |  |  |  |
| **2.2.1** | Along spillway axis A-B | **Nb.Profile** |  |  |  |
| **2.2.2** | Along spillway axis C-D | **Nb.Profile** |  |  |  |
| **2.2.3** | Along spillway selected axis | **Nb.Profile** |  |  |  |
| **2.3** | **Seismic refraction along the power plant (120m long profiles)** |  |  |  |  |
| **2.3.1** | Along power plant axis A-B | **Nb.Profile** |  |  |  |
| **2.3.2** | Along power plant axis C-D | **Nb.Profile** |  |  |  |
| **2.3.3** | Along power plant selected axis | **Nb.Profile** |  |  |  |
| **3** | **Test pits for soil identification** |  |  |  |  |
| **3.1** | **Test pits for soil identification in borrow areas** | **Nb.** |  |  |  |
| **3.2** | **Test pits for soil identification along the dam axis** |  |  |  |  |
| **3.2.1** | Along the dam axis A-B | **Nb.** |  |  |  |
| **3.2.2** | Along the dam axis C-D | **Nb.** |  |  |  |
| **3.2.3** | Along the dam axis G-H | **Nb.** |  |  |  |
| **3.2.4** | Along the dam selected axis | **Nb.** |  |  |  |
| **3.3** | **Test pits for soil identification along spillway axis** |  |  |  |  |
| **3.3.1** | Along spillway axis A-B | **Nb.** |  |  |  |
| **3.3.2** | Along spillway axis C-D | **Nb.** |  |  |  |
| **3.4** | **Test pits for soil identification under the power plant** |  |  |  |  |
| **3.4.1** | Along power plant axis A-B | **Nb.** |  |  |  |
| **3.4.2** | Along power plant axis C-D | **Nb.** |  |  |  |
| **3.4** | **Test pits for soil identification at switchyard location** | **Nb.** |  |  |  |
| **3.5** | **Boreholes and drillings** |  |  |  |  |
| **3.5.1** | Along the dam axis (depth: -60m, or till bedrock is reached if first) | **Nb.** |  |  |  |
| **3.5.2** | Drilling on soils and rocks until 50m | **Nb.** |  |  |  |
| **3.5.3** | Drilling on soils and rocks from 50 until 100m | **Nb.** |  |  |  |
| **3.5.4** | At the left and right dam abutments on the riverbanks | **Nb.** |  |  |  |
| **4** | **Overburden in situ testing** |  |  |  |  |
| **4.1** | **Standard penetration test (SPT)** | **Nb.** |  |  |  |
| **4.2** | **Dynamic cone penetration test (DCPT)** | **Nb.** |  |  |  |
| **4.3** | **Shelby tubes** | **Nb.** |  |  |  |
| **5** | **Disturbed samples** | **Nb.** |  |  |  |
| **6** | **Undisturbed samples with double or triple tube core barrel** | **Nb.** |  |  |  |
| **7** | **In situ soil testing** | **Nb.** |  |  |  |
| **8** | **In situ rock testing** | **Nb.** |  |  |  |
| **9** | Lugeon test 5 pressure step | **Nb.** |  |  |  |
| **10** | **Laboratory testing** |  |  |  |  |
| **10.1** | **Soil testing** |  |  |  |  |
| **10.1.1** | Particle size analysis | **Nb.** |  |  |  |
| **10.1.2** | Water content and Volume weight | **Nb.** |  |  |  |
| **10.1.3** | Standard Proctor compaction test | **Nb.** |  |  |  |
| **10.1.4** | Modified Proctor compaction test | **Nb.** |  |  |  |
| **10.1.5** | Relative density | **Nb.** |  |  |  |
| **10.1.6** | Hydrometer analysis | **Nb.** |  |  |  |
| **10.1.7** | Atterberg limits | **Nb.** |  |  |  |
| **10.1.8** | Swedish fall cone test | **Nb.** |  |  |  |
| **10.1.9** | Mineralogy analyses by X-ray diffraction (XRD) | **Nb.** |  |  |  |
| **10.1.10** | Methylene Blue | **Nb.** |  |  |  |
| **10.1.11** | Sand equivalent test | **Nb.** |  |  |  |
| **10.1.12** | CBR | **Nb.** |  |  |  |
| **10.1.13** | Potential volume change meter | **Nb.** |  |  |  |
| **10.1.14** | Expansibility index | **Nb.** |  |  |  |
| **10.1.15** | Uniaxial compressive strength (UCS) test | **Nb.** |  |  |  |
| **10.1.15** | Oedometric test (One dimensional consolidation test) | **Nb.** |  |  |  |
| **10.1.16** | Triaxial strength test (CU+U) (samples) | **Nb.** |  |  |  |
| **10.1.17** | Dispersivity test | **Nb.** |  |  |  |
| **10.1.18** | Permeability test | **Nb.** |  |  |  |
| **10.2** | **Rock testing** |  |  |  |  |
| **10.2.1** | Mechanical tests for cut and support design (tests on intact rock cores) | **Nb.** |  |  |  |
| **10.2.2** | Compressive strength and elastic moduli | **Nb.** |  |  |  |
| **10.2.3** | Uniaxial compressive test | **Nb.** |  |  |  |
| **10.2.4** | Cerchar test (abrasivity index) | **Nb.** |  |  |  |
| **10.2.5** | Shear strength of discontinuities | **Nb.** |  |  |  |
| **10.2.6** | Test for concrete coarse aggregate (tests on crushed rock) | **Nb.** |  |  |  |
| **10.2.7** | Petrographic description (thin section) | **Nb.** |  |  |  |
| **10.2.8** | Alkali aggregate reaction - short and long term | **Nb.** |  |  |  |
| **10.2.9** | Micro-Deval | **Nb.** |  |  |  |
| **10.2.10** | Los Angeles abrasion value | **Nb.** |  |  |  |
| **10.2.11** | Soundness of fine and of coarse aggregates by use of magnesium sulphate | **Nb.** |  |  |  |
| **10.2.12** | Relative density and absorption of fine and coarse aggregate | **Nb.** |  |  |  |
| **10.2.13** | Porosity, density and water absorption | **Nb.** |  |  |  |
| **10.2.14** | Fragmentability index | **Nb.** |  |  |  |
| **10.2.15** | Alterability/degradability index | **Nb.** |  |  |  |
| **10.2.16** | Expansibility | **Nb.** |  |  |  |
| **10.2.17** | Slake durability test | **Nb.** |  |  |  |
| **10.2.18** | Point load | **Nb.** |  |  |  |
| **10.2.19** | Velocity of elastic waves | **Nb.** |  |  |  |
| **10.3** | **Test for the determination of water aggressivity** | **Nb.** |  |  |  |
| **11** | **Instrumentation and monitoring system (To be detailed)** |  |  |  |  |

