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The Defense Mapping Agency

DMA Technical Manual
Land Gravity Surveys

NOVEMBER 1980

DEFENSE MAPPING AGENCY
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DEFENSE MAPPING AGENCY TECHNICAL MANUAL 80-002

LAND GRAVITY SURVEYS

FOREWORD

1. This manual is one of a series of technical manuals intended to replace Geodetic Survey Squadron Manual 96-2. Those sections of GSSM 96-2 covered by this manual are now obsolete. There is no copyrighted material in this publication. Reproduction in whole or part is permitted for any purpose of the United States Government.

2. Comments, suggestions or any errors noted on any aspect of this manual should be forwarded to the Geodetic Survey Squadron according to the guidelines in chapter 1. Additional copies of this manual may be obtained from the same address.

FOR THE DIRECTOR:

CLARK T. LEHMANN
Colonel, USA
Chief of Staff

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CHAPTER 1

INTRODUCTION

1. PURPOSE AND SCOPE

This manual provides detailed instructions for the implementation of land gravity surveys along with methods of survey design, field instructions, and typical accuracy specifications. A glossary of gravimetric survey terms is included as appendix A. These instructions are intended to be used in conjunction with written project instructions, which will give the specific accuracy requirements. The methods presented herein are to be employed for all gravity surveys. No changes will be made without prior approval.

2. MAINTENANCE

This manual is subject to annual review and approval by the Geodetic Survey Squadron. Users of this publication are encouraged to recommend changes and submit comments for its improvement. Comments should be keyed to the specific page, paragraph, and line of the text in which the change is recommended. Reasons should be provided for each comment, to ensure understanding and complete evaluation. Suggestions should be addressed as follows:

DMAHTC Geodetic Survey Squadron
Attn: Chief, Techniques Office
F. E. Warren AFB, WY 82001

3. REFERENCES

a. Defense Mapping Agency Topographic Center. General Land Gravity Survey Instructions. November 1974.

b. Instruction Manual for LaCoste & Romberg, Inc., Model G Land Gravity Meter. LaCoste & Romberg, Inc., Austin, Texas.

CHAPTER 2

ACCURACY REQUIREMENTS

1. GENERAL

The establishment of a gravity station requires not only a gravity observation but also the determination of the station position and the elevation. The position and elevation accuracy requirements stated herein are typical values that may be either relaxed or tightened according to the project instructions issued for a particular job.

2. GRAVITY BASE STATIONS

The primary purpose of a gravity base station is to provide an accurate absolute gravity reference on which to base relative regional gravity surveys. High numerical accuracy in position and elevation is therefore not necessary, though it is desirable. The prime requisite in a gravity base station is a good station description, which facilitates the accurate occupation of the point with a gravimeter.

a. Geographic Position Accuracy. Geographic positions must be scaled as accurately as possible from available large-scale maps. If adequate mapping or geodetic control are not available, positions may be given to ± 0.5 degree.

b. Vertical Accuracy. Elevation for a gravity base station is needed primarily for descriptive information and must therefore be as accurate as can be obtained from available map sources.

c. Gravity Accuracy. All gravity base surveys must be related to the current International Gravity Standardization Net (IGSN), a worldwide system of absolute gravity values, or to base nets that are adjusted to the IGSN. An IGSN station is identified by the date of its adjustment and adoption, for example, IGSN 1971.

(1) Ties to the IGSN. If an area does not have base stations in the IGSN system, ties are to be made as described herein. All ties to the IGSN must be accurate to ± 0.05 (1σ) milligal (mgal) with respect to the selected IGSN stations. Sufficient observations must be made to establish statistically that this accuracy is obtained. IGSN base station descriptions and information will be provided for all projects.

(2) Fundamental Gravity Base Station. In many countries a gravity base station, usually located in the capital city, has been designated as a fundamental gravity base station; in most cases these stations have been included in the IGSN adjustment. However, if a country or region lacks a fundamental base station and requires that one be established, it will be observed with the same accuracy as ties to the IGSN, described in 2c(1) above.

(3) Gravity Base Networks. Gravity base networks must be planned and observed so that all stations are accurate to ± 0.05 (1σ) mgal with respect to the originating IGSN system bases. National nets or nets covering large areas require the use of two or more IGSN stations so that scale conditions may be introduced in the adjustment. A gravity base network must be established prior to the start of any regional gravity survey.

