

GENERAL SPECIFICATION

SURVEYS

GS EP GEO 212

Onshore Geophysical Site Survey Multichannel surface waves geophysical survey
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00	01/2011	First issue
Rev.	Date	Purpose of the revision

Owning entity: DEV/TEC	Managing entity: DEV/TEC/GEO
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1. Scope

The content of this General Technical Specification indicates the minimum standards required by Company for multichannel surface waves geophysical survey. However, should Company consider that any aspects 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 the award of Contract.

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 surveyed area is acceptable
- **Interpretation phase.**

Reports shall include measured and computed data and interpreted cross-sections as per objectives of the Particular Technical Specifications (Exhibit A2).

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.

External Documents

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published at the effective date of this document.

Reference	Title
ISO 80000-1	Quantities and units – Part 1 General

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Total General Specifications

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published in the applicable yearly collection.

Reference	Title
GS EP GEO 211	Seismic refraction 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. Objectives and methodology

3.1 Objectives

Surface waves methods, also called Multichannel Analysis of Surface Waves (MASW), are primarily used to determine shear-wave velocity profiles in near-surface. Shear waves are directly proportional to shear modulus (Gd) required for quantifying the soil stiffness (or soil rigidity).

The MASW method is based on the Rayleigh waves, which propagate in a vertical plane near the surface of the soil. Surface waves are interferences of body waves (P and S) trapped in superficial layers. Only the vertical component is considered in the MASW method.

The penetration depth of surface waves is directly related to their wave length. Small wave lengths have a propagation close to the surface, and large wave lengths have a deeper propagation. Because the wave length is related to the signal frequency and assuming a regular increase of the shear wave velocity with increasing depth, higher frequencies propagate at low velocity in a very shallow horizon and lower frequencies propagate at higher velocity in deeper horizons. This property is used to calculate the dispersion curve which gives variations of Rayleigh wave velocity versus frequency.

Main applications are related to earthquake engineering and characterisation of the soil response to cyclic and dynamic solicitations for critical structures including but not limited to:

- Storage tanks
- Refinery
- Compressors
- Multi-storey buildings
- Nearshore structures.

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3.2 Methodology

Surface Waves analysis is performed in three steps:

- Calculation of Rayleigh waves dispersion diagram
- Selection of the accurate dispersion curve
- Numerical inversion to obtain Vs profiles.

Investigation depth is limited by the low frequency content of the source spectrum, by the natural frequency of the sensors and by the site geology itself.

4. Units and abbreviations

4.1 Units

Only the ISO **International System** of units ([ISO 80000-1](#)) shall be used in all relevant measurements, processing and reporting.

4.2 Abbreviations

Ed	Dynamic Young Modulus
Gd	Dynamic Shear Modulus
GIS	Geographical Information System (chart database)
DGPS/GPS	Differential/Global Positioning System
MASW	Multichannel Analysis of Surface Waves
RTK	Real Time Kinematics (DGPS system)
SEG-2	Society Exploration Geophysicists format 2
SEG-Y	Society Exploration Geophysicists format Y
v	Poisson's ratio
Vp	P-wave velocity
Vs	S-wave velocity
WGS 84	World Geodetic System 1984

5. Seismic spread layout

The standard spread shall comprise a minimum of 24 to 48 receivers with 4 shots (2 at each end and 2 at an offset distance). Details are provided in the following subsections.

Contractor shall endorse Company's requirements in terms of spread layout. If Contractor considers that the proposed spread layout may not achieve the Company's objectives, Contractor shall propose an alternative layout, which shall be properly justified and ultimately approved by Company.

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5.1 Number of receivers and shots

The standard spread shall be composed of 24 to 48 receivers at the minimum with 4 shots (2 at each end, and 2 at an offset distance). A typical layout is presented in Figure 1.



Figure 1 - Standard seismic spread layout, 24 channels-4 shots

5.2 Sensor spacing

The sensor spacing shall be selected in such a way to avoid spatial aliasing, implying a sensor spacing (d) of less than half of the minimum S wave-length (λ).

For example,

With $V_s = 200$ m/s and $f = 40$ Hz, $\lambda = 5$ m and the sensor spacing shall be less than 2.5 m.