## For the Solar PV plants

The geotechnical investigations required for the implementation of PV solar plants are essentially focusing on checking that the selected site (several hectares) if fit for the implementation and installation of the various components.

The main aspects which should be analyzed are groundwater level, resistivity of the soil, load-bearings properties of the soil, presence of rock or other obstructions or singularities, suitability of chosen foundations and drivability of piled foundations, soil pH and chemical degree of ground contaminants.

Basically, the selected site must satisfy the main following conditions:

* Relatively smooth topography avoiding brutal slopes changes and escarpments;
* Absence of geological faults;
* Good homogeneity of soils composition to avoid differential settlements;
* Favorable natural drainage patterns minimizing earth moving adjustments in order to avoid the intrusion of runoff waters, scouring of streams and erosion and the accumulation of water under the form of temporary ponds during heavy rains;
* Proper drainage network to prevent the flooding of the canals/culverts where electric cables and mains are running;
* Nature of surface soil with minimum of pulverulent material for avoiding generation of dust detrimental to the efficiency of the PV panels;
* The site should be at a suitable distance of roads with heavy traffic for the same reason and properly.
* Access roads and service roads inside the site surface layer should not generate dust;
* The site must be correctly positioned in relation to the direction of the prevailing winds;
* Absence of tall vegetation intercepting the solar radiations;
* Availability of water is an important factor as large quantities of water are necessary for maintenance purposes (cleaning);

The geological and geotechnical investigations main objective is to ensure that the bearing capacities of soils in place or added surface layers are sufficient for withholding the loads of equipment and for ensuring the stability of foundations concrete blocks or slabs,

Investigations will therefore comprise at least:

* Geological mapping of possible faults and singularities through general visual inspection and through geophysical investigations if visual surface inspection identifies areas of doubt;
* Identification and location of aquifers for assessment of predictable variations through installation of piezometers and recording of measurements;
* Execution of test pits at an appropriate depth (50 cm to 2.00 m depending on the nature of soil) for identification of soil strata. Test pits must be located in such a way that the resulting mapping shows areas of different characteristics and their delineation;
* Execution of shear vane tests in sufficient number allowing to also translate results on a map showing the areas of different characteristics and their delineation;
* CBR test at the proposed locations of plant components of heavy weight (Transformers, batteries bay, converters etc..), foundations platforms and service roads.

