



Exploration & Production

GENERAL SPECIFICATION

SURVEYS

GS EP GEO 214

Onshore geophysical site survey - Electric Geophysical Survey
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1. Scope

The content of this General Technical Specification indicates the minimum standards required by Company for Electrical Resistivity Tomography (ERT) geophysical survey. However, should Company consider that any aspect of the work requires more detailed investigation, Company Reserves the right to apply further Particular Technical Specifications.

All Equipment and Materials necessary to complete the survey in accordance with this Contract shall be supplied by Contractor. Such Equipment and Materials shall include all spare parts and spare Equipment units as may be necessary to provide normal and continuous operations, and shall be in good operating condition prior to start of mobilization.

Such Equipment shall be properly maintained in such a way as to assure accuracy within the tolerances set by the manufacturer for such Equipment. Contractor undertakes to provide a statement of the surveying accuracy of this Equipment.

The Work defined in these Specifications shall be performed in accordance with the Agreement.

The Work shall include the following phases:

- **Data acquisition phase**
- **Data processing phase:** This phase is to be carried out in conjunction with data acquisition in order to be sure that survey objectives are reached
- **Interpretation phase.**

Reports shall include measured and computed data and interpreted maps as per objectives of the Particular Technical Specifications.

The final product shall be an Expert Report.

The scope of the Work is included in the Particular Technical Specifications.

2. Reference documents

The reference documents listed below form an integral part of this General Specification. Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published at the EFFECTIVE DATE of the CONTRACT.

Standards

Reference	Title
ASTM D 6431 - 99 (2010)	Standard guide for Using the Direct Current Resistivity Method for Subsurface Investigation
ISO 1000	Specification of SI units and recommendations for the use of their multiples and of certain other units

Professional Documents

Reference	Title
Not applicable	



Regulations

Reference	Title
Not applicable	

Codes

Reference	Title
Not applicable	

Other documents

Reference	Title
Not applicable	

Total General Specifications

Reference	Title
GS EP GEO 210	Onshore Geophysical Site Survey - Cross hole geophysical survey
GS EP GEO 211	Onshore Geophysical Site Survey - Seismic refraction geophysical survey
GS EP GEO 212	Onshore Geophysical Site Survey - Multichannel surface waves geophysical survey
GS EP GEO 213	Onshore geophysical site survey - Micro-Gravity Geophysical Survey
GS EP GEO 215	Onshore geophysical site survey - Radar Geophysical Survey
GS EP GEO 216	Onshore geophysical site survey - Electro-Magnetic Geophysical Survey
GS EP GEO 401	GIS requirements for engineering site surveys and studies
GS EP GPA 202	Seismic HSE for Land Activities
GS EP POS 003	Onshore Land Surveying and Positioning Works
GS EP POS 004	The Use of Differential Global Positioning System

3. ERT survey objectives and methodology

3.1 ERT survey objectives

Electrical Resistivity Tomography is a geophysical survey technique, giving high-resolution imaging of electrical properties of the subsurface soils and rocks.

Fields of application are wide and concern either hydro-geological, environmental or civil engineering surveys as:

- Delineation of pollution plumes, limits of landfills
- Landslide geometry characterization
- Localisation of dams, dikes or embankment leakages
- Water level characterization
- Aquifer characterization
- Location and extension of fractured zones in bedrock
- Location of quarries and deposits for railway or roads construction (mapping of sand and gravels lenses in a clay environment)
- Cathodic Protection.

3.2 Methodology

The ERT method is based on the measurement of the apparent soil resistivity using a linear array of equally spaced electrodes planted in the ground surface. The idea of using multi-electrode arrays was first suggested in 1981. The array is multiplexed to a resistivity-meter which gathers all apparent resistivity measurements between different dipoles to create an apparent resistivity sections (see Figure 1).