5.3 Spread length

The spread length is the distance between the two extreme receivers (1 and 24/48). It controls the resolution and the achievable investigation depth of the linear array.

The investigation depth depends on two main factors:

1. The wave length λ of the generated seismic signal. Typically, the maximum investigation depth is $\lambda/3$
2. The spread length L . Typically, the maximum investigation depth is $L/4$.

Therefore, the spread length shall be at least 4 times the intended investigation depth. In such a case the low frequency content of the source becomes the predominant parameter.

Note: Even with a very low frequency source, the Rayleigh wave spectrum will be limited by the natural frequency of the site. This natural frequency appears for site with a strong velocity contrast between sediment and bedrock.

The natural frequency of a site can be determined by the following formula:

$$f \approx \frac{V_s}{4D}$$

where D is the expected depth of the bedrock and V_s is the expected shear wave velocity. The amount of Rayleigh energy is extremely low for $\lambda > 4D$, which gives a maximum investigation depth $\lambda/3 = 4/3D$.

In any case, Contractor shall perform a pre-interpretation on site after performance of the first spread to check the effective investigation depth.

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5.4 Shot location

5.4.1 End shots

A minimum distance shall be established to avoid seismic signal saturation on the first traces. Signal processing is not possible on saturated traces.

5.4.2 Offset shots

Offset shot distance shall be determined to have at least half the wavelength between the corresponding offset shot point and the centre of the spread. The maximum expected wavelength shall be considered.

For example, with a maximum anticipated wave length of 60 m, the distance from the offset shot point and the centre of the spread shall be at least 30 m.

Contractor shall perform a pre-interpretation on site to check that offset shot location has been correctly determined in order to obtain a clear dispersion diagram.

6. Equipment and Procedures

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 recommended procedures.

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

6.1 Seismic recorder

The seismic recorder shall have at least the following characteristics (reference is made to typical equipment such as Geometrics Stratavisor or Geode, DMT Summit or equivalent):

- Number of channels: between 24 to 48 traces (depending on the Particular Technical Specifications)
- Minimal sampling rate of 4 KHz
- Pre-trigger of 0.1s minimum
- Recording length of at least 4 s
- Triggering option on positive, negative or contact closure with adjustable threshold
- 24 bits A/D converter
- Cross talk: -125 db for frequency of 20 – 30 Hz
- Data format: SEG-2 standard and SEG-Y.

6.2 Seismic receiver

The receivers shall be of Geophone type with a typical natural frequency of 4.5 Hz.

The coupling of the geophones with the ground shall be ensured in order to enhance signal/noise ratio.

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Contractor shall provide in his tender, the response curve and sensitivity of the geophones proposed for the project.

6.3 Source

Source choice is of primary importance for data quality.

The preferred source to generate a signal with frequency spectrum as wide as possible (particularly with low frequency) is explosive.

If the use of explosives is prohibited at the survey site (e.g. urban or industrial area context, military area, high voltage aerial line, etc.), Contractor shall propose a special non destructive weight drop source adapted to generate low frequency signals.

A simple 5 kg hammer source can be accepted for frequencies above 10 Hz.

A weight drop source developing a minimum energy of 500 joules shall be used for lower frequencies (type PEG-40 kg or equivalent).

The impact plate shall be of a material adapted to low frequency generation (type Teflon or equivalent).

In some areas, natural and/or anthropogenic seismic sources can be proposed.

6.4 Cable

The cable shall be mounted with water proof connectors. It shall be noted that a cable with simple Muller connectors is not acceptable to Company.

7. Positioning

7.1 Positioning system

The spread positioning shall be performed by using satellite DGPS or preferably the RTK system. 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 DGPS or RTK system 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 DGPS/RTK 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) for each spread receiver and shot point shall be known with a centimetre accuracy.

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8. Work procedures

8.1 Calibration

The acquisition equipment (source, geophones and recorder) shall be well maintained and properly tested/calibrated as per 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 recorded shall be of high professional quality, leading to no ambiguities in the surface waves identification for all traces (Figure 2).

