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Standard Guide for Using the Gravity Method for Subsurface Investigation¹

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1. Scope

1.1 Purpose and Application:

1.1.1 This guide summarizes the equipment, field procedures, and interpretation methods for the assessment of subsurface conditions using the gravity method.

1.1.2 The gravity method described in this guide is applicable to investigation of a wide range of subsurface conditions.

1.1.3 Gravity measurements indicate variations in the earth's gravitational field caused by lateral differences in the density of the subsurface soil or rock or the presence of natural voids or man-made structures. By measuring spatial changes in the gravitational field, variations in subsurface conditions can be determined.

1.1.4 Detailed gravity surveys (commonly called micro-gravity surveys) are used for near-surface geologic investigations and geotechnical, environmental, and archaeological studies. Geologic and geotechnical applications include location of buried channels, bedrock structural features, voids, and caves, and low-density zones in foundations. Environmental applications include site characterization, ground water studies, landfill characterization, and location of underground storage tanks (1)².

1.2 Limitations:

1.2.1 This guide provides an overview of the gravity method. It does not address the details of the gravity theory, field procedures, or interpretation of the data. Numerous references are included for that purpose and are considered an essential part of this guide. It is recommended that the user of the gravity method be familiar with the references cited and with the Guides D 420, D 5753, D 6235, and D 6429, and Practices D 5088, and D 5608.

1.2.2 This guide is limited to gravity measurements made on land. The gravity method can be adapted for a number of special uses: on land, in a borehole, on water, and from aircraft and space. A discussion of these other gravity methods, including vertical gravity gradient measurements, is not included in this guide.

1.2.3 The approaches suggested in this guide for the gravity method are the most commonly used, widely accepted, and proven. However, other approaches or modifications to the gravity method that are technically sound may be substituted.

1.2.4 *This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education, experience, and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM document is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

1.3 Precautions:

1.3.1 *It is the responsibility of the user of this guide to follow any precautions in the equipment manufacturer's recommendations and to establish appropriate health and safety practices.*

1.3.2 *If this guide is used at sites with hazardous materials, operations, or equipment, it is the responsibility of the user of this guide to establish appropriate safety and health practices and to determine the applicability of any regulations prior to use.*

1.3.3 *This guide does not purport to address all of the safety concerns that may be associated with the use of the gravity method. It is the responsibility of the user of this guide to establish appropriate safety and health practices and to determine the applicability of regulations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

- D 420 Guide to Site Characterization for Engineering, Design, and Construction Purposes³
- D 653 Terminology Relating to Soil, Rock, and Contained Fluids³
- D 5088 Practice for Decontamination of Field Equipment Used at Nonradioactive Waste Sites³
- D 5608 Practice for Decontamination of Field Equipment

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² The boldface numbers in parentheses refer to the list of references at the end of this standard.

³ Annual Book of ASTM Standards, Vol 04.08.

- Used at Low Level Radioactive Waste Sites³
- D 5730 Guide for Site Characterization for Environmental Purposes With Emphasis on Soil, Rock, the Vadose Zone, and Ground Water⁴
- D 5753 Guide for Planning and Conducting Borehole Geophysical Logging⁴
- D 6235 Guide for Expedited Site Characterization of Hazardous Waste Contaminated Sites⁴
- D 6429 Guide for Selecting Surface Geophysical Methods⁴

3. Terminology

- 3.1 *Definitions*—Definitions shall be in accordance with the terms and symbols in Terminology D 653.
- 3.2 Additional technical terms used in this guide are defined in Sheriff (2) and Bates and Jackson (3).

4. Summary of Guide

4.1 *Summary of the Method*—The gravity method makes measurements of gravity variations at stations along a profile line or grid relative to an arbitrary selected local base station gravity value. The gravity measurements are then corrected for other effects that cause variations in gravity. Lateral variations or anomalies in the resulting residual gravity data can then be attributed to lateral variations in the densities of subsurface materials, for example, buried channels, structures, or caves. The data are interpreted by creating geologically consistent density models that produce similar gravity values to those observed in the field data.