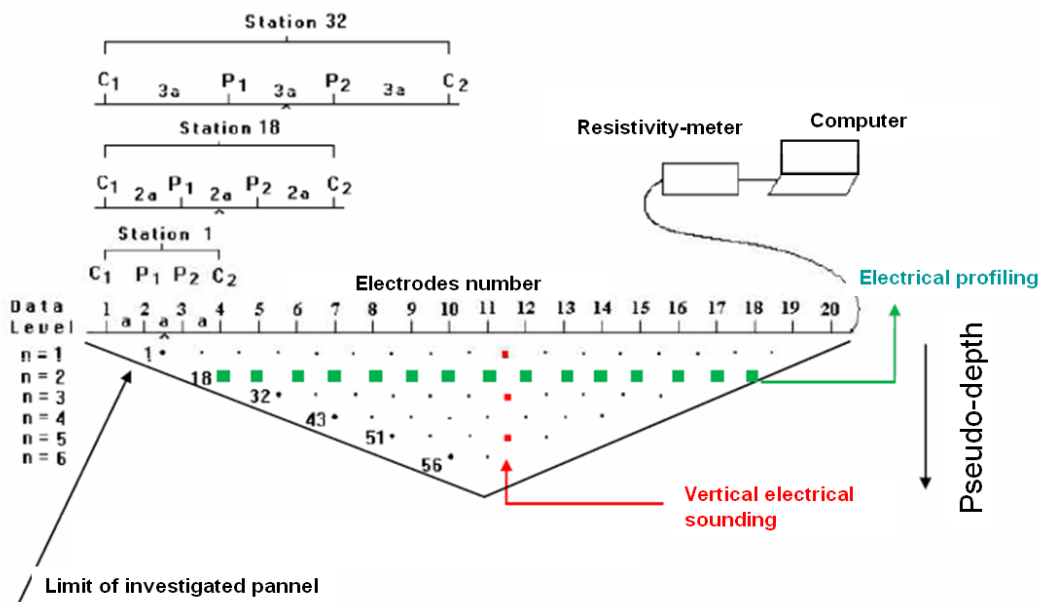


Figure 1 - Electrical Resistivity Tomography lay out

The final true resistivity section is obtained using an inversion algorithm, which will calculate the best soil resistivity model fitting with the measured data, representing apparent resistivity.

ERT may also be applied as a monitoring method to follow soil resistivity variations with time.

4. Units and abbreviations

4.1 Units

Only the ISO **International System** of units ([ISO 1000](#)) shall be used in all relevant measurements, processing and reporting.

4.2 Abbreviations

GIS	Geographical Information System (chart database)
DGPS / GPS	Differential / Global Positioning System
RTK	Real Time Kinematics (DGPS system)
ERT	Electrical Resistivity Tomography
ρ (Rho)	Resistivity (in Ohm-metres)
I	Intensity of injected current (in Amperes)
ΔV	Potential difference measured between two electrodes (in Volts)
W	Power in Watts equivalent to one ampere of current (A) flowing through an electrical potential difference of one volt (V).

5. ERT layout

Contractor shall request all available information from Company, to finalize his technical proposal, such as geological context, results of previous geophysical investigations, access to the site and state of the ground surface.

Contractor shall endorse Company's requirements in terms of electrodes geometry (number and spacing) and acquisition procedure (Wenner, Schlumberger, dipole-dipole...). If Contractor considers that the proposed electrodes geometry and acquisition procedure may not achieve Company's objectives, Contractor shall propose an alternative layout, which shall be properly justified and submitted to Company's approval.

5.1 Determination of measurements array

The determination of electrode geometry and acquisition method will be carried out on the basis of Company's objectives.

Contractor shall keep in mind that ERT results are presented in a trapezium shaped image, and shall ensure that the investigation depth defined by Company is the investigation depth obtained under **the whole length of the profile**, and not the maximum investigation depth obtained under the few electrodes located in the centre of the array. If necessary, Contractor will propose an overlap between spreads to avoid any data gaps (Figure 2).

