

GENERAL SPECIFICATION

SURVEYS

GS EP GEO 217

**Near-surface 2D high-resolution seismic reflection
geophysical survey onshore**

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1. Scope

The General Technical Specification details the minimum standards required by Company for onshore Near-Surface High-Resolution Seismic Reflection geophysical surveys, meaning surveys targeted at the top 100 meters below ground level. However, should Company consider that any aspect of the work requires more detailed investigation, Company reserves the right to apply further Particular Technical Specifications (Exhibit A2).

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. 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 should be carried out in conjunction with acquisition to ensure that survey objectives are reached
- **Interpretation phase.**

Reports shall include measured and processed data and interpreted seismic sections as per objectives of the Particular Technical Specifications.

The final product shall be an Expert Report.

The Scope Of Work is included in the Particular Technical Specifications (a Contract Exhibit).

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
ASTM D7128 (reapproved 2010)	Standard Guide for Using the Seismic Reflection Method for Shallow Subsurface Investigation
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 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 214	Onshore Geophysical Site Survey - Electric 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 GPA 203	Seismic HSE for Shallow Water and Transition Zone Activities
GS EP POS 003	Onshore land surveying and positioning works
GS EP POS 004	The use of Differential Global Navigation Satellite System

3. High-Resolution seismic reflection survey objectives and methodology

3.1 Seismic reflection survey objectives

High-resolution seismic reflection is a very effective method to map the structural extension of geological layers from the very near-surface to a depth of one to three hundred meters below ground (refer to [ASTM D7128](#)).

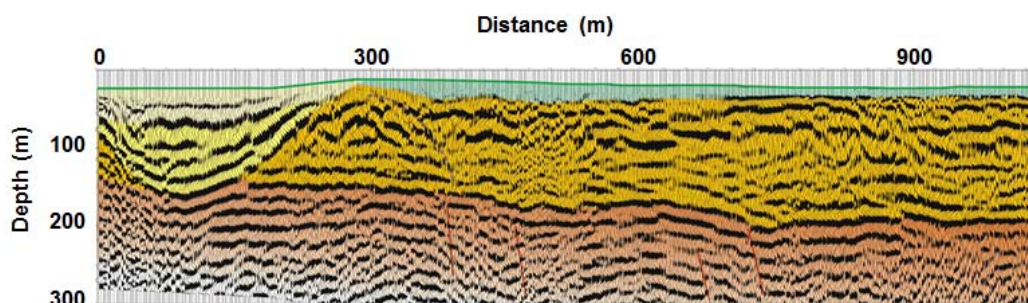
Applications are numerous and concern either geological, civil engineering, environmental or hydrological purposes:

- Determination of the thicknesses of geological units and mapping variation of depth to bedrock
- Search for paleo-channels beneath alluvium or other consolidated sediments
- Detection of faults which is of primary importance when studying earthquake hazards, or when searching for high-permeability pathways

- Detection of shallow water table
- Characterization of lateral changes in lithological units related to evolution of elastic properties or density of the materials (variation of reflection coefficient)
- Detection of gas accumulations to select appropriate location for drilling (indicator such as bright spots related to higher acoustic impedance due to gas accumulation).

This method may be also applied, in association with other methods such as microgravity, for the detection of air-filled sub-surface cavities and tunnels.

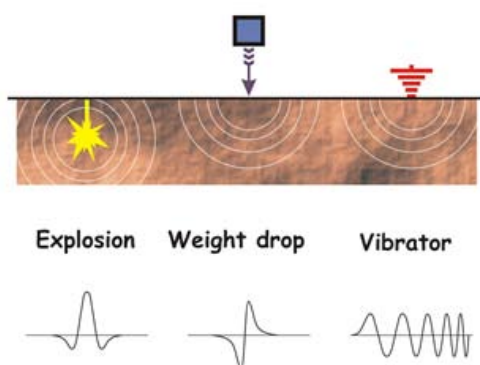
Figure 1: Example of seismic reflection section showing a paleo-channel



3.2 Methodology

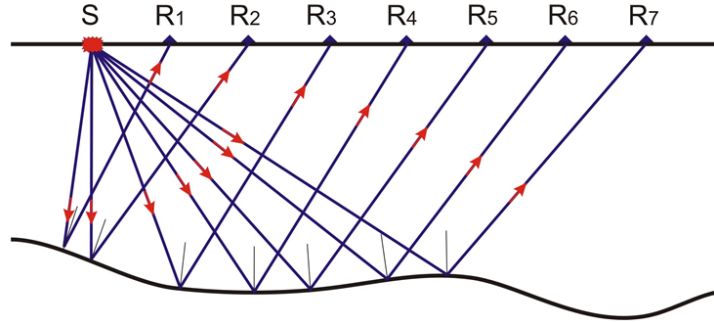
The seismic reflection method consists of generating seismic waves into the ground, using an energy source such as dynamite, weight drop or vibrator.

Figure 2: Different land seismic sources



Those seismic waves are partly reflected back to the surface by each reflecting geological interface.

These reflected energy waves are then recorded over a predetermined time period (called the record length) by receivers deployed at the surface.

