



Exploration & Production

GENERAL SPECIFICATION

SURVEYS

GS EP GEO 213

**Onshore geophysical site survey -
Micro-Gravity Geophysical Survey**

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1. Scope

The content of this General Technical Specification indicates the minimum standards required by Company for microgravity 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 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 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 6430 - 99 (2010)	Standard guide for using the Gravity 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 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 POS 003	Onshore Land Surveying and Positioning Works
GS EP POS 004	The Use of Differential Global Positioning System



3. Microgravity survey objectives and methodology

3.1 Microgravity survey objectives

Microgravity is a method used for geological and geotechnical investigations, to detect density anomalies related to ground disturbances.

Main field of application in civil engineering is to identify and characterize subsurface voids (old quarries, galleries related to abandoned mines, karstic cavities, sinkholes...) more or less filled in or flooded.

Other application fields are listed below:

- Mining: search for dense lodes and massive ore bodies, search for not very dense fractured or weathered zones
- Hydrogeology: karstic and weathered zones, river deposits
- Environment: object or target to be detected

3.2 Methodology

The microgravity method is based on the measurement of the relative value of the vertical component of gravity at the ground surface, in order to establish the subsurface distribution of densities.

Target is to locate area of lateral evolution of the subsurface soil density, in order to appropriately define a complementary boreholes campaign to characterize and identify origin of those density anomalies, which can be either related to mass deficit (voids, fractured zone or low density deposits...), or mass excess (hard bedrock elevation, high-density buried object..).

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)
WGS 84	World Geodetic System 1984
Gal	Unit of gravitational acceleration ($1 \text{ Gal} = 10^{-2} \text{ m/s}^2$), with the Earth's average gravity of approximately 980 Gals
μGal	One part per billion of a Gal ($1 \mu\text{Gal} = 1/1000000 \text{ Gal}$)



5. Microgravity layout

Contractor shall request from Company all available prior information, to finalize the technical program, 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 the layout for measurements. If Contractor considers that the proposed measurement grid may not achieve Company's objectives, Contractor shall propose an alternative layout, which shall be properly justified, and submitted to Company approval.

5.1 Determination of measurement grid

Determination of measurement grid will be established on the basis of Company's objectives and characteristics of the site. Targets shall be defined in terms of size, depth, orientation and expected density contrasts. Gravity data may be obtained along a single line profile, widely spaced profile lines, or over a uniform grid.

Contractor will have to calculate, by forward modelling, the expected amplitude and width of the gravity anomaly related to the different targets listed by the Company. This will determine the required measurement station spacing.

For example, the gravity anomaly (Δg_z) caused by a cavity represented as an empty sphere is given by the following equation:

$$\Delta g_z = \frac{2}{3} \cdot m \cdot \frac{z}{d^3} = \frac{2}{3} \cdot m \cdot \frac{z}{(x^2 + z^2)^{3/2}}$$

$$\text{with } m = (\sigma_2 - \sigma_1) \cdot \frac{4}{3} \cdot \pi \cdot R^3$$

Where:

R	Sphere radius
m	Mass deficit
($\sigma_2 - \sigma_1$)	Density difference between the sphere density and the ground density
z	Depth of the sphere centre
x	Measurement offset
d	Distance between the sphere centre and the point of measurement.

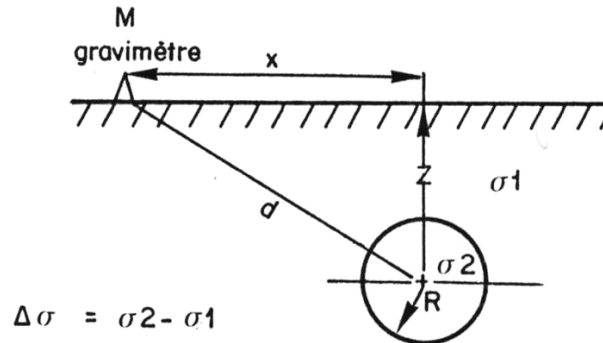


Figure 1 below presents an example of gravity anomaly caused by an empty sphere, of 2 m diameter, and located at 1.5 m depth.