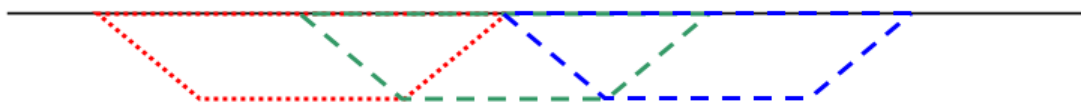


Figure 2 - Spreads overlap to maintain investigation depth under the whole profile



Contractor shall clearly define in his technical proposal, at a minimum:

- Array geometry: number of electrodes, electrodes spacing and location of infinite electrode if pole-pole or pole-dipole acquisition procedures are selected
- Acquisition procedure: Schlumberger, Wenner, dipole-dipole, pole-dipole or pole-pole
- Number of measured levels
- Proposed total acquisition cycle time with acquisition delay and acquisition time (current injection duration)
- Fixed standard deviation (error limit) with maximum number of stack fixed to obtain this standard deviation. A maximum standard deviation of 1% is required.

In a complex geological context, Company recommends performing 2 different acquisition procedures for the same geometry array, for example to combine Schlumberger and dipole-dipole procedures. The objective is to compare the 2 resistivity images, in order to identify reliable information from artefacts.

Contractor shall clearly document his acquisition procedure, which will depend of Company's objectives. Each acquisition procedure will have his advantages and drawbacks in terms of lateral and vertical resolutions or investigation depth. For example Wenner or Schlumberger procedures will be more efficient for resolving vertical changes (i.e. to map horizontal structures such as water level or sedimentary layers). A dipole-dipole procedure will be more efficient for resolving lateral changes (i.e. to map vertical structures such as dykes or fracture detection). Deepest investigation depths will be obtained by using a pole –pole procedure, knowing this yields the poorest resolution.

As shown on Figure 3, even with the same acquisition geometry (spread length and electrodes spacing), investigation depth will be different in function of selected acquisition procedure.

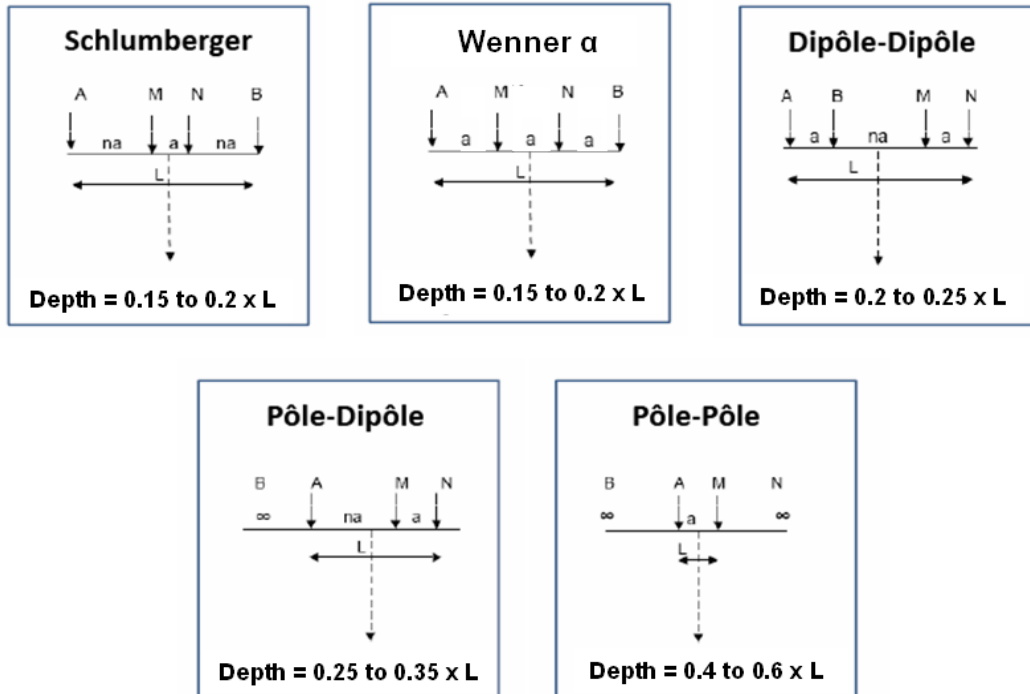


Figure 3 - Estimated investigation depth related to acquisition procedure as a function of spread length (L) – where A and B are current injection electrodes, and M and N are potential measurements electrodes

5.2 Measurement array validation using numerical modelling

Contractor shall present in his technical proposal examples of forward and reverse modelling to evaluate investigation depth and resolution of the final resistivity section, using geological information given by Company in the Particular Technical specifications.