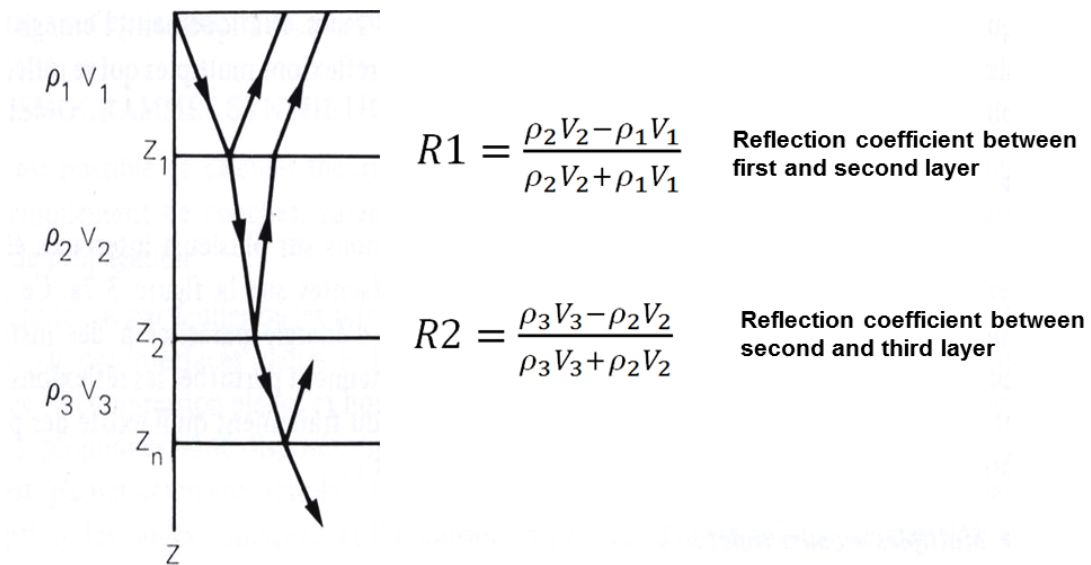
Figure 3: Reflection ray paths


Efficiency of the method will mainly depend on the acoustic impedance contrast between the different geological interfaces. Acoustic impedance is given by the product of mass density and seismic wave velocity.

Acoustic impedance $I = \rho V$, where ρ is the density of the layer and V its seismic velocity.

At normal incidence the reflection coefficient $R = (I_2 - I_1) / (I_2 + I_1)$.

$$R = \frac{\rho_2 V_2 - \rho_1 V_1}{\rho_2 V_2 + \rho_1 V_1}$$

Figure 4: Reflection coefficient


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.

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4.2 Abbreviations

GIS	Geographical Information System (chart database)
DGPS / GPS	Differential / Global Positioning System
RTK	Real-Time Kinematics (DGPS system)
SEG-2	Society Exploration Geophysicists format 2
SEG-Y	Society Exploration Geophysicists format Y
Vp	Velocity of Seismic compressional wave
ρ	Density
I	Seismic impedance: product of seismic compressional wave velocity and density of the material
R	Reflection coefficient: ratio of the amplitude of the reflected wave to the amplitude of the incident wave
dB	Decibel
VSP	Vertical Seismic Profile
CMP	Common Mid-Point profiling
AGC	Automatic Gain Control
NMO	Normal Move-Out corrections
WGS 84	World Geodetic System 1984
HSE	Health Safety and Environment
ERP	Emergency Response Plan
QA/QC	Quality Assurance/Quality Control
HAZID	Hazard Identification

5. Seismic spread layout

Definition of the spread layout parameters depends on target depth, and resolution required on this target.

Main parameters include location of survey lines, source and receiver geometry, number of active channels and fold (multiple coverage rate).

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

5.1 Determination of source and receiver geometry

Determination of source and receiver geometry includes determination of the source-receiver offset with receiver spacing.

The geometry shall be defined following two steps:

- A first step of design proposed and justified on the basis of numerical modelling results
- A second step of final survey design proposed on the basis of a preliminary in field data acquisition test, performed at the beginning of the survey in close collaboration with Company's representative.

The object is to obtain the optimal acquisition window to separate target reflections from coherent noise, with visualisation of the reflected waves on several adjacent seismic traces, which fully and coherently sample the target reflection wavelet.

5.1.1 Numerical modelling

When sufficient preliminary information are available, such as known seismic properties, layer/target geometry, or logging results performed in a nearby borehole (sonic, density, resistivity, gamma logs), it is strongly recommended that Contractor should in advance perform forward modelling to generate a synthetic seismogram.

Results of modelling will be very useful to identify the best acquisition geometry, in order to separate target reflections from coherent noise events such as direct waves, refractions, air waves and surface waves (ground roll).