Fieldwork should be conducted in the presence of experienced geotechnical or geological engineers who will name test sites, sample and test sites, prepare technical records and undertake site observations.

### Field tests

The following list of suggested types of investigations is indicative only. References to methods and standards are for guiding purposes, the Consultant responsibility resting with the choice of them in compliance with local (in Liberia) applicable regulations and norms.

* **Cone penetrometer (CPT) tests** at depths up to 5 meters deep. CPT tests may be refused penetration. CPT tests can be repeated if the penetration refusal is encountered before the target depth and have included two attempts per location in this mission. Any refusal of penetration will be recorded in a report and the Consultant shall evaluate the need for predrilling for the Project.
* **Test wells** on the entire site must be excavated. The test pits would be excavated with a backhoe or excavator and excavated to a target depth of 5 m to 6 m or prior penetration if penetration is refused. Shear tests on pocket penetrometers and pallets must be performed in cohesive soils during the test. A dynamic cone penetrometer test will be performed next to each test pit. These in situ tests will allow the Consultant to assess the resistance of the soil and allow the Consultant to provide basic recommendations. The first test pit would be left open until the completion of the last test pit to allow monitoring of groundwater levels. Once the test is completed, the test pits will be photographed with an information panel before being backfilled with the excavated material. A register will be developed in which all soils encountered will be presented by variations in soil type, consistency, colour, plasticity, constituent elements and moisture in situ condition. All test locations will be recorded using a differential GPS (sub-meter), and the coordinate measuring device recorded in the geotechnical engineering records.
* **Electrical resistivity tests** in the field. Electrical resistivity (ERT) tests will be performed at appropriate locations by a geotechnical engineer or geologist using an advanced method that exceeds ASTM G57-95a (2001) Standard Test Method for Field Measurement of Soil Resistivity using the four-electrode Wenner method. A digital resistivity meter will be used for tests with metal picket electrodes. A maximum spacing of 20 metres will be used and orthogonal resistivity surveys will be conducted at each site. In addition to calculating apparent resistivity, the geophysical resistivity inversion software will be used to provide an interpretation of the actual resistivity values (ohm m) at each drilling site, based on layered earth models. This allows a more accurate representation of the resistivity profile image with the analysis performed by an experienced geophysicist. Observations and notes on the site (e.g., topography, surface soils and local geology) will be recorded and digital photographs taken with the location indicated on a geological map.

### Laboratory Tests

Samples will be taken during the fieldwork and appropriate laboratory tests will be scheduled during the investigation and reviewed at the end of the fieldwork to ensure that appropriate measures are taken. The tests will be carried out under all soil conditions encountered on site.

Laboratory tests will be conducted on selected samples collected as part of the investigation. A sufficient number of tests must be carried out so that, in the opinion of the Consultant and the Client, adequate information is available to allow the development of recommendations for the Project (e. geotechnical design for levelling and earthworks, foundations, roads and roads, erosion and sedimentation, etc.).

Laboratory tests should be performed on representative soil samples obtained from the following elements of soil drilling or test pits. All samples obtained during the tests must be placed in moisture-proof containers during transport to the laboratory.

Sample containers must be labelled with the project name/number, date and number of the test pit, type and number of samples, and depth of the sample. Laboratory tests must be conducted in accordance with applicable industry standards, which may include ASTM, CSA or equivalent for Liberia where the project sites are located.