4.1.1 Measurements of variations in the subsurface density of soil and rock are made from the land surface using a gravimeter (Fig. 1). The lateral variations in density are used to interpret subsurface conditions along a profile line or grid of gravity measurements.

4.1.2 Gravity measurements can be interpreted to yield the depth to rock, the location of a buried valley or fault, or the presence of a cave or cavity. The results obtained from

modeling can often be used to characterize the densities of natural or man-made subsurface materials.

4.2 *Complementary Data*—Geologic and water table data obtained from borehole logs, geologic maps, and data from outcrops or other complementary surface geophysical methods (D 6429) and borehole geophysical methods (Guide D 5753) are usually necessary to properly interpret subsurface conditions from gravity data.

5. Significance and Use

5.1 *Concepts*—This guide summarizes the equipment, field procedures, and interpretation methods used for the determination of subsurface conditions due to density variations using the gravity method. Gravity measurements can be used to map major geologic features over hundreds of square miles and to detect shallow smaller features in soil or rock. In some areas, the gravity method can detect subsurface cavities.

5.1.1 Another benefit of the gravity method is that measurements can be made in many culturally developed areas, where other geophysical methods may not work. For example, gravity measurements can be made inside buildings; in urban areas; and in areas of cultural, electrical, and electromagnetic noise.

5.1.2 Measurement of subsurface conditions by the gravity method requires a gravimeter (Fig. 1) and a means of determining location and very accurate relative elevations of gravity stations.

5.1.2.1 The unit of measurement used in the gravity method is the gal, based on the gravitational force at the Earth's surface. The average gravity at the Earth's surface is approximately 980 gal. The unit commonly used in regional gravity surveys is the milligal (10^{-3} gal). Typical gravity surveys for environmental and engineering applications require measurements with an accuracy of a few μ gals (10^{-6} gals), they are often referred to as microgravity surveys.

5.1.2.2 A detailed gravity survey typically uses closely spaced measurement stations (a few feet to a few hundred feet) and is carried out with a gravimeter capable of reading to a few μ gals. Detailed surveys are used to assess local geologic or structural conditions.

5.1.2.3 A gravity survey consists of making gravity measurements at stations along a profile line or grid. Measurements are taken periodically at a base station (a stable noise-free reference location) to correct for instrument drift.

5.1.3 Gravity data contain anomalies that are made up of deep regional and shallow local effects. It is the shallow local effects that are of interest in microgravity work. Numerous corrections are applied to the raw field data. These corrections include latitude, free air elevation, Bouguer correction (mass effect), Earth tides, and terrain. After the subtraction of regional trends, the remainder or residual Bouguer gravity anomaly data may be presented as a profile line (Fig. 2) or on a contour map. The residual gravity anomaly map may be used for both qualitative and quantitative interpretations. Additional details of the gravity method are given in Telford et al (4); Butler (5); Nettleton (6); and Hinze (7).

5.2 Parameter Being Measured and Representative Values:

5.2.1 The gravity method depends on lateral and depth variations in density of subsurface materials. The density of a soil or rock is a function of the density of the rock-forming

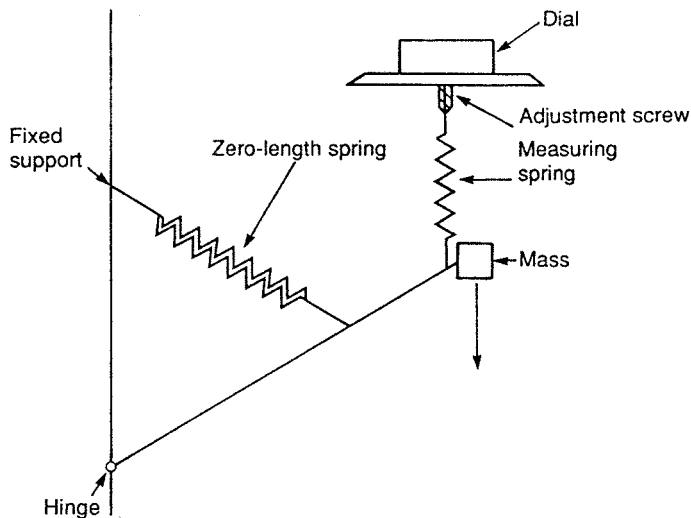


FIG. 1 Gravimeter (from Milsom (13))

⁴ Annual Book of ASTM Standards, Vol 04.09.