Figure 5: Example of forward modelling to define optimal acquisition window

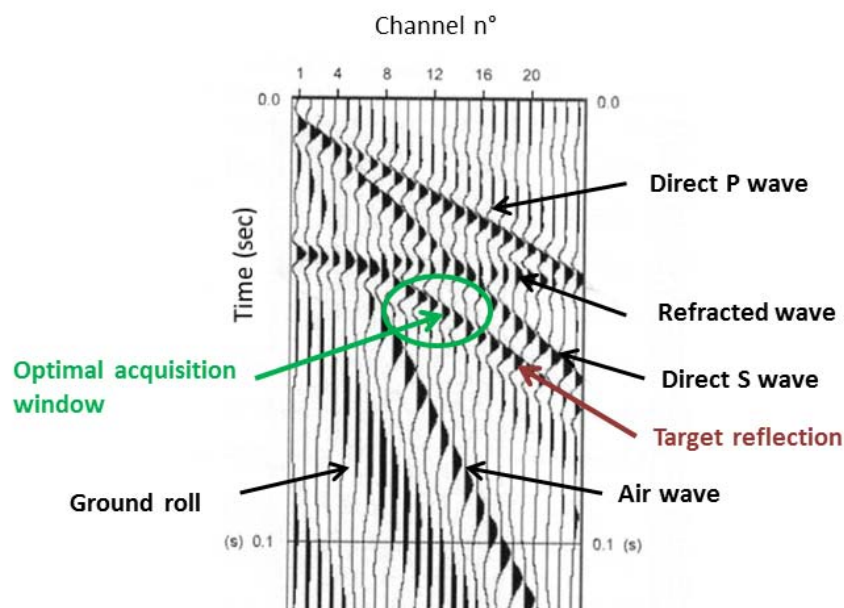


Figure 5 gives an example of forward modelling showing the optimal acquisition window (in green), located in the centre of the seismogram between channels 8 and 16.

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5.1.2 Preliminary in field data acquisition test

Synthetic seismograms cannot replace the preliminary in-field data acquisition tests which shall be performed at the beginning of the survey.

The final survey geometry shall be defined after the preliminary in-field data acquisition test, performed at the beginning of the survey in close collaboration with Company's representative.

Company requires a walk-away wavefield test, consisting in moving the source by different offsets from a closely spaced line of geophones. The distance between source and receivers should be at least 1.5 times the depth of the investigation target.

The location of the test profile shall be determined in close collaboration with Company's representative. If possible, the test profile shall be located close to an existing borehole.

The purpose of this test is for Contractor to define the final survey design with equipment characteristics. It includes the definition of:

- The optimal source-receivers geometry
- The determination of active channels count and fold value
- The specifications of source and receivers (refer to chapter 6: Equipment).

The comparison between the seismogram effectively obtained in the field and the synthetic seismogram obtained by numerical modelling shall be provided and commented by Contractor at this stage of the survey design.

Contractor shall define, once the walk-away wave field test is completed, the acquisition parameters and equipment specifications retained for the final survey.

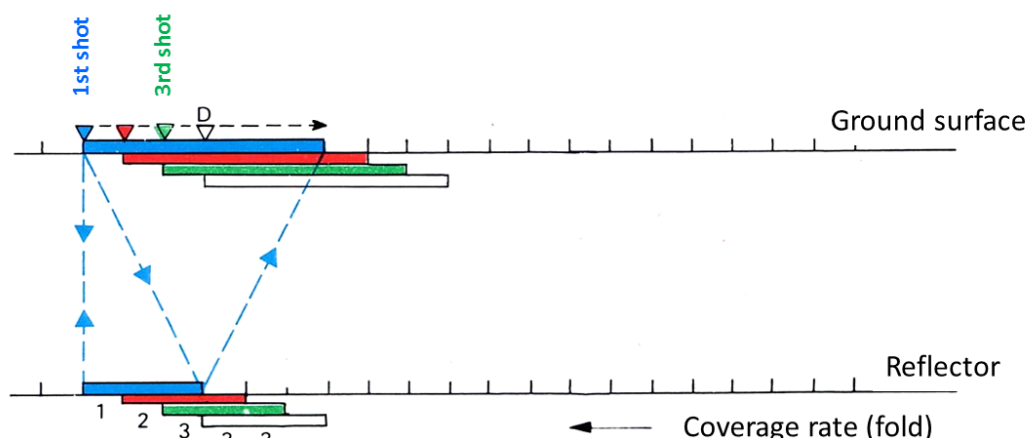
It means at a minimum:

- Record length in ms with associated sampling rate
- Number of active channels recorded for a single shot
- Source point spacing
- Source offset
- Receivers natural frequency
- Receivers spacing
- Fold value
- Number of receivers per channel (if more than one geophone is used per channel, the geophone group should not be placed in a dispersed array, only placed close to one another for reasons of point-receiver S /N improvement.
- Type of source
- Zero-time procedure
- Stack count.

5.2 Determination of active channels number and multiple coverage rate

The more common used technique for Near-Surface High Resolution seismic reflection survey is Common Mid-Point (CMP) reflection profiling. As shown on figure 6, this technique involves multiple equally-spaced seismic sensors, with multiple source points equally-spaced.

Figure 6: Common Mid-Point reflection profiling (CMP)



Each move of the source along the profile is associated with a move of the sensor spread by the same distance, so that the source – receiver geometry remains the same. Since few years, due to the large number of channels available on modern seismic recorders, all available channels may remain live for a large number of shots, before to physically move the spread. Final selection of active channels for each shot may be performed during processing phase. Contractor shall submit exact acquisition procedure to the Company Representative for final approval.

The best approach recommended by Company to define the final survey fold value, is to perform a walk-away test with the maximum fold available, using the maximum active channels of the recorder, with a source point every receiver spacing. Final decision should be taken after data processing, by progressively reducing the fold number to select the optimal configuration to fulfil Company's objectives, in term of efficiency and costs.