3. REGIONAL GRAVITY STATIONS

Regional or anomaly gravity surveys are performed for the purpose of defining the variations of the gravity field in some detail over the area of consideration. Most applications require some specified accuracy in the station (point) free air anomaly. Errors in position, elevation, and gravity observation all contribute to error in the free air anomaly. Specification of a mean anomaly or contouring accuracy requires that attention be given to station distribution and spacing.

a. Geographic Position Accuracy. Geographic positions of the regional gravity stations must be accurate to within ± 0.1 minute of arc in latitude and longitude with respect to a major horizontal datum. In areas of relatively flat to moderate gravity gradients this positional accuracy may be relaxed to ± 0.2 minute of arc, provided vertical accuracy remains constant. The accuracies described above are obtainable from most large-scale maps (1:50,000 scale or larger) and some medium-scale maps (1:250,000 scale or larger). Specific accuracy requirements will be tailored to point anomaly, mean anomaly, or contouring requirements for each survey.

b. Vertical Accuracy. All elevations for regional gravity stations must have an accuracy commensurate with the point anomaly accuracy requirement. For areas covered by large-scale maps (1:50,000 or larger) having sufficient checked spot elevations, benchmarks (BM), or adequate contour interval, regional gravity station elevations will be given to provide a ± 1 mgal point anomaly accuracy (usually ± 3 meters of elevation). All elevations will be referred to an accepted vertical datum.

(1) For areas adjacent to the sea that do not have adequate vertical control, a local datum may be used, provided corrections for marine tides are available or the range between mean high and low tides does not exceed 3 meters.

(2) Barometric leveling is discouraged and will be used only as a last resort. Of the three methods generally described in surveying textbooks, only the two-base method is to be used. If barometric leveling is to be used, specific instructions and specifications will be provided.

c. Gravity Accuracy. Regional gravity stations must have an observed gravity value accurate to ± 0.3 (1σ) mgal with respect to the originating gravity base net.

CHAPTER 3

GRAVITY SURVEY PROCEDURES

1. GENERAL

The following survey procedures have been developed for use with the LaCoste and Romberg geodetic gravimeter. Experience has proved that these procedures, used in conjunction with the observing procedures in chapter 4, make it possible to obtain the accuracies stated in chapter 2.

2. THE LOOP

The basic building block in gravity survey design and execution is the loop. This procedure is required in order to computationally remove gravimeter drift; it also provides redundant observations at stations.

a. Ladder Sequence Loop. Given stations A, B, and C to be observed, the loop sequence A-B-C-B-A is preferred and for base ties is a requirement. This is known as the ladder sequence loop.

b. Modified Ladder Sequence Loop. Difficult field conditions encountered while base ties are being observed may require a modified ladder sequence loop. Given stations A, B, C, and D to be observed, the sequence A-B-C-D-B-A is executed. This loop method is permissible for all regional surveys.

c. Line Sequence Loop. Often in the observing of regional loops it is not possible to return to the starting base. Given bases A and B and stations 1, 2, and 3 to be observed, the line sequence A-1-2-3-2-B may be used.

d. Loop Time and Drift Observations. The observing schedule for a loop must be designed so as to complete it in the shortest possible time, not to exceed 72 hours. Transportation stops of 1 hour or more require that drift observations be made. This is accomplished by observing the gravimeter at the beginning of the stop and again at the same location at the termination of the stop. Geographic position for drift stations is recorded to ± 1.0 degree. All observations in a loop sequence are performed in accordance with chapter 4. A base or regional station may be used for drift observations.

e. Loop Closure. The difference in fore leg and back leg observations at a station in a loop must not exceed ± 0.05 (1σ) mgal for a base loop or ± 0.2 (1σ) mgal for a regional loop after earth tide and linear drift corrections are applied. Field check computations must be made for base loops. Chapter 7 contains instructions for these computations.

f. Time Keeping. Often in the process of observing a loop, two or more time zones are crossed. Keep loop observation times in one time zone only.

3. TRANSPORTATION

a. Excessive vibration and jolting can cause erratic drift in gravimeters. They must at all times be transported in their aluminum carrying cases, and automotive transportation is preferred for all types of surveys. The carrying case must be belted through the handle on a spare seat, or the case may rest on a 4-inch foam pad on the floor between the seats. On rough roads or cross-country trips, the automobile must be driven slowly enough to prevent excessive jolts.

b. Gravimeters are never transported in the luggage compartment of an aircraft while a loop is being observed. On all piston, prop-jet, or helicopter aircraft, they must be carried belted to a seat or in the observer's lap; on jet aircraft, they may be carried under the seat.