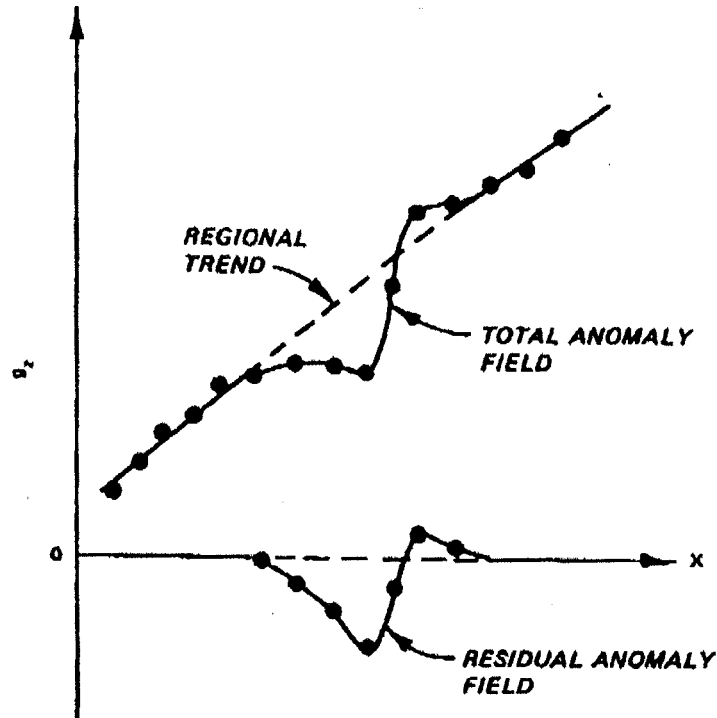


FIG. 2 Graphical Method of Regional-Residual Separation (from Butler (4))

minerals, the porosity of the medium, and the density of the fluids filling the pore space. Rock densities vary from less than 1.0 g/cm³ for some vesicular volcanic rocks to more than 3.5 g/cm³ for some ultrabasic igneous rocks. As shown in Table 1, the normal range is less than this and, within a particular site, the realistic lateral contrasts are often much less.

5.2.2 Table 1 shows that densities of sedimentary rocks are generally lower than those of igneous and metamorphic rocks. Densities roughly increase with increasing geologic age because older rocks are usually less porous and have been subject

to greater compaction. The densities of soils and rocks are controlled, to a very large extent, by the primary and secondary porosity of the unconsolidated materials or rock.

5.2.3 A sufficient density contrast between the background conditions and the feature being mapped must exist for the feature to be detected. Some significant geologic or hydrogeologic boundaries may have no field-measurable density contrast across them, and consequently cannot be detected with this technique.

5.2.4 While the gravity method measures variations in density in earth materials, it is the interpreter who, based on knowledge of the local conditions or other data, or both, must interpret the gravity data and arrive at a geologically reasonable solution.

5.3 Equipment:

5.3.1 Geophysical equipment used for surface gravity measurement includes a gravimeter, a means of obtaining position and a means of very accurately determining relative changes in elevation. Gravimeters are designed to measure extremely small differences in the gravitational field and as a result are very delicate instruments. The gravimeter is susceptible to mechanical shock during transport and handling.