The source spacing is a whole-number increment of the receiver spacing. This number gives the value of the coverage rate (fold value). For example, for a 48 active channels acquisition with a point source located every each receiver spacing, the fold rate equals 24, which means that each reflection point on the reflector target is associated with the 24 traces of 24 different receivers. This redundancy in target sampling is one of the key parameters to the signal/noise ratio enhancement.

5.3 Location of profiles

The length of investigated profiles shall be longer than the target size. For example when surveying a fault or a buried channel, the investigated lines should cross over the target area to ensure a proper imaging of both the target and the surrounding geological context.

Contractor shall propose a profile length which ensures that the full-fold coverage is maintained over the whole target area and its surroundings.

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Particular attention shall be paid to anticipate the effect of the dip of the target structures, which may involve an extension or a lateral shift of the profile to correctly image the target.

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 Seismic recorder

The seismic recorder shall have at least the following characteristics:

- Number of channels: 96 as a minimum, depending on the number of receivers and on the Particular Technical Specifications
- Minimal sampling rate of 10 KHz
- Pre-trigger option with a minimum of 4,096 samples
- Triggering option on positive, negative or contact closure with adjustable threshold
- Stacking possibility
- 24-bit A/D converter
- Cross-talk : -125 dB for frequency of 20 – 30 Hz
- Data format: SEG-2 standard and/or SEG-Y.

6.2 Source and receivers characteristics

The final choice of receiver and source characteristics shall be made after the preliminary in field data acquisition test, performed at the beginning of the survey in close collaboration with Company's representative.

Those tests shall include a comparison of dominant reflection frequencies at target depth for different types of sources and receivers.

Contractor shall clearly define in his technical proposal, the type and specifications of the different sources and receivers which will be mobilized on site to perform the preliminary test.

6.2.1 Receivers characteristics

The selection of geophone frequency range will depend on the frequency response of the site.

For example, geophones with a 100 Hz natural frequency shall be used for a site with a frequency response over 400 Hz. This would apply to a study directly conducted on bedrock, with an investigation depth of no more than 30 meters, where the frequency response could reach 800 to 1000 Hz in the best case.

Most shallow reflection surveys are now performed with modern geophones that have a natural frequency of 30-50 Hz, which gives a clean and uniform response at frequencies up to 400-500

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Hz. The reason is that the vast majority of site geological conditions will not transmit energy in the range of 300-400 Hz over distances of more than 10 meters.

Geophones with a natural frequency of 10 to 14 Hz shall be used for surveys with an investigation depth over 100 meters.

Receivers coupling:

Geophones are generally coupled to the ground surface with spikes having a minimum length of 7 cm to penetrate past the highly unconsolidated topsoil. In some cases with hard ground conditions, gravity coupling with plates can be a reasonable compromise, but this option shall be tested by Contractor during the preliminary in field data acquisition test.

6.2.2 Number of geophones for each seismic trace

Use of geophones strings will help to reduce coherent noise such as Ground roll, but will degrade the lateral resolution of the final results, as the recorded signal is stacked on the whole string length.

Company requires the use of single high-frequency geophones for surveys with an investigation depth not exceeding 100 meters. The lateral resolution stays optimal, and the low-frequency ground roll is partially filtered by the high natural frequency of the geophones (up to 30 Hz).

For surveys with investigation depth over 100 meters, the final choice between a string of geophones or single geophone shall be made after the preliminary in field data acquisition test.

6.2.3 Source characteristics

Without any preliminary information on the seismic response of the site, 2 different types of sources could be mobilized for the preliminary in field tests.

Those sources shall be selected on the bases of multiple parameters such as:

- Energy needed to obtain a good signal/noise ratio
- Frequency range adapted to resolution requirements
- Terrain limitations (urban area, high-voltage power line, natural protected area...)
- Accessibility of the profile locations.

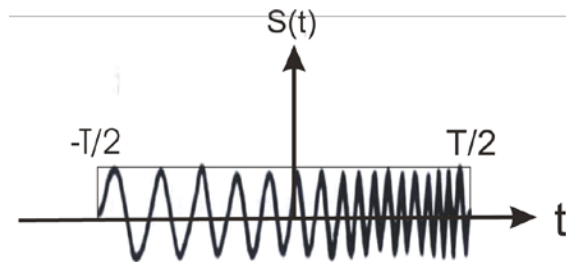
The selected source shall give the best signal/noise ratio with the best achievable resolution for a given target depth.

Two basic types of sources are available: vibrator and impulsion sources.

Vibrator sources:

Vibrator or coded signal sources deliver their energy over a given time interval using a frequency sweep as shown on figure 7.

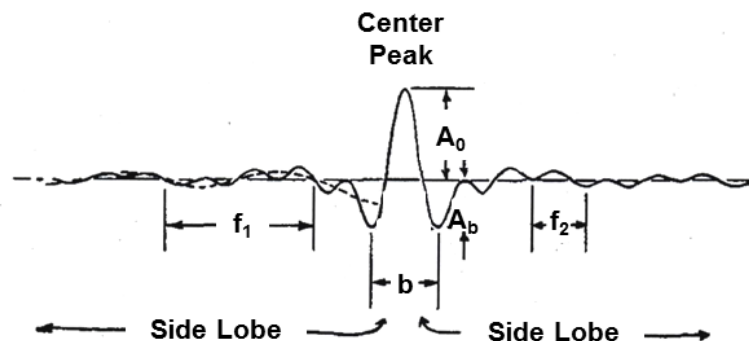
Figure 7: Example of linear frequency sweep



Thus, compared to impulsive sources, coded sources require an extra processing step called autocorrelation to compress the source signal wavetrain into an interpretable impulse signal.