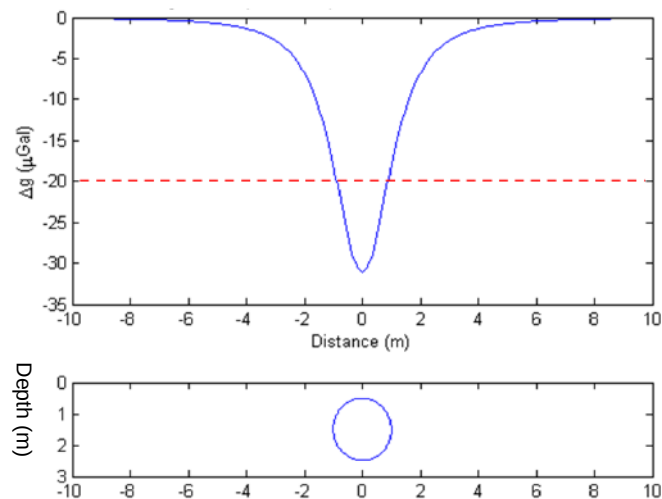


Figure 1 - Gravity anomaly of a 2 m diameter sphere, located at 1.5 m depth

Figure 2 gives an example of microgravity anomalies due to an air-filled, 2 m diameter cylinder, at three different depths. With a water-filled cylinder, the anomaly magnitudes would decrease by a factor of 0.6.

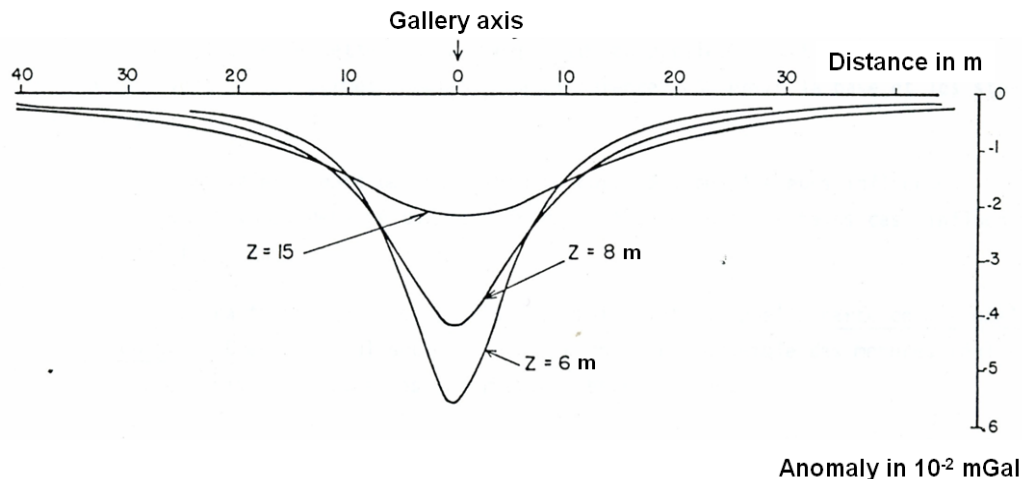


Figure 2 - Microgravity anomalies for 2-m diameter cylinders, located at 6 m, 8 m and 15 m depths

This figure illustrates some basic concepts:

- Shallower features of the same size will produce a greater magnitude anomaly with a narrower width; and
- Deeper features of the same size will produce a smaller magnitude anomaly with a broader width.

In general, the measurement grid is determined considering that a cavity can be detected when the negative anomaly is higher than 20 μGal . This value supposes that the measurement accuracy is better than $\pm 10 \mu\text{Gal}$, which involves following a very precise data acquisition procedure.

5.2 Data acquisition procedure

Data acquisition shall follow the minimum requirements listed below:

- At least 25% data redundancy, with a random selection of rerun points
- Establishment of a base station network, to restrict the duration of the measurement program to less than 60 minutes. A 45-minute program is strongly recommended
- Levelling accuracy to the nearest cm (see chapter 7, Levelling and Positioning)

Those rules are of primary importance to define as precisely as possible the instrument drift and sun / moon variations.

Automatic measurements shall be performed with parameters as follow:

- Each reading to be at least 45 seconds long, in order to reduce the r.m.s. error. This recording time shall be increased in noisy conditions



- At least 2 seconds of “start delay”
- Regular control of battery state and internal temperature.

Accuracy of microgravity measurements will strongly depend on site noise conditions. Noise can occur in the data due to natural sources (ground motion from distant earthquakes, waves impacting the shoreline, and wind), and man-made sources (vibrations from vehicles, railroads, construction equipment, etc.). Contractor shall be attentive to noise conditions, and shall interrupt measurements to wait for better noise conditions, especially in case of strong earthquakes which can create vibration during several days.

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 equipments 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.