Figure 4 presents an example of modelling performed on a 2-layer geological profile, with an 80 m thickness horizon of 100 Ohm.m resistivity, overlaying a low-resistivity horizon at 10 Ohm.m.

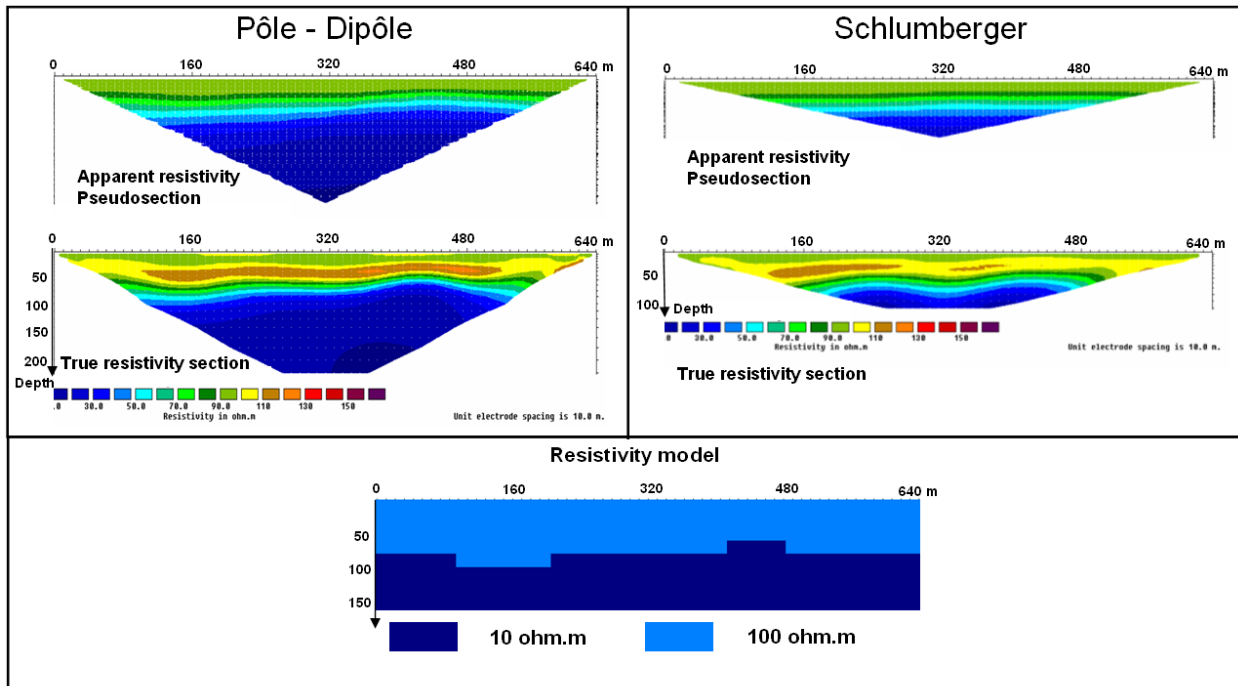


Figure 4 - Example of forward and inverse modelling performed on a 2-layer geological profile

On this geological example, a Pôle-dipôle acquisition array gives an investigation depth twice as high as a Schlumberger array.

6. Equipment

Contractor shall provide all necessary equipment to perform the work including 100% spare parts to limit any delay in the operations. All the different equipment shall be regularly maintained and calibrated using the manufacturer's procedure.