Figure 8 shows the result of the autocorrelation of a linear sweep on a two octave bandwidth ($F_2/F_1=4$). This signal is commonly named the Klauder wavelet. Quality of the final seismic section will mainly depend on the shape of the Klauder wavelet.

Figure 8: Example of Klauder wavelet for a 2-octave bandwidth sweep



Particular requirements for implementation of a vibrator source:

Contractor shall keep in mind when using a vibrator source that:

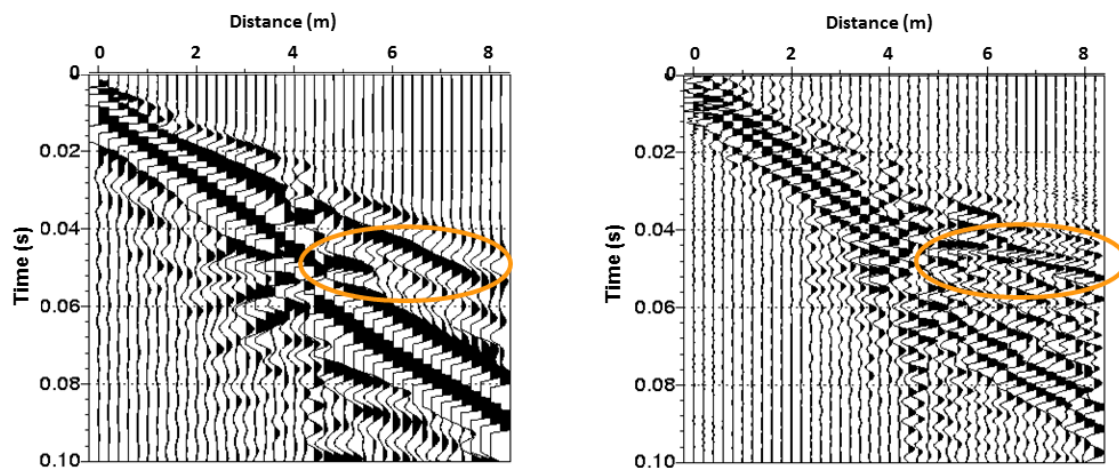
- The quality of the final auto-correlated signal (Klauder wavelet) will strongly depend on the quality of the source to ground coupling. Regular tests of source signal auto-correlation shall be carried out to verify that the final impulsion signal is of good quality.
- The main frequency of the signal for a linear sweep is given by the following formulae $F = (F_{min} + F_{max})/2$, where F_{min} is the minimum frequency (f_2) of the sweep and F_{max} the maximum frequency of the sweep (f_1). For example, a linear sweep with a frequency range of 10-90 Hz, will have a main frequency of 50 Hz. Contractor shall define a sweep with central frequency in phase with resolution requirements.

- The centre peak-to-side lobe ratio A_0/A_b is one of the more important parameters to measure the spikiness of the autocorrelation pulse. This ratio depends of the sweep bandwidth. CONTRATOR shall select a sweep with a minimum of 2 octave bandwidth ($f_1/f_2 = 4$), which makes the ratio $A_0/A_b = 2$.
- The quality of the final auto-correlated signal will also depend on the quality of the reference source signal used in the correlation process. Contractor shall record the signal effectively transmitted to the ground with a geophone installed close to the coupling plate.

A major advantage of vibrators over traditional impulsive sources is the ability to optimize resolution of the seismic waveform.

Figure 9 gives an example of the advantage of mini-vibrator sources compared to a conventional sledge hammer source. The reflection on the water level located at 5-m depth is clearly visible on the record obtained using the vibrator source, with a sweep of 100-800 Hz, and not visible on the low-frequency record obtained with the sledge hammer.

Figure 9: Comparison of frequency content obtained between sledge hammer source (left) and vibrator source (right)



Impulsion sources:

There is a wide variety of impulsion sources including weight drops, explosives or shotgun.

Contractor shall select the source offering the best compromise between repeatability, spectral characteristics, efficiency, total energy and safety.

In most of the case, buried blasting caps or small explosives will give the best results in term of high-frequency associated to high energy, but Contractor shall keep in mind that use of explosives is associated with restrictions, regulation and safety considerations.

Furthermore, explosives involve drilling holes 0.3 to 1 m deep, which will be difficult in area with frequent rock outcrops.

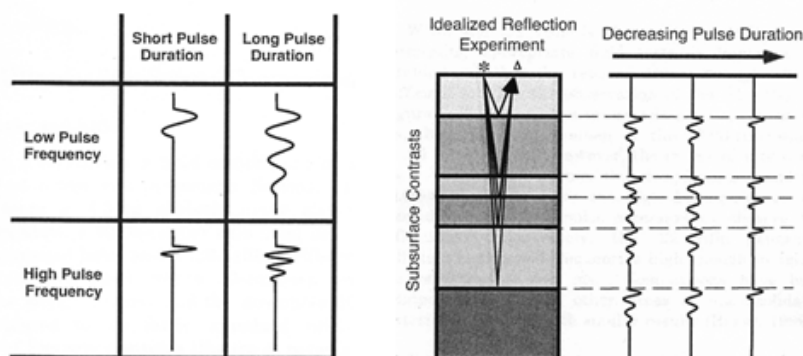
Similar problems may occur for shotgun-type sources, which involve drilling of a hole of 0.5-m depth at a minimum, to penetrate the shot into the soil. This operation may considerably reduce the advantage of such a source in a rocky environment. contractor shall also keep in mind that in recent years, cartridges used in shotguns are classified as explosives in many countries.