Equipment shall have a 1-microgal accuracy (μGal).

Important: Gravity meters are extremely sensitive instruments, which measure relative differences in gravity from station to station. Gravity meters measure changes in the vertical component of gravity by balancing gravitational forces with a spring and mass system. Contractor shall take particular attention to avoid any risk of equipment shock during a measurement session. If such an incident occurs, measurements shall be interrupted to verify the integrity and reliability of the gravity meter.

7. Positioning and Levelling

Microgravity is the geophysical method which necessitates the highest level of accuracy in term of positioning measurements.

Two measurements need to be performed:

1. X, Y, Z measurement of the marked point
2. Tripod height measurement. Once the instrument is levelled on its tripod, the height from the ground to the base of the instrument needs to be recorded.

An error of 3 mm in Z induces an error of 1 μGal on the measured point.

Therefore, X, Y measurements shall be made with centimetre accuracy, while the Z measurement shall be made with higher relative elevation accuracy, of about 3 mm.

Contractor shall propose a laser survey equipment, to insure this particularly high level of precision in Z height.

Contractor shall precisely describe, in the technical proposal, the topographic measurement procedure.

Levelling and positioning works shall comply with the Total General Specification **GS EP POS 003** and **GS EP POS 004**.

8. Data processing and interpretation

8.1 On-site quality control

QA/QC of acquired data shall be performed on site by Contractor.

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

Contractor shall produce on site, before demobilisation:

- Computation of significant anomaly value
- Residual anomaly map.

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

In that case, complementary points shall be placed in staggered rows, to enhance the resolution of the residual map.

8.2 Calculation of significant anomaly value

Contractor shall calculate the significant anomaly value, to evaluate the accuracy of survey measurements. This value is obtained using the 25% redundancy of stations.

Company recommends producing a histogram (bar chart) of the deviation, obtained for each point which has been measured twice.

Figure 3 gives an example of such a bar chart, of Gaussian type.

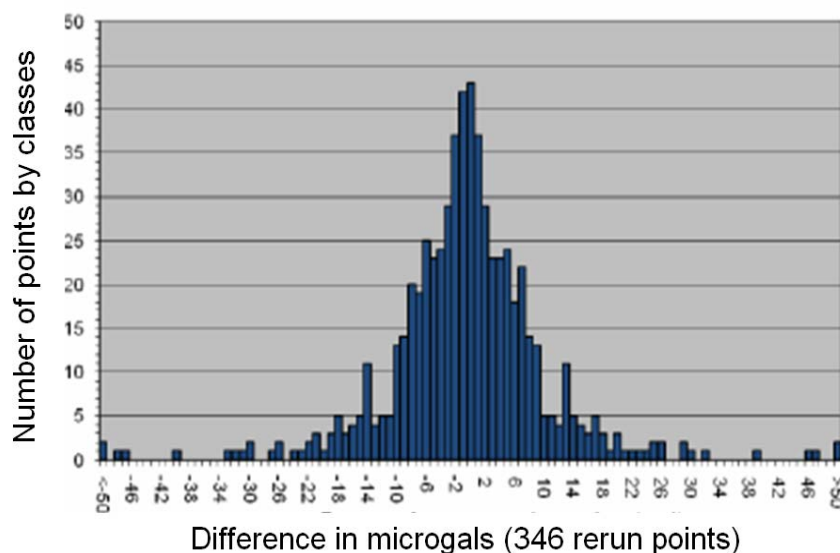


Figure 3 - Histogram of the difference observed on rerun points

The significant threshold is equal to twice the Standard Deviation. For the example shown on Figure 3, the standard deviation is equal to 7.5 μGal , which gives a significant value of 15 μGal .

All anomalies superior to 15 μGal will be considered as significant.



Calculation of this significant threshold is of primary importance to quantify the quality of survey, and to analyse the final residual anomaly map.

8.3 Production of Bouguer anomaly map

Production of the Bouguer anomaly map shall include:

- Sun / moon and instrument drift corrections
- Altitude and free air corrections (topography and height from the ground to the base of the instrument)
- Latitude corrections
- Terrain corrections, to compensate influence of nearby “hills”, “valleys” or constructions.

Contractor shall precisely describe his procedure to perform Terrain corrections, particularly in case of strong topographic variations, or in urban or industrial areas with presence of constructions. Terrain corrections that are not applied correctly can produce false anomalies, not due to subsurface features. If available, Company will provide the Digital Terrain Model related to the investigated area, to optimize the Terrain correction. If necessary - if results of first-pass Terrain correction are not satisfactory, complementary topographic measurements shall be required to enhance the quality of the Digital Terrain Model.