5.3.2 *Gravimeter*—The gravimeter must be selected to have the range, stability, sensitivity, and accuracy to make the intended measurements. Many gravimeters record digital data. These instruments have the capability to average a sequence of readings, to reject noisy data, and to display the sequence of gravity measurements at a particular station. Electronically controlled gravimeters can correct in real time for minor tilt errors, for the temperature of the instrument, and for long-term drift and earth tides. These gravimeters communicate with computers, printers, and modems for data transfer. Kaufmann

TABLE 1 Approximate Density Ranges (Mg/m³) of Some Common Rock Types and Ores (Keary and Books (12))

Alluvium (wet)	1.96–2.00
Clay	1.63–2.60
Shale	2.06–2.66
Sandstone	
Cretaceous	2.05–2.35
Triassic	2.25–2.30
Carboniferous	2.35–2.55
Limestone	2.60–2.80
Chalk	1.94–2.23
Dolomite	2.28–2.90
Halite	2.10–2.40
Granite	2.52–2.75
Granodiorite	2.67–2.79
Anorthosite	2.61–2.75
Basalt	2.70–3.20
Gabbro	2.85–3.12
Gneiss	2.61–2.99
Quartzite	2.60–2.70
Amphibolite	2.79–3.14
Chromite	4.30–4.60
Pyrrhotite	4.50–4.80
Magnetite	4.90–5.20
Pyrite	4.90–5.20
Cassiterite	6.80–7.10
Galena	7.40–7.60

(8) describes instruments suitable for microgravity surveys. A comprehensive review of gravimeters can be found in Chapin (9).

5.3.3 *Positioning*—Position control for microgravity surveys should have a relative accuracy of 1 m or better. The possible gravity error for horizontal north-south (latitude) position is about 1 $\mu\text{gal}/\text{m}$ at mid-latitudes. Positioning can be obtained by tape measure and compass, conventional land survey techniques, or a differential global positioning system (DGPS).

5.3.4 *Elevations*—Accurate relative elevation measurements are critical for a microgravity survey. A nominal gravity error of 1 μgal can result from an elevation change of 3 mm. Therefore, elevation control for a microgravity survey requires a relative elevation accuracy of about 3 mm. Elevations are generally determined relative to an arbitrary reference on site but can also be tied to an elevation benchmark. Elevations are obtained by careful optical leveling or by automatic digital levels.

5.4 *Limitations and Interferences:*

5.4.1 *General Limitations Inherent to Geophysical Methods:*

5.4.1.1 A fundamental limitation of all geophysical methods is that a given set of data cannot be associated with a unique set of subsurface conditions. In most situations, surface geophysical measurements alone cannot resolve all ambiguities, and some additional information, such as borehole data, is required. Because of this inherent limitation in the geophysical methods, a gravity survey alone can never be considered a complete assessment of subsurface conditions. Properly integrated with other geologic information, gravity surveying is a highly effective, accurate, and cost-effective method of obtaining subsurface information.

5.4.1.2 In addition, all surface geophysical methods are inherently limited by decreasing resolution with depth.

5.4.2 *Limitations Specific to the Gravity Method:*

5.4.2.1 A sufficient density contrast between the background conditions and the feature being mapped must exist for the feature to be detected. Some significant geologic or hydrogeologic boundaries may have no field-measurable density contrast across them, and consequently cannot be detected with this technique. An interpretation of gravity data alone does not yield a unique correlation between possible geologic models and a single set of field data. This ambiguity can only be resolved through the use of sufficient supporting geologic data and by an experienced interpreter.

5.4.2.2 *Interferences Caused by Ambient, Geologic, and Cultural Conditions:*

(1) The gravity method is sensitive to noise (vibrations) from a variety of natural ambient and cultural sources. Spatial variations in density caused by geologic factors may also produce unwanted noise.

(2) *Ambient Sources of Noise*—Ambient sources of noise include earthquakes, microseisms, tides, winds, rain, and extreme temperatures.

(a) (a) *Earthquakes*—Local earthquakes seldom are a problem during gravity observations. They occur and are gone before they are any inconvenience. Distant earthquakes how-

ever, can lead to gravity changes of 100 μgals or more with periods of tens of minutes or more. These effects can delay gravity observations for several hours or even days.

(b) (b) *Microseisms*—Microseisms are defined as feeble earth tremors due to natural causes such as wind, water, or waves (Sheriff (1)). They are believed to be related to wave action on shorelines and to the passage of rapidly moving pressure fronts whose effects are seen as sinusoidal variations in the gravity data. Their amplitude can readily exceed several tens of μgals .