A weight drop is a good alternative to avoid issues related to use of explosives, but such sources are heavy, and involve the use of 4-wheel drive vehicles to access source points.

Contractor shall also pay particular attention to the phenomenon of rebound inherent to this type of source. The second impact produced by the mechanical rebound shall be designed to occur after the end of total record time, to avoid any interference with the reflected events.

Particular attention shall be brought to the pulse duration of the impulsive source, that is of primary importance to the vertical resolution (figure 10). The shorter the pulse duration, the better will be the vertical resolution.

Figure 10: Pulse duration as key parameter in vertical resolution



6.3 Cable

The cable shall be equipped with water proof connectors. A cable with simple Mueller connectors is not acceptable to Company except in desert areas.

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 DGPS or RTK system shall be verified by making a comparison with a fixed point of 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 works.

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 computed with a decimetric accuracy (+/- 10 cm) in order to integrate topography in the data processing (static corrections).

8. Work procedures

8.1 Calibration

8.1.1 Zero-time procedure

Zero-time procedure is of primary importance for ensuring data quality and shall be properly described by Contractor in the technical proposal.

Contractor shall check the Time-break stability during field acquisition.

Systems like hammer switches, closure switches or radio links are well known for generating spurious time breaks with errors of a few milliseconds.

This can be a serious problem especially in high-frequency work. For example, even with a precision of 0.25 ms in the time break, energy at 1 kHz can be 90° out of phase.

Therefore, Contractor shall propose a zero time procedure which insures an accuracy of at least 0.1 ms.

As a consequence of the instability of time breaks, high-frequency data should not be stacked vertically unless the time breaks have been checked for errors, or time break variations removed by cross-correlating stack techniques.

In other words, data should be vertically stacked only after verifying that serious Time Break errors are not present.

8.1.2 Acquisition equipment

The acquisition equipment (source, geophones and recorder) 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.

It includes at a minimum:

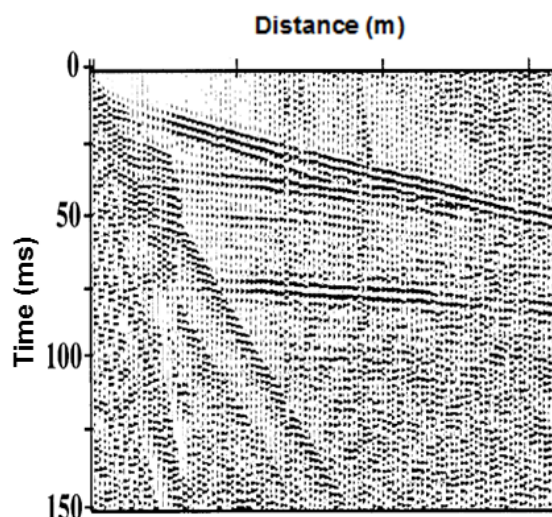
- Results of geophone calibration including frequency, damping, sensitivity, distortion, resistance, polarity and impedance tests
- Results of seismic recorder inter-channels cross-feed tests.

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.

The source shall be selected so as to obtain a minimum signal/noise ratio of 5 (i.e. noise amplitude lower than 20% of signal amplitude).

Figure 11: Example of good data quality acquisition in seismic reflection



In the case of noisy, non-interpretable or incomplete data, the seismic record shall be **reshot**.

The number of reversed traces shall not exceed 10% of the total number of active traces.

The number of dead traces shall not exceed 5% of the total number of active traces.

Two consecutive dead traces will not be accepted by Company.

Contractor shall mobilize the equipment necessary for the Geophysicist to perform a pre-interpretation on site, which include a PC with seismic processing and interpretation software, and a printer for the production of QC documents.

Important:

When controlling data quality, geophysicist should verify that the data are not clipped due to recorder saturation observed in the analogue-to-digital conversion. Digital processing is not efficient on a saturated signal, and introduces artefacts on processed data; particularly when performing filtering operations which will create high frequency content into the data at the corners of the clipped wavelets.

Records including saturated traces will not be accepted and will be reshot.

8.3 Characterisation of Near-Surface velocity gradients for static corrections

Contractor shall pay particular attention to the method used for characterisation of Near-Surface velocity gradients.

In the case of a survey performed with an impulsion source, with first break arrivals of good quality, Company requires the provision of a velocity model of the near-surface using inversion tomography software.

By taking advantage of the multiplicity of shots performed in a reflection survey, a ray-bending tomography approach can provide a more detailed picture of velocities than a classical refraction interpretation which uses only a few shots.

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This approach will not only contribute to improve the quality of static correction, but will also contribute to optimize the final time-to-depth conversion, especially at early travel times where seismograms are commonly poor for shallow reflection data.