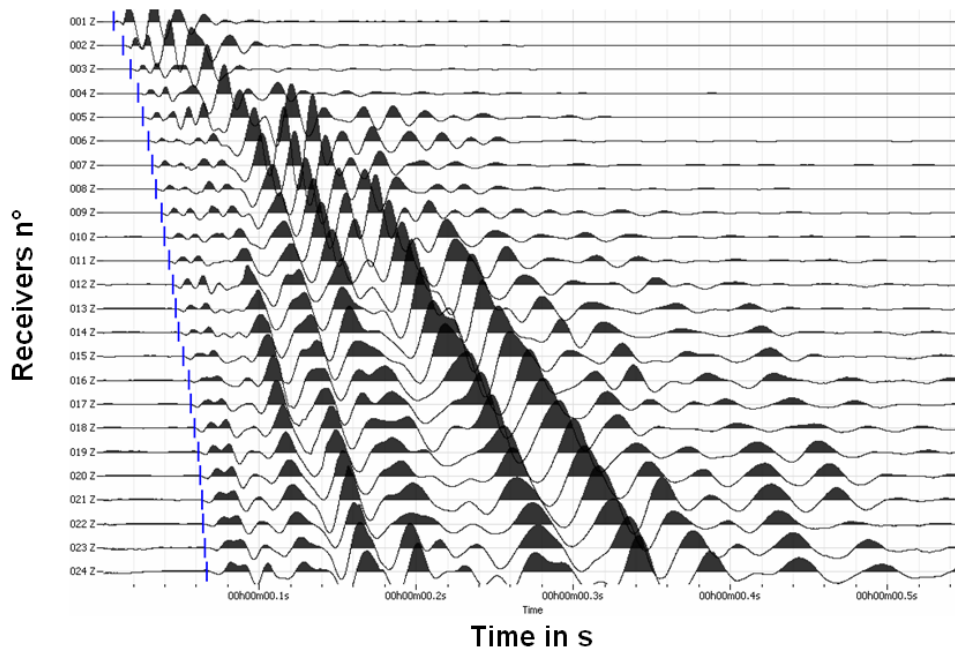


Figure 2 - Example of good data quality in surface waves acquisition

Number of reversed and dead traces shall not exceed 5% of the total number of active traces.

Contractor shall mobilize the equipment necessary for the geophysicist to perform a pre-interpretation on site, which includes seismic and QC interpretation software, PC and printer for edition of QC documents.

QA/QC shall integrate the dispersion diagram computation in order to ensure the quality of the data (Figure 3).

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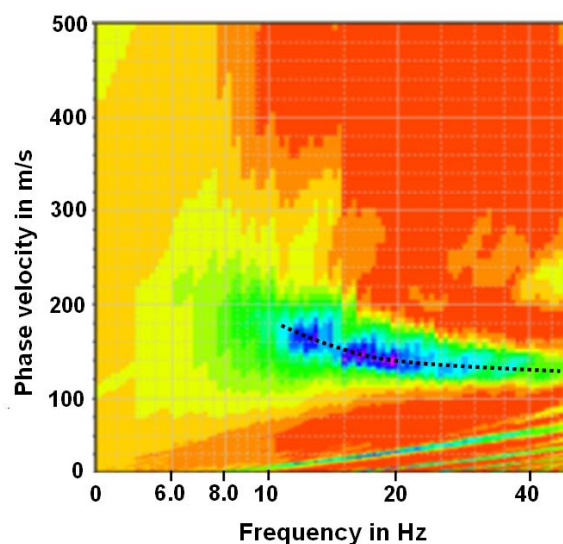


Figure 3 - Example of clear dispersion diagram (black dots # picked dispersion curve) - aliasing features noted below 100 m/s

8.3 Interpretation

An inversion process is required to obtain Vs profiles from dispersion curves. This is known to be a non-unique problem especially when considering data uncertainties. Many Vs profiles can fit a dispersion curve within a range of common data errors (5, 10 or 20%).

Software providing a unique solution without uncertainty levels is not acceptable to Company.