(c) (c) *Earth Tides*—Solar and lunar tides affect the force of gravity at the Earth's surface by as much as 300 μgals with a rate of change as large as 1 $\mu\text{gal}/\text{min}$. These solid earth tides are predictable and can be corrected for as a part of gravity data correction procedures.

(d) (d) *Wind and Rain*—Wind and heavy rain can cause movement of the gravimeter. The gravimeter should be shielded from the wind and rain.

(e) (e) *Extreme Temperatures*—Extreme temperature changes over short periods of time can cause instrument drift. In order to minimize this effect, the gravimeter should be insulated from extreme heating or cooling. Slow gradual changes in temperature are normally accommodated by repeat base station measurements and drift corrections made as a normal part of the gravity survey.

(f) (f) *Geologic Sources of Noise*—Geologic sources of noise may include unknown variations in the natural spatial distribution of soil and rock and their densities.

(g) (g) *Topography*—Hills, mountains, and valleys affect gravity measurements. Depending on the objectives of the survey, topographic corrections may be needed (Hinze (7)).

(h) (h) *Cultural Sources of Noise*—Cultural sources of noise include vibration from vehicles, heavy equipment, trains, and even persons walking near the gravimeter.

5.4.3 *Summary*—During the course of designing and carrying out a gravity survey, the sources of ambient, geologic, and cultural noise must be considered and time of occurrence and location noted. The exact form of the interference is not always predictable because it depends upon the type and magnitude of noise and distance from the source of noise.

5.5 *Alternate Methods*—In some cases, the factors previously discussed may prevent the effective use of the gravity method, and other geophysical (Guide D 6429) or non-geophysical methods may be required to investigate subsurface conditions.

6. Procedure

6.1 This section includes a discussion of personnel qualification, considerations for planning and implementing the gravity survey, and interpretation of gravity data.

6.1.1 *Qualification of Personnel*—The success of a gravity survey, as with most geophysical techniques, is dependent upon many factors. One of the most important factors is the competency of the person(s) responsible for planning, carrying out the survey, and interpreting the data. An understanding of the theory, field procedures, and methods for interpretation of gravity data along with an understanding of the site geology is necessary to successfully complete a gravity survey. Personnel

not having specialized training or experience should be cautious about using this technique and solicit assistance from qualified practitioners.

6.2 *Planning the Survey*—Successful use of the surface gravity method depends to a great extent on careful and detailed planning as discussed in this section.

6.2.1 *Objectives of the Gravity Survey*—Planning and design of a gravity survey is done with due consideration to the objectives of the survey and the characteristics of the site. These factors will determine the survey design, the equipment used, the level of effort, the interpretation method selected, and budget necessary to achieve the desired results. Important considerations include site geology, desired depth of investigation, topography, and access. The presence of noise-generating activities and operational constraints (which may restrict survey activities) must also be considered. It is good practice to obtain as much of the relevant information as possible about the site prior to designing a survey and mobilization to the field. For example, data from any previous gravity work, other surface geophysical methods, boreholes, and geologic and geophysical logs in the study area and topographic maps or aerial photos should be used to plan the survey.

6.2.2 A simple geologic/hydrologic model of the subsurface conditions at the site is developed early in the design phase and should include the thickness and type of soil cover, depth and type of rock, depth to water table, stratigraphy and structure, and targets to be mapped with the gravity method.

6.2.3 *Assess Density Contrast:*

6.2.3.1 One of the most critical elements in planning a gravity survey is the determination of whether there is an adequate density contrast to produce a measurable gravity anomaly.

6.2.3.2 Assuming that no previous gravity surveys have been made in the area, knowledge of the geology from published references containing the geologic character or densities of earth materials and from published reports of gravity studies performed under similar conditions is required. From this information, the feasibility of using the gravity method at the site can be assessed.

6.2.3.3 Forward modeling using analytical equations or numerical modeling methods can be used to calculate gravity data for a given set of subsurface conditions. Given the depth and the shape of the subsurface feature and the difference in density, such models can be used to assess the feasibility of conducting a gravity survey and to determine the geometry of the field-survey. However, all too often, sufficient information about the depth, shape, and density contrast will not be available to accurately model a site before fieldwork is carried out.