* **Thermal conductivity / installation resistivity tests** are required. The perspective depths must reach a range between 0.3 and 1.5 m. Samples for thermal resistivity tests will be submitted to the laboratory for a drying curve test.
* **Sampling sites**. However, the selected soil samples would be delivered to a NATA-accredited laboratory for the following tests:
* Granulometric distribution (sieve analysis)
* Standard Compaction tests
* Wet and dry density tests
* Water content
* Atterberg limits (including linear withdrawal)
* Shrinkage and swelling tests
* Soil Aggressivity following soil aggressiveness tests
* 4 days of soaked CBR tests. These samples must be taken at horizons of 0-20 cm and 0-30 cm below the natural soil and along the inner road and/or platforms. If the underground conditions at the site are considered consistent, the CBR tests would be reduced to three tests.

**Table 2: Type and quantities of investigations for the sites of PV Solar Plants (per site)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Table to be filled for the 3 different steps of investigations for applicable items. (and for each site of PV solar plant when identified))** | | | | | | |
| **Nº** | **Description** | **Unit** | **Provisional**  **quantity** | **Unit Price** | **Total** |
|  | **(a)** | **(b)** | **(c)** | **(d)** | **(e) = (c x d)** |
| **1.** | **Mobilization and management of activities** |  |  |  |  |
| **1.1** | Mobilization, including access to the site, transport and put in operation of equipment, local camp and facilities, catering for staff, desk work and reporting activities etc. | **LS** |  |  |  |
| **1.2** | Demobilization | **LS** |  |  |  |
| **2** | Overburden in situ testing |  |  |  |  |
| **2.1** | Standard penetration test (SPT) | **Nb.** |  |  |  |
| **2.2** | Dynamic cone penetration test (DCPT) | **Nb.** |  |  |  |
| **2.3** | Shelby tubes | **Nb.** |  |  |  |
| **3** | Disturbed samples | **Nb.** |  |  |  |
| **4** | Undisturbed samples with double or triple tube core barrel | **Nb.** |  |  |  |
| **5** | In situ soil testing | **Nb.** |  |  |  |
| **6** | In situ rock testing | **Nb.** |  |  |  |
| **7** | Laboratory testing |  |  |  |  |
| **7.1** | Soil testing |  |  |  |  |
| **7.1.1** | Particle size analysis | **Nb.** |  |  |  |
| **7.1.2** | Water content and Volume weight | **Nb.** |  |  |  |
| **7.1.3** | Standard Proctor compaction test | **Nb.** |  |  |  |
| **7.1.4** | Modified Proctor compaction test | **Nb.** |  |  |  |
| **7.1.5** | Relative density | **Nb.** |  |  |  |
| **7.1.6** | Hydrometer analysis | **Nb.** |  |  |  |
| **7.1.7** | Atterberg limits | **Nb.** |  |  |  |
| **7.1.8** | CBR | **Nb.** |  |  |  |
| **8.** | Thermal Conductivity tests | **Nb.** |  |  |  |

# Referencing of tested areas

All test pits, boreholes location will be geo-referenced with their accurate coordinates. They will be materialized on the site with fix benchmarks and posts allowing to easily spot them during further on-site visits.

# Norms and standards

The Consultant will detail in his proposal what norms and standards will be applied for the execution of the various tests and laboratory analysis. Standards and norms will be compliant with the ones applied in Liberia.

# Methods of investigations

The adequacy of the analysis of the structure of the hydropower scheme will be primarily dependent on the extent of the information obtained about foundation conditions of the site and the physical properties of the foundation materials. To evaluate these properties, the type and application of sampling methods is important. The recommendation is however that the selected methods of sampling or sampling devices will guarantee the recovery of satisfactory and representative samples in all materials with the minimum disturbance to the sample.

The possible suitable methods of investigations to be performed by the Consultant are broadly described hereafter.

# Types of Exploration

The general types of explorations used to investigate potential dam and hydropower schemes project sites fall into four categories:

* geologic reconnaissance and mapping;
* boreholes;
* special excavations;
* and geophysical measurements.

## Geologic Reconnaissance and Mapping

Geologic reconnaissance and mapping are crucial for understanding critical items influencing siting, design, and construction of the components of the hydropower scheme. The available geologic maps and any geological data and information resulting from previous surveys and studies covering the St Paul River basin (or the larger region) will be collected by the Consultant for evaluating any stability, settlement or seepage problems that may occur during the construction and the future operation of the project. This data collection will require the Consultant to enquire near various bodies in the countries of the region and to perform focused research on the Internet for gathering pertinent historical and academic material of pertinence. The correlation between documentary information and actual onsite conditions will be performed by the Consultant geologist during onsite visits.