In the case of a survey performed with a vibrator source, with first break arrivals of poor quality, Company requires to perform up-hole or down-hole measurements (Vertical Time measurements). This point shall be discussed with Company Representative, to evaluate quality of first break picking on records obtained during the preliminary in field data acquisition test. The object is to characterize velocity gradients in the first few meters, on the key areas where lateral velocity variations are suspected.

8.4 Vertical Seismic Profile (VSP)

If required, a Vertical Seismic Profile should be performed in a deeper borehole

The purpose of the VSP measurement is to obtain a robust time to depth conversion law, giving accurate depth estimations of reflectors identified on the final seismic cross-section. VSP allows correlation of stratigraphic units, and provides parameters used to improve velocity processing of existing data.

If VSP is conducted, results shall be used to distinguish primary reflections from multiples.

9. Data Processing

Accurate processing requires that the various components of seismic energy must be visible on single shots (raw data), because some must be removed (refractions, air waves, direct waves and ground roll) or enhanced (reflected signal).

Data processing will be efficient if reflections are visible on raw shot records obtained during the walk-away field test. If no reflections are visible at the level of interest on the raw single record, there is no chance of obtaining good results, even with data processing of good quality.

Contractor shall keep in mind that data processing intends to enhance and correctly image coherent reflection events, not to produce artificial reflectors.

A Common Mid Point (CMP) conventional processing flow shall include at least:

- Input of source and sensors geometry (X Y Z coordinates)
- Trace edits, Removal of bad or noisy traces
- Scaling of amplitudes (for example Automatic Gain Control – AGC with appropriate window length)
- Spectral analysis and filtering to minimize random noise due to wind, heavy rain, road proximity, etc.
- Deconvolution
- Statics corrections and analysis
- Migration
- FK filtering or Mute to remove coherent noise as direct and refracted waves, air waves or ground roll

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- Velocity analysis to implement correction for non-vertical incidence (velocity semblance, constant velocity panels). Application of Normal Move Out correction (NMO) with stretch mute
- Sorting into CMP gathers
- CMP Stacking
- Post-stack processing to enhance the coherent reflections visible on seismic section (Frequency domain filtering, coherence filtering, post-stack migration....)
- Time – Depth conversion.

This conventional processing sequence may be optimized in the Particular Specifications or during the processing.

Contractor shall keep in mind that data processing of near-surface data is, in most cases, more complicated than the processing usually applied for deeper targets, such as in oil and gas exploration.

This is due to the extremely high velocity gradients observed in the first few meters. Also near-surface data sometimes exhibits lateral variations on the scale of a few high-frequency seismic wavelengths.

Contractor shall be particularly attentive to the following data processing pitfalls usually observed in near-surface seismic reflection surveys:

Incorrect or uncompensated static corrections:

Static corrections are one of the critical steps in shallow data processing. Early or delayed arrivals of seismic energy result from a laterally non-uniform, near-surface velocity or elevation.

These effects are more extreme in shallow surveys than in deeper conventional reflection survey. Because the data contain high frequencies, the static corrections may be more than the dominant periods of the reflection wavelets. Badly managing the statics with processing routines can remove coherent information.

Contractor shall run tests for different static processing flows, to ensure that this processing phase is not destructive for the coherent reflector.

If a water table reflection can be identified, flattening this reflection is the most effective method of correcting shallow reflection data for near-surface static irregularities.

Separating shallow reflections from shallow refractions:

Contractor must be careful not to misinterpret the shallow refractions as shallow reflections, which can have very similar phase velocities, and may interfere with each other, destructively or constructively, over a large range of geophone offsets.

One useful indicator to distinguish refractions from reflections on a processed seismic section is frequency inversion with depth.

Under normal geological conditions, the frequency of reflections on a shallow reflection seismogram will decrease with depth, as a result of attenuation with increasing traveltimes.

When the apparent frequency of coherent events changes from low at short travel times to high at longer times, shallow refractions may have been stacked into the data.

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Deconvolution:

Application of the same deconvolution operator to the whole shallow reflection data set may degrade the quality of the final cross-section.

The problem is related to variability of the source wavelet, which may change over a short distance in function of near-surface conditions (variations of source coupling), and to frequency of shallow reflections, which often varies rapidly with depth.

Contractor shall test processing flows with and without deconvolution, to check its effectiveness on the final section.

10. Interpretation

Structural geological interpretation of the final sections (after Time-Depth conversion) shall be performed using all available information, such as borehole logs, geological maps, data from outcrops, up-hole or VSP measurements. This correlation may be extended to any other available complementary geophysical results (Refraction, Electrical Resistivity Tomography, Microgravity, Ground Penetrating Radar...).

If necessary, the velocity function used to convert the two-way travel time to depth may be optimized to improve the correlation between the interpreted section and the true geological structure.

Contractor shall present, in the final report, a specific section to comment on interpretation, with alignments charts illustrating correlation between seismic sections and all other available results.

Contractor shall present for each interpreted section, the corresponding brute section without any color interpretation overlaid.

If no borehole data are available to ground truth the Time-Depth conversion and geological interpretation, Contractor may propose one or more complementary boreholes designed to verify geological horizons identified on seismic sections.

The vertical scale of the section shall be selected carefully in close collaboration with Company's representative. A scale without too much vertical exaggeration is useful to establish the presence or absence of true dips, and to put both structure and stratigraphy into a geological context.