6.3 *Survey Design:*

6.3.1 There must be a clear technical objective to the gravity survey. The target's size, depth, orientation, number and distribution, and density should be estimated. A forward model of the gravity anomaly caused by a specific geologic condition can be used to determine its shape and size. This will determine the required measurement station spacing. The length of a profile line or area of survey should be larger than the area of

interest so that measurements are taken in background conditions to establish a regional gravity gradient. For example, in mapping a buried channel, the gravity survey line should cross over the channel so that its boundaries can be determined.

6.3.2 The distance between station measurements should be close enough to define the expected anomaly. An anomaly must be defined by a minimum of 3 points and preferably by more points.

6.3.3 Preliminary location of survey lines is usually done with the aid of topographic maps and aerial photos if an on-site visit is not possible. Consideration should be given to:

6.3.3.1 The need for data at a given location,

6.3.3.2 The accessibility of the area with adequate space for the gravity line or grid,

6.3.3.3 The proximity of wells or test holes for control data, and

6.3.3.4 The need for topographic corrections.

6.3.4 The extent and location of any buried structures and other cultural features that may introduce noise into the data or noise that will prevent measurements from being made should be considered when locating survey lines.

6.4 *Type of Survey*—In reconnaissance surveys over large areas, measurement station spacing may be large (hundreds of metres or more). Under these conditions, the cost of obtaining gravity data may be relatively low, but the resulting subsurface data are not very detailed. In detailed surveys, measurement station spacing is relatively small (a few metres). Under these conditions, the effort for obtaining gravity data is higher, but resulting subsurface data is more detailed.

6.5 *Survey Geometry*—Gravity data may be obtained along a single profile line, widely spaced profile lines, or over a uniform grid. The station spacing will be determined by the resolution required.

6.6 *Survey Implementation:*

6.6.1 *On-Site Check of Survey Plan*—A systematic visual inspection of the site should be made upon arrival to determine if the initial survey plan is reasonable. At this point, modifications to the survey plan may be required.

6.6.1.1 The results of initial measurements can be used to confirm the existence of an adequate density contrast and can also be used to assess noise at the site. Results of these initial measurements may require that changes be made to the original survey plan.

6.6.2 *Lay Out the Survey Lines*—Locate the best position for the gravity survey lines based on the survey design described in 6.3 and the on-site visit. Designing the survey grid to avoid proximity to features such as ditches, rivers, or ravines can minimize the need for terrain corrections. The gravity station should be at least 3 to 4 times the distance from the feature as the feature's height.

6.6.3 *Establish a Base Station or Stations*—Establish a base station at any stable, accessible location near or within the survey area (a concrete surface that is reasonably level is ideal). The base station is used as a reference point with repeated measurements throughout the day. This provides a means to detect and correct any offsets in the gravimeter measurements caused by jarring, vibration, or extreme temperature shifts.

6.6.3.1 The base station gravity reading should be obtained at the beginning and end of each workday, and at least once each hour during the course of the survey.

6.6.4 *Obtain the Location and Elevation of the Measurement Stations*—The local (x , y) coordinates of the measurement station can be obtained by tape measure and compass to the nearest 0.5 m (2.0 ft). For a microgravity survey, relative elevations with an elevation accuracy of 50 cm (2.0 ft) is necessary.

6.7 Survey Methods:

6.7.1 *Measurements at a Single Gravity Station*—Consistency is extremely important in a gravity survey. A clear and concise field procedure should be established and followed methodically at every station. The general sequence for obtaining a measurement at a station is as follows:

6.7.1.1 Place the baseplate over gravity station and level it,

6.7.1.2 Place the gravimeter on the baseplate and level it,

6.7.1.3 Measure the height of the gravimeter,

6.7.1.4 Take an initial measurement,

6.7.1.5 Recheck level bubbles or electronic levels, and

6.7.1.6 Monitor the reading over a period of time for consistency.

6.7.2 The station location, station elevation, instrument height above survey point, meter reading, time of reading, and general comments are recorded at each station. Even if the measurements are digitally recorded, a careful set of notes with comments is recommended.