Calibration certificates shall be presented to the Company Representative before the start of the acquisition.

6.1 Resistivity-meter

The resistivity-meter shall have at least the following characteristics:

- Maximum output voltage of at least 400 V
- Output power of at least 100 W
- Resolution in voltage measurements of 1 μ V, with an accuracy of at least 1% over the whole temperature range
- Automatic Self Potential compensation
- Digital Stacking capability of enhancing the signal/noise ratio
- Display of standard deviation to give an indication of the noise level
- Pulse duration programmable from 0.2 s to a minimum of 8 s



- 50 Hz and 60 Hz power line rejection
- Induced Polarization measurement capability
- Operating temperature range from at least -5° C to +50° C
- Available test to check that electrodes are properly connected to the resistivity-meter.

6.2 Electrodes

Contractor shall propose stainless steel electrodes which create less noise than electrodes made of ordinary steel.

7. Positioning

7.1 Positioning system

The spread positioning shall be performed with DGPS (preferably a RTK system) or theodolite equipment. Equipment, procedures and calibration shall comply with General Specifications **GS EP POS 003** and **GS EP POS 004**.

Before the start of the site works, the equipment shall be verified by comparison with a fixed point with known coordinates and elevation. At Company's request, or if any doubts remain about the accuracy of the positioning system, this check shall be repeated after completion of the work.

The local geodetic system to be used shall be the one provided by Company.

7.2 Positioning accuracy

The coordinates and elevations (X, Y, Z) of each electrode shall be known with a decimetric accuracy (+/- 10 cm) in order to integrate topography in the data interpretation.

8. Work procedures

8.1 Calibration

The acquisition equipment (resistivity-meter, multi-electrodes cable) shall be well maintained and properly tested / calibrated as per the manufacturer's procedures. Calibration / test certificates shall be made available to Company before the start of acquisition.

8.2 Acquisition - QA/QC

QA/QC of acquired data shall be performed on site by Contractor. The raw data shall be of high professional quality, leading to no ambiguities in the potential (ΔV) and current intensity (I) measurements.

In ERT measurements, a particular attention shall be given to the coupling of ground electrodes, to reduce the contact resistance as much as possible; poor electrode grounding results in low transmitted power with associated bad resistivity readings.

Contractor shall take all necessary measures to ensure good electrode coupling, especially in case of dry soil conditions, which means:

- Increasing burial depth to find a more conductive soil



- Applying water or mud mixed with salt around electrodes
- Connecting 2 or 3 electrodes in parallel at each measurement point, to decrease the contact resistance by increasing the ground contact surface.

In dry and permeable soil like sand, water can be drained away before the end of measurement. In such a case Contractor shall propose a solution to increase viscosity to keep the mixture in place for a sufficiently long time.

Any hammer used to knock the electrodes into the ground shall be non-metallic to avoid static electricity effects (rubber or resin).

Contractor shall inspect all connectors and cables jumpers for dirt, oxide and damage that may cause data quality problems.

The quality of measurements will depend on the standard deviation value fixed by the operator.

Contractor shall set a standard deviation not exceeding 1%, with a maximum resistivity measurement cycle (number of stack) set to a minimum value of 4.

Contractor shall take care about current intensity injection during the whole duration of panel acquisition, especially for long profile with an important number of measurement levels, to avoid any risk of battery weakness appearing during the acquisition procedure.

Contractor shall care about the offset distance of infinite electrode in case of a pole-dipole or pole-pole acquisition procedure.

For pole-dipole procedure, the infinite current injection electrode shall be located at a distance higher than $6 \cdot L$ where L is the total length of the array. Measurements shall be performed in a forward and reverse manner to remove any bias in the inversed model due to the asymmetrical nature of this array.

For a pole-pole procedure, the 2 infinite electrodes (current and potential electrodes) should be located at a distance higher than $10 \cdot L$.