The choice of the density value used for the different corrections is one of the key parameters for production of the Bouguer anomaly map.

Contractor shall detail the procedure followed, to determine the site density, which can be based on density measurements performed directly on core-drill samples, and/or on Nettleton profile calculation.

8.4 Production of Residual anomaly map

The last step of data processing and interpretation is to produce the Residual anomaly map, which consists in subtracting the Regional anomaly map from the Bouguer anomaly map.

Contractor shall describe the procedure followed to calculate the regional anomaly. In case of a 2D survey, the regional anomaly shall be calculated in a one step 2D approach; a line-by-line calculation is not acceptable, as it would produce linear artefacts on the residual anomaly map.

8.5 Numerical modelling

Contractor shall present in the final report a few examples of forward modelling, based on different geological models, which could explain the main density anomalies observed on the final residual anomaly map.

8.6 Correlation with other available datasets

Contractor shall present, in the final report, a specific chapter to comment on the correlation between microgravity results (residual anomaly map), and all available complementary information, such as borehole logs, geologic maps, data from outcrops, or from other surface or borehole geophysical methods. Correlation charts shall be produced, to clearly illustrate the anomaly areas selected for complementary borehole campaigns.



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 roles; he/she 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 Party Chief shall be a qualified geophysicist/geologist, fully experienced in the processing and interpretation of microgravity data.

During operations, the Party Chief shall act as sole Contractor Representative, and 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 of a nominal minimum of 3 personnel, comprising the following roles and responsibilities:

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

One to three local helpers may 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**.

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 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, 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 responsibilities also include 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 acquired data. Such adverse conditions shall be defined by 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 the Emergency Response Plan (ERP) and medical evacuation from the worksite. Such planning shall explicitly involve the structures and facilities of Company where appropriate (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 present 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 incident / accident reports shall be forwarded to Company's Representative within 24 hours. An investigation form shall be included as 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.



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 (Exhibit A2). 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 be limited to:

- Log of daily events
- Site location map
- List of equipments and technical descriptions
- The number of measured points with location map
- Topography and leveling procedure
- Bar chart for calculation of standard deviation on rerun points
- Description of density determination
- Preliminary Bouguer anomaly map
- Preliminary Residual anomaly map
- Preliminary conclusions.

The Field report shall be provided to Company before the start 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 in 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 - name of Survey
- Name of the structure(s), field(s)



- Contractor name
- Start/end dates of onshore work.

Certification: the first page shall show certification specifics of the report, namely:

- 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 points 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, including definition of the grid geometry based on forward modeling
- The number of measured points with location map
- Bar chart for calculation of Standard Deviation on rerun points
- Description of density determination
- Comments on final Bouguer anomaly chart
- Comments on final Regional anomaly chart
- Comments on final Residual anomaly chart
- Correlation between residual anomaly chart and other geophysical method results (if available)

- Correlation between residual anomaly map and geological formation, on the basis of available geotechnical information (if available)
- Presentation of forward modeling results, performed on geological assumptions which could explain any microgravity anomaly
- Conclusion summarising the main results
- Recommendations for the positioning and the depth of boreholes to ground-truth the interpretation of the microgravity.

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

Section 3: Charts & profiles

- Location map of measured points
- Topographical charts
- Final Bouguer anomaly chart
- Final Regional anomaly chart
- Final Residual anomaly chart.

Charts scales will be defined in Technical Particular Specifications.

• Volume 2: “Operations report”

Section 1: Technical Report

- Scope of work and completion
- Time allocation: percentage durations of operations, transit, stand-by and breakdown
- 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
- List of equipments and technical descriptions
- 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 presented in Excel format with at least following information: Line, Station, X, Y, Elevation, Latitude, Longitude, Reading, Height, Date, Time.



11.5 Deliverables

Reports and charts shall be compiled as specified in listed General Specifications, and provided 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 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 data
- Observer's log (ascii)
- Positioning data (ascii)
- Residual anomaly map in ascii format, giving X, Y, and residual anomaly values.

12. Other references

Following documents are applicable:

- Standards: [ASTM D 6430 - 99 \(2010\)](#)
- Total General Specifications: **GS EP GEO 210, GS EP GEO 211, GS EP GEO 212, GS EP GEO 214, GS EP GEO 215 and GS EP GEO 216.**