## Boreholes

Of the different types of explorations, borings are the most practical and accurate method of obtaining sub-surface information. The most important aspect of the drilling procedures is the recovery of the material penetrated. A boring with low recovery is of limited value and will generally raise more questions than it answers.

## Special Excavations

Special excavations are defined as those openings made with machinery other than drill rigs for the purpose of obtaining soil or rock samples or conducting in situ testing. They consist of test pits, test trenches, large diameter borings, tunnels, shafts, drifts or adits.

## Geophysical explorations

Geophysical explorations are an indirect method of obtaining generalized sub-surface geologic information by using special instruments to perform certain physical measurements. Geophysical observations and findings are statistical and provide guiding measurements.

Geophysical explorations complement core drilling, test pits, or other direct methods of sub-surface exploration and will provide a rapid evaluation of certain geologic conditions. However, their reliability is only as good as their confirmation by conventional means of exploration.

# Location of Explorations

Adequate information about foundation properties and characteristics is critical to a full understanding of the adequacy of the design of the structures. Therefore, explorations will be adequately distributed over the dam site, including abutments and dam foundation, and at appurtenant structures, including, spillways, intakes and outlets, at the powerhouse and switchyard sites, (whether surface or subsurface), and along the reservoir rim, and at the construction material borrow sites.

The search for borrow sites shall be made preferentially in the future reservoir area for environmental reasons, so that the footprint of the project is reduced as well as minimizing the need for restoration of quarries areas to their natural original state.

# Laboratory Tests

Laboratory testing of foundation material may include the performance of such routine tests as direct shear, unconfined and triaxial compression, sliding friction, modulus of elasticity, tensile strength, natural and dry density, moisture content, consolidation, Atterberg limits, grain-size analysis, and permeability. Where unusual geological conditions exist, tests for foundation rebound, slaking, collapsibility, dispersive characteristics, permeability, compaction, and determination of the mineral and chemical composition of the rock and ground water may be required and proposed by the Consultant for approval. In addition, where liquefaction potential may need to be evaluated, dynamic laboratory tests such as cyclic direct shear and/or cyclic triaxial compression tests may be appropriate.

Laboratory tests will be needed to provide information regarding the behavior of foundation rock under the various construction conditions to which it will be subjected, such as, rebound due to removal of load, application of load, scour, exposure to weather, wet-dry cycles. Laboratory tests will establish the quality of construction materials such as concrete aggregates, impervious material, rockfill, and riprap.

There is a special emphasize regarding the laboratory tests for the Aggregate Alkali Reaction (AAR) which take several months/years to be completed. This means that once aggregates for concrete mixes are identified, the AAR tests should be immediately initiated.

# Field Tests

Within the scope of investigations for a hydropower scheme comprising dams, the most important field tests to performed are permeability and grouting. Permeability tests can be done either by pumping out or hydraulic pressure.

The pumping-out test consists of bailing or pumping water from wells or boreholes and observing the effect of this operation on the water level in these and nearby holes. The test usually is performed in one or more of the exploratory borings.

The hydraulic pressure test consists of pumping water under pressure into an isolated zone in the rock or overburden through a borehole and noting the quantity of water pumped at any given pressure. (Lugeon test)

Test grouting may be useful but usually rather performed by the Contractor at the time of construction inception. It consists of performing experimental grouting operations on exploratory boreholes to determine the extent to which subsurface materials are “groutable”.

While the above field tests may be used to provide information on the foundation, additional field (in-situ) tests for evaluating the physical characteristics of the rock mass as a whole may be justified and suggested by the Consultant as follows: Blasting test, rock bolt pull-out tests, flat jacking tests, Goodman jacking tests, chamber tests, and direct shear strength.

# Instrumentation and monitoring

In addition to the geological and geotechnical investigations, the Consultant shall propose and include the costs of implementing an adequate system of instrumentation and monitoring methods for the surveillance of the project site. The instrumentation and monitoring will aim at, without limitation, observing and recording seepage, leakage, pressure and movements of soils at particular or singular locations. The system will comprise inter alia, piezometers installed at representative locations, observation wells, geodesics benchmarks, limnimetric gages in the riverbed and an automated weather station (for measurement/recording of rainfalls, atmospheric pressure, wind directions, temperature, humidity).

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