Brute section shall be proposed conventionally in black and white, in wiggle trace format with positive amplitudes shaded black. In addition, Contractor may propose other colour displays of any of the attributes (amplitude, frequency, phase, coherency..) which may enhance the interpretability of the section.

11. Personnel

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

11.1 Management

Contractor shall nominate a **Project Manager** who will be in charge of the whole project for both technical and administrative responsibilities. He shall be the Contractor Representative. The

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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 Near-Surface High-Resolution Seismic Reflection acquisition, 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. For particular long duration survey, Party chief may be replaced in agreement with Company Representative.

11.2 On site

Contractor survey crew consists nominally of a minimum of 4 to 5 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 Observer geophysicist in charge of data acquisition and recording
- 1 x Surveyor in charge of positioning and line clearing

For surveys performed with explosives:

- 1 x blaster licensed to handle and set off explosives
- 1 x drilling operator in charge of light drilling operation

For surveys performed with non-destructive source:

- 1 technician in charge of handling the non-destructive source.

Helpers will assist the team in equipment transportation, line clearing and seismic spread installation.

12. HSE

Contractor is required to adhere at all times to Company's Health, Safety and Environment standards. In particular, reference is made to **GS EP GPA 202** and **GS EP GPA 203**, and to Exhibit H1 (General HSE requirements) and H2 (Specific HSE requirements) which are Contract Exhibits associated with the Call for Tender.

12.1 Contractor's responsibility

As part of the Project Execution Plan, Contractor shall provide a Safety Plan, to include: complete hazard identification (HAZID) risk assessment (HIRA), and procedure for evacuating injured personnel (MEDEVAC/EVASAN procedure).

Company's general safety instructions will be supplied to Contractor who shall review them critically, and point out any incompatibility there may be with their 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 advise Contractor of any specific regulations and/or work permit procedures 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 about safety procedures for the different equipments 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 in the Job Safety Assessment document, which shall be signed with the Permit to Work document 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 by common agreement between the Contractor and Company Representatives.

12.2 Emergency on site

As mentioned above, Contractor is required to submit his safety plan to Company, before mobilisation, for each project or different area within a project, and including the Emergency Response Plan (ERP) detailing medical evacuation from the worksite, and the Bridging Document detailing responsibilities of Contractor and Company. 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.

12.3 Anomaly / near-miss / accident reporting

Any anomaly, near-miss 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.

13. Reporting

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

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13.2 Daily Work Sheet

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

- Daily data records
- List of personnel and equipment on site
- Planning forecast for next day
- Minutes of meeting
- List of anomalies, near-miss or accident.

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.

13.3 Field Report

This Report shall include but not limited to:

- Log of daily events
- Site location map
- List of equipment and technical descriptions
- Results and comments on preliminary walk away acquisition test
- Array geometry and acquisition parameters (Acquisition time in ms with associated sampling rate, number of active channels recorded per shot, source offset , receivers spacing, zero – time procedure, stack number, fold number, etc.)
- Count and naming of measured profiles with location map
- Topography and leveling procedure with coordinates and elevations (X,Y,Z) of source and receivers points
- Raw data examples
- Software used to process data, including name and version number
- Processing flow history that includes an example of each intermediate step
- Preliminary seismic sections, time scale
- Preliminary conclusions.
- HSE.

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

13.4 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.

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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.

13.4.1 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.

13.4.2 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.

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Section 2: Results

- Introduction
- General situation plan
- Summary of local geological / geotechnical information
- Objectives defined by client with first definition of array geometry and acquisition procedure based on forward modeling
- Interpreted final seismic sections
- Correlation between seismic sections and other geophysical method results (if available); refer to **GS EP GEO 210**, **GS EP GEO 211**, **GS EP GEO 212**, **GS EP GEO 213**, **GS EP GEO 214**, **GS EP GEO 215** and **GS EP GEO 216**.
- Conclusion summarising the main results.
- Recommendations for the positioning and the depth of boreholes to ground-truth the interpretation of the seismic sections.

Section 3: Charts & profiles

- Location map of measured profiles
- Topographical charts
- Final sections as Brute Stacks (non-interpreted)
- Interpreted final seismic sections in time and depth
- Composite charts illustrating correlation between seismic sections and other geophysical method results (if available).

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

Charts scales will be defined in Technical Particular Specifications.

Volume 2: "Operations report"

Section 1: Technical Report

- Scope of Work and state of completion
- List of equipments
- Time allocation - durations of operations, transit, stand-by and breakdowns, as time tally and percentage of total
- Topographic and levelling procedure
- The results of the positioning system accuracy check and monitoring
- The results of all calibrations
- The results of numerical modeling
- The results of preliminary walkaway tests

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- The settings and all recording parameters used (Acquisition time in ms with associated sampling rate, active channels per shot, source offset , receivers spacing, zero–time procedure, stack number, fold number, etc.)
- Comments on data quality
- Comments on selected processing flow
- 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, with X,Y,Z coordinates of source points and receivers
- Appendix 5: Detailed field notes of the whole set of investigated profiles.

13.5 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 2007; 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 are to be included as annex to the Final Report, in digital form (stored on CD / DVD or storage disk):

- Raw data in SEG-2/SEG-Y format
- Observer's log (ascii format)
- Positioning data (ascii format)
- Final interpreted seismic sections in ascii format giving X,Y,Z and amplitude value .