Contractor shall integrate in his technical proposal the performance of some classical 1-D Vertical Electrical Sounding to validate the investigation depth obtained on the inversed model resistivity section. This control may be carried out by simply extracting VES from a Schlumberger array in the pseudo-section of measured apparent resistivity.

Contractor shall mobilize the equipment necessary for the Geophysicist to perform a pre-interpretation on site, which includes resistivity imaging interpretation software, a PC and printer for the production of QC documents.

Contractor shall produce on site, before demobilisation:

- Measured Apparent Resistivity Pseudo-section
- Inverse Model Resistivity Section.

If necessary, a second phase of complementary measurements can be decided on the basis of the first results, in order to better ascertain the extent and amplitude of the main anomalies.

Where discrepancies occur between geotechnical information (e.g. boreholes) provided by Company and inversed resistivity sections results, Contractor shall re-interpret the data to propose new inversion results in agreement with the geotechnical results.



8.3 Interpretation

Interpretation includes 2 main steps:

1. Validation of the measured apparent resistivity values
2. Inversion process using software to determine a true resistivity model, which will give calculated apparent resistivity pseudo-section in line with the measured apparent resistivity values from the field survey.

Validation of the measured apparent resistivity values:

Contractor shall control the quality of field raw data before the inversion process. Good quality data usually show a smooth variation of apparent resistivity values in the pseudo-section. Bad data points characterized by low or high isolated values should be removed in the apparent resistivity data file.

Inversion process

Contractor shall keep in mind the problem of non-uniqueness in the inversion process. For the same measured data set, there is a wide range of models giving rise to the same calculated apparent resistivity values. To reduce the range of possible models, Contractor shall introduce into the inversion subroutine all the assumptions concerning the nature of the investigated soil, using available geological and geotechnical information. Good practise is to start the inversion with an initial model and adequate inversion parameters taking into account all available information.

Contractor shall specify in the final report all parameters used in inversion process.

8.4 Correlation with other available datasets

Contractor shall present, in the final report, a specific chapter to comment on the correlation between resistivity classes and geological horizons on the basis of all available informations, such as borehole logs, geological maps and data from outcrops. This correlation may be extended to other available surface or borehole geophysical results.

Contractor shall propose a complementary boreholes campaign to identify the areas of anomaly. This choice shall be clearly illustrated using a set of correlation charts, for each of the selected anomaly areas.

9. Personnel

Contractor shall provide in his proposal the organisation and composition of the team involved in the survey. Curricula Vitae of all personnel shall be included in the technical tender.

9.1 Management

Contractor shall nominate a **Project Manager** who shall be in charge of whole project on both technical and administrative grounds; he shall be the Contractor Representative. If he cannot be involved in the site survey, the Project Manager shall nominate a **Party Chief** to be responsible for the whole acquisition and interpretation work. The Project Manager and/or the Party Chief shall be fully experienced in ERT data processing and interpretation.

During the operations, the Party Chief shall act as sole Contractor Representative and shall sign the Daily Work Sheets.



The Project Manager and Party Chief shall remain assigned by Contractor to the project for the whole duration of the project. The Project Manager and Party Chief shall be entirely familiar with the Contract.

9.2 On site

The Contractor survey crew shall consist nominally of a minimum of 3 personnel, comprising the following roles and responsibilities:

- 1 x Party Chief in charge of the survey, liaison with Company's Representative, data QA/QC and pre-interpretation on site
- 1 x Operator geophysicist in charge of data acquisition recording
- 1 x Surveyor in charge of positioning.

One to three local helpers could assist the team for line clearing and equipment transportation.

10. HSE

Contractor is required to adhere at all times to Company's Health, Safety and Environment standards. In particular, reference is made to General Specification **GS EP GPA 202**.

Particular safety precautions for ERT survey:

Electrical resistivity measurements use current sources and voltages that may result in shock hazard and possible electrocution to the operator and field personnel. Adequate safety precautions should be taken to eliminate contact of personnel with measurement equipment, and especially with the electrodes during the current injection phase.