The preferred inversion method is based on a stochastic approach (Neighbourhood algorithm, Genetic algorithm or other), and the solution must be a set of valid profiles (Geopsy software or equivalent to be proposed).

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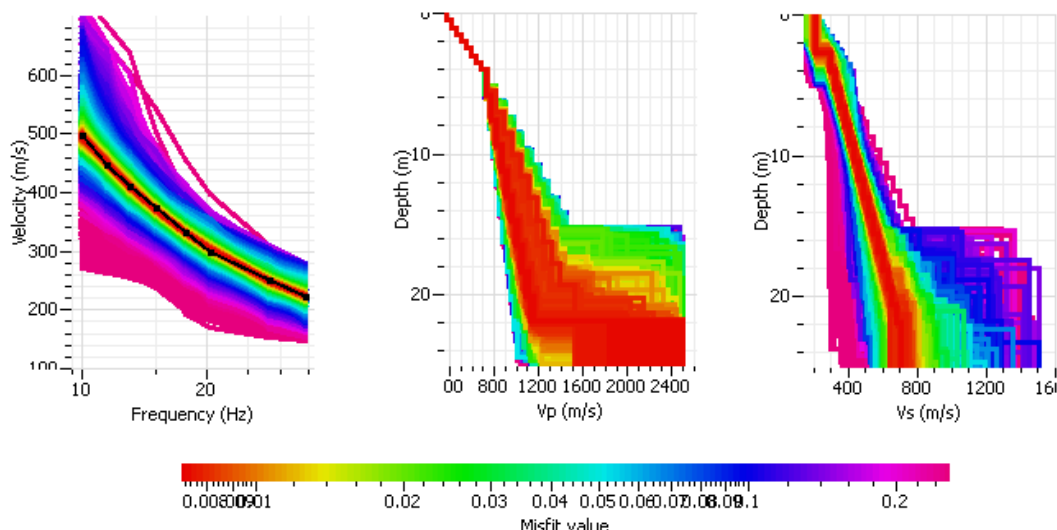


Figure 4 - Typical inversion results (Good convergence in red)

Contractor shall perform a standard seismic refraction interpretation by picking first break arrivals, to obtain a reliable Vp profiles. Reference is made to General Specification **GS EP GEO 211**. This information on the Vp velocities shall then be integrated in the initial model used to start the inversion process.

Ultimately, dynamic Young moduli (Ed), dynamic shear modulus (Gd) and the Poisson's ratio (ν) of the different formations shall be calculated from Vp and Vs velocities using the following formulae:

$$\nu = (V_P^2 - 2V_S^2) / 2 \cdot (V_P^2 - V_S^2)$$

$$E_d = 2\rho \cdot V_S^2 \cdot (1 + \nu)$$

$$G_d = \rho \cdot V_S^2$$

where ρ is the density of the materials (to be estimated from available geotechnical information).

The final interpretation shall integrate all available data.

Notes: Low velocity zones (LVZ, decreasing velocity with increasing depth) introduce equivalence problems in the inversion, making non-uniqueness even worse. They are commonly encountered in least-square results, and rarely connected to any real soft layer at depth. By default, LVZs must be proscribed. However in certain cases and with approval from Company's representative, a controlled number of LVZs can be admitted if supported by other investigation methods or geological reports.

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.

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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 technically involved, the Project Manager shall nominate a **Geophysicist** to be responsible for the whole acquisition and interpretation work. The Project Manager or Geophysicist shall be fully experienced in seismic refraction and surface wave acquisition.

The Party Chief shall be a qualified geophysicist/geologist, specialised in seismic refraction and surface wave acquisition. During the operations, the Party Chief shall act as sole Contractor Representative and shall sign the Daily Work Sheets.

The Project Manager and Geophysicist shall remain assigned by Contractor to the project during the whole duration of the project. The Project Manager, Geophysicist 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 4 to 5 personnel, comprising the following roles and responsibilities:

- 1 x Party Chief in charge of survey and relation with Company's Representative
- 1 x Geophysicist in charge of QA/QC and pre-interpretation on site
- 1 x Operator in charge of acquisition recording
- 1 x Surveyor in charge of positioning
- 1 x Blaster licensed to handle and set off explosives (optional).