6.8 *Gravity Program*—Measurements made between two successive base station measurements make up a program. Programs should be planned to minimize the distance between the last measurement station and the base station. Each program should include at least 20 % remeasurement (overlap) of stations from previous programs. After correction for drift, remeasurement station measurements should agree with each other to within 5 to 20 μgal (depending on survey objectives and noise conditions), or a third measurement should be made during a subsequent program (Butler (5)). Periodic base station measurements and repeated station measurements are essential quality control procedures for gravity surveys.

6.9 *Quality Control (QC)*—No amount of computer processing can remedy a low-accuracy field survey. It is imperative that the quality of data be monitored as the survey proceeds. It is critical to have sufficient record keeping so that the entire time sequence of events, along with the gravity data and any anomalous conditions that may affect the data, can be easily reconstructed and checked for errors.

6.9.1 *Calibration and Standardization*—In general, the manufacturer's recommendations should be followed for calibration and standardization of equipment. If no such recommendations are provided, a periodic check of equipment should be made. A check should also be made after each equipment problem and repair. An operational check of equipment are carried out before each project and before starting fieldwork each day.

6.10 *Data Processing*—Procedures for correcting gravity field data are discussed thoroughly in standard references, such as Grant and West (10) and Telford et al (4).

6.10.1 *Corrections*—Butler (5) summarizes the corrections needed for a microgravity survey, which include:

6.10.1.1 *Meter Factor*—The meter factor is the value that converts the gravimeter readings to values in μgal . Each meter has its own table of conversion factors for the various ranges of meter readings.

6.10.1.2 *Instrument Drift*—Drift is assumed to be linear between the hourly observations at the base stations, and a linear drift correction is applied to all measurements between base station observations.

6.10.1.3 *Earth Tides*—Earth tidal corrections are made using a theoretical computation of tides at the site (Longman (11)).

6.10.1.4 *Latitude Correction*—A latitude correction must be made to take into account the gravity increase with increasing latitude. The correction is more than 0.5 milligal/km for all latitudes between 25 and 65°. For microgravity surveys, it is usually sufficient to assign a reference latitude to the base station and then to compute latitude corrections for all other stations (Butler (5)). Determination of relative positioning to within 1 m or better will keep errors in the latitude correction well below 1 μgal .

6.10.1.5 *Elevation Corrections*—Two corrections are necessary to account for elevation differences between stations in a microgravity survey.

(1) *Free-Air Correction*—A free-air correction is made to compensate for the change in gravity due to the elevation of a station above an arbitrary datum above sea level. An increase in elevation, above datum, causes a decrease in gravity because the station is further from the center of the earth. The normal free-air vertical gravity gradient (0.30855 milligal/m) is essentially constant and can be used for all stations in a microgravity survey (Butler (4)). The gravity values should also be corrected for variable meter height above ground level (the height from the base plate to the ground surface).

(2) *Bouguer Correction*—A Bouguer correction is made to compensate for the mass of near-surface soil or rock between the gravity station and the datum. A bulk average density is often assumed for the site. When the observed gravity value at a station is corrected as previously described, the result is called the Bouguer anomaly for the station (Butler (5)).

6.10.1.6 *Terrain Correction*—A terrain correction compensates for gravity values due to nearby "hills" or "valleys." These terrain corrections must be added to the station gravity values. The effects caused by more distant terrain features (caused by large mountains or valleys approximately 1 km or more distant), while possibly quite large in magnitude, will influence each station value in a small area microgravity survey to an equal extent. These more distant terrain feature corrections need not be considered for a microgravity survey (Butler, (5)). For a microgravity survey, the correction for terrain effects within 50 m of a station can be significant and must be carefully considered.

(1) Terrain corrections can be estimated using analytical equations or hand calculations of the terrain effect at a few points along the survey line. For a detailed terrain correction to be made to a set of gravity data, a detailed topographic map and computer calculations are required. After the terrain