10.1 Contractor's responsibility

As part of the Project Execution Plan, a complete hazard identification and risk assessment (HAZID and HIRA) shall be provided by Contractor. The procedure for evacuating injured personnel (MEDEVAC/EVASAN procedure) shall be included in this safety plan.

Company's general safety instructions will be supplied to Contractor who shall review them critically, and point out any incompatibility there may be with his own safety plan.

When the survey works take place at an oil or gas production site operated by Company, Contractor shall report to the Company site manager. Before commencement of the field works, Company will provide to Contractor any specific regulations and/or work permit procedure relating to the survey site.

All matters concerning the safety of all survey personnel present during the field works at the survey site shall be Contractor's responsibility. Contractor's responsibility also includes briefing any Sub-Contractors on the safety procedures for the different equipment and tasks.

Before commencement of the survey works, a pre-job/kick-off meeting shall be organized by Company and Contractor. This meeting shall be attended by the Representatives of Company, Contractor and Sub-Contractors, and any other parties involved in the survey works, including the Company site manager and safety manager, and local authorities (if required). The purpose of this meeting shall be to review the scope of the survey works to be carried out, and to identify any other activities involved on or off site. Minutes of the meeting shall be drawn up and signed by both Company and Contractor Representatives.



In adverse weather conditions, Contractor may be required to cease the survey operations, when it is considered that such adverse conditions may affect the safety of survey personnel and equipment, or the quality of the site works. Such adverse conditions shall be defined in common agreement between the Contractor and Company Representatives.

10.2 Emergency on site

As mentioned above, Contractor is required to submit his safety plan to Company, for each project or different area within a project, before mobilisation, and including an Emergency Response Plan (ERP) detailing medical evacuation from the worksite. Such planning shall explicitly involve the structures and facilities of Company where appropriate (vicinity of worksite). The Contractor safety plan shall be submitted to Company for endorsement before the start of the operations.

Contractor shall submit to Company a crew list of all persons actually on site, by the time of the initial mobilisation, or any subsequent crew changes during the Work.

10.3 Incident / Accident reporting

Any incident or accident shall be investigated, even if not resulting in lost time injury (near-misses). The reports shall be forwarded to Company's Representative within 24 hours. An investigation form shall be included in an appendix to contractor's safety plan.

11. Reporting

11.1 Project Execution Plan

Contractor shall provide to Company a Project Execution Plan at least one week before the start of the survey. The Project Execution Plan shall detail in particular:

- The work procedures
- The safety plan including ERP and source handling procedure
- The project management and organisation, including all contact details.

11.2 Daily Work Sheet

Daily Work Sheets are prepared by Company and shall be signed by Contractor Representative. Details are provided in the Particular Technical Specifications. In addition, Contractor shall provide to Company the following information:

- Daily data records and QA/QC of the data records
- List of personnel on site.

Whenever a profile has been completed, a QA/QC of the profile shall be issued to the Company Representative no later than 24 hours after the completion of the said profile.

11.3 Field Report

This Report shall include but not limited to:

- Log of daily events
- Site location map



- List of equipments and technical descriptions
- The number of measured profiles with location map
- Array geometry and acquisition procedure
- Acquisition parameters (standard deviation, measurement cycle with acquisition delay and acquisition time, maximum number of stack...)
- Topography and leveling procedure
- Measured Apparent Resistivity Pseudosections
- Inverse Model Resistivity Sections
- Preliminary conclusions.

The Field report shall be provided to Company at the completion of the demobilisation.

11.4 Final Report

The report shall be an **Expert Report**. It shall be structured, concise and include clear and practical conclusions with respect to the survey objectives.

The final Report shall be presented in two (2) volumes:

- Volume 1: Survey Results including data examples, track plots and charts
- Volume 2: Technical appendices including Equipment description, logs and other technical documents as required by Company Representative.

Title: The final report shall be entitled:

- Name of recipient - Company affiliate/subsidiary/project
- Site reference and location name, Country
- "Survey Report for:"
- Title Survey
- Name of the structure(s), field(s)
- Contractor name
- Start/end dates of onshore work.