2 to 4 local helpers shall assist the team in equipment transportation, line clearing and seismic spread installation.

If the use of explosives is prohibited, the blaster will be replaced by a technician who will be in charge of the non destructive weight drop source manipulation.

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**.

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 the Contractor. The procedure for evacuating injured personnel (MEDEVAC/EVASAN procedure) shall be included in this safety plan.

Dedicated procedures shall be developed in the safety plan for the use of explosives, weight drop or shotgun sources.

Company's general safety instructions will be supplied to Contractor who shall read 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,

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Company will provide to Contractor any specific regulations and/or work permit procedure regarding 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 authority (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 at or off the 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 Emergency Response Plan (ERP) and medical evacuation from the worksite. Such planning shall explicitly involve the structures and facilities of Company where appropriate (in the vicinity of the worksite). The Contractor safety plan shall be endorsed by Company 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
- The project management and organisation, including all contact details.

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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 Specifications (Exhibit A2). In addition, Contractor shall provide to Company the following information:

- Daily records
- QA/QC of 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 completion.

11.3 Field Report

This Report shall include but not limited to:

- Log of daily events
- Location map
- Summary of available geological information
- Test & calibration reports
- List of equipments and technical descriptions
- The number of seismic spreads recorded with geometry specifications
- Raw data examples
- Preliminary dispersion diagrams for each shot and associated picking
- Preliminary synthesis of velocity (V_p) classes identified on site
- Representative V_s inversion examples
- Preliminary correlation between velocity classes and geological formation on basis of available geotechnical information
- 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 respects 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.

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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 surveyed with key coordinates and situation plan
- Summary of main survey results
- Conclusion and recommendations

Section 2: Results

- Introduction
- General situation plan
- Geodetic parameters and datum
- Location map of the performed seismic profiles.
- Summary of local geological/geotechnical information

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- Achieved scope of work
- The number of seismic spreads recorded with geometry specifications
- Raw data examples
- Dispersion diagrams for each shot and associated picking
- Inverted Vs profiles and their associated theoretical dispersion curves
- Synthesis of velocity classes (Vp and Vs) identified on site
- Emphasis on Vs uncertainties versus depth for each profile
- Description of each interpreted seismic profile
- Table presenting computed dynamic moduli (Ed, Gd) with density, Vp and Vs values for each level
- Correlation between geological/geotechnical formations and computed moduli (Ed, Gd) and velocities (Vs, Vp)
- Conclusion summarising the main results
- Recommendations for the positioning and the depth of boreholes to ground-truth the interpretation of the seismic refraction and surface waves.

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

Section 3: Charts & profiles

- Track plots
- Topographical charts
- Interpreted and synthetic profiles
- Tabulated results as per format below:

Depth (m)	Density ρ (T/m ³)	Vp (m/s)	Vs (m/s)	Poisson's ratio ν (–)	Ed (kPa)	Gd (kPa)
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Horizontal and vertical scales will be defined in the Particular Technical Specifications (Exhibit A2).

• Volume 2: “Operations report”

Section 1: Technical Report

- Achieved scope of work
- Percentage times of operations, transit, stand-by and breakdown
- Geodetic parameters and datum
- The results of the positioning system accuracy check and monitoring
- The results of all calibrations, trials and tests

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- The settings and all recording parameters used
- List of equipments
- Recorded traces
- Geological/Geotechnical logs (if any).

Section 2: Appendices

- Appendix 1: A detailed field note for each seismic spread, with name and specifications of each shot (location and distance), and acquisition parameters
- Appendix 2: personnel involved
- Appendix 3: daily survey diary
- Appendix 4: detailed description of the equipment including positioning system
- Appendix 5: All topographical data
- Appendix 6: Raw data in SEG-2 and SEG-Y formats.

11.5 Deliverables

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

- a) 5 Paper copies, unless otherwise specified in the Particular Technical Specifications
- b) Electronic data (charts and reports) shall be also provided in 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 seismic data in SEG-2/SEG-Y format
- Observer's log (ascii)
- Positioning data (ascii)



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- First break times (ascii)
- Dispersion curves values (ascii).