Certification: The first page of the report shall show certification, specifically:

- Name of Party Chief in charge of the field work
- Name of person responsible for interpretation
- Name and signature of QA/QC issuing authority
- Date of issue.

11.4.1 Draft Final Report

One draft copy of the final report, with all relevant maps and illustrations, shall be submitted to Company, for review and approval.



Contractor shall issue the final report after incorporation of Company's amendments or addenda.

11.4.2 Final Report Content

The Final Report shall comprise the following:

- **Volume 1: "survey results"**

Section 1: Abstract giving a brief description of the operations

- Date of survey
- Location of measured profiles with key coordinates and situation plan
- Summary of main survey results
- Conclusion and recommendations.

Section 2: Results

- Introduction
- General situation plan
- Summary of local geological / geotechnical information
- Objectives defined by client with definition of array geometry and acquisition procedure based on forward modeling
- Comments on final Inversed Model Resistivity Section
- Correlation between true resistivity sections and other geophysical method results (if available)
- Correlation between resistivity classes and geological formation on the basis of borehole information (if available)
- Presentation of forward modelling results performed on geological assumptions which could explain observed resistivity anomalies
- Conclusion summarising the main results
- Recommendations for the positioning and the depth of boreholes to ground-truth the interpretation of the resistivity section.

Location maps and situation plans shall comply with the Total General Specifications **GS EP GEO 401**.

Section 3: Charts & profiles

- Location map of measured profiles
- Topographical charts
- Measured Apparent Resistivity Pseudosections
- Inverse Model Resistivity Sections.

Charts scales will be defined in Technical Particular Specifications.



- **Volume 2: “Operations report”**

Section 1: Technical Report

- Achieved scope of work
- List of equipments
- Time allocation - durations of operations, transit, stand-by and breakdowns, as percentage of total
- Topographic and levelling procedure
- The results of the positioning system accuracy check and monitoring
- The results of all calibrations, trials and tests
- The settings and all recording parameters used (standard deviation, measurement cycle with acquisition delay and acquisition time, maximum number of stack...)
- Comments on data quality
- Comments on inversion parameters used in inversion process.
- Geological / Geotechnical logs (if any).

Section 2: Appendices

- Appendix 1: Log of daily events
- Appendix 2: Personnel involved
- Appendix 3: Detailed description of the equipment including positioning system
- Appendix 4: All topographical data
- Appendix 5: Raw Data of the whole set of investigated profiles with field note.

11.5 Deliverables

Reports and charts shall be compiled as specified in these General Specifications, and delivered in paper and electronic format. All reports and charts shall thus comply with the following requirements:

- a) Five paper copies, unless otherwise specified in the Particular Technical Specifications
- b) Electronic data (charts and reports) shall be also provided as two copies.

Final Survey Report

Electronic data shall be provided in the following formats:

- Text documents: Word for Windows 2003; and unprotected Adobe Acrobat PDF
- Drawings, charts: AutoCad 2008 and unprotected Adobe Acrobat PDF
- Images: geo-referenced JPG or TIFF format.

GIS Requirements

As a separate deliverable, the data acquired and the charts shall be provided in a format fully compatible with requirements of the Company's GIS (Geographical Information System, or survey database). Reference is made to General Specification **GS EP GEO 401**.



Ancillary Data

In addition to the above results of the survey, Contractor shall include the ancillary data detailed below. Items to be included as annex to Final Report, in digital form (stored on CD / DVD or storage disk):

- Raw data
- Observer's log (ascii)
- Positioning data (ascii)
- True resistivity section in ascii format giving X, Y, Z and resistivity value.

12. Other references

Following documents are applicable:

- Standards: [ASTM D 6431 - 99 \(2010\)](#)
- Total General Specifications: [GS EP GEO 210](#), [GS EP GEO 211](#), [GS EP GEO 212](#), [GS EP GEO 213](#), [GS EP GEO 215](#) and [GS EP GEO 216](#).