4. BASE STATION NETWORKS

A gravity base net is established for the purpose of extending the IGSN system to preselected locations throughout a country or region and to make available absolute gravity references on which regional gravity surveys may be based.

a. Fundamental Base Stations. A fundamental gravity base station is a special case. The same methods of establishment are used as in base nets, but because direct absolute gravity determinations may be desirable at some future date, special care must be taken in the site selection. The site must be permanent and free from all effects of vibration and subsidence, and it must be accessible, indoors, and spacious. The station is marked with a disk and described according to the instructions in chapter 6.

b. Excenter Base Stations. Excenter stations may be established in the vicinity of a fundamental or national base station to insure the availability of a gravity value in the event that the station is destroyed or becomes inaccessible. Base net methods are used to establish excenter stations.

c. Station Selection Criteria. The required number of base stations in a net and the distance between them depends on the regional surveys to be performed, the topography, and the road system of the region. Base stations should be located as close as possible to the regional survey area to reduce travel time during survey operations. Highly accurate position and elevation are not necessary to a good base station location. The criteria for selecting a site are as follows:

(1) Permanency

(2) Stability; i.e., freedom from vibration and subsidence

(3) Accessibility for 24 hours a day

(4) Freedom from interference by power transformers (at least 100 feet away), pedestrians, autos, elevators, and machinery

(5) Space enough to observe two gravimeters simultaneously

(6) Protection from weather

All gravity base station disks are located on concrete, granite, stone, marble, or other hard floor or wall surfaces. A shankless disk is attached to the floor or unpainted wall surface with quick-setting epoxy. The disk is placed as close to the wall as possible to avoid accidental removal or damage. Monumentation of gravity base stations in foreign areas will be decided on by the host country.

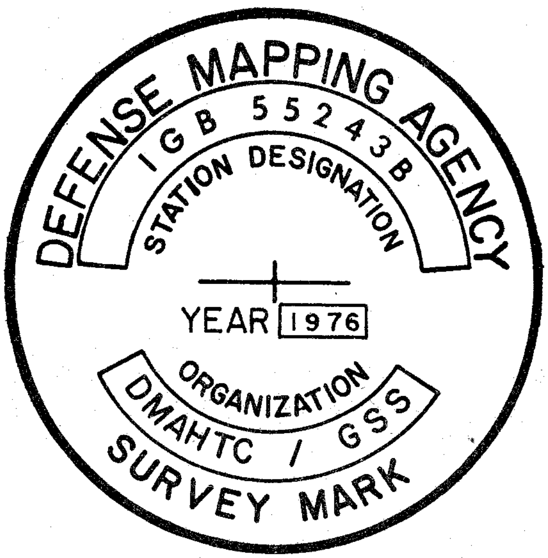


Figure 3-1. Gravity station mark.

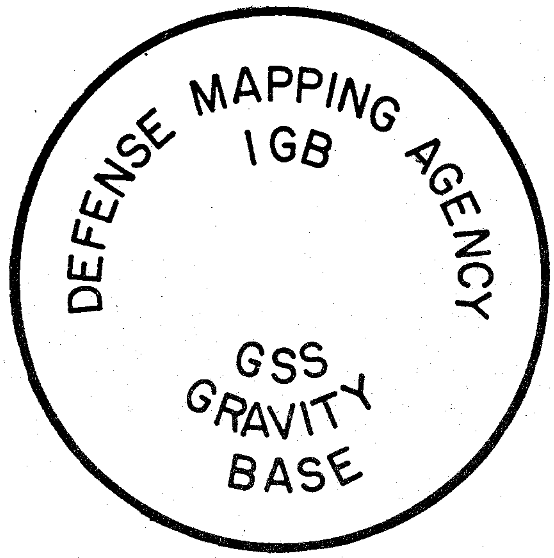


Figure 3-2. Former gravity station mark.

Although many gravity base stations are located in airports, an airport location is not ideal. However, if a station is to be established at an airport, it should be located in the main lobby, next to a readily recognizable architectural feature. Passenger boarding gates or waiting rooms <u>will not be used</u>.

In some instances, a benchmark may be located near a proposed base station site. If the benchmark location does not meet the criteria for the selection of a base station, the base should be established at another location. The elevation of the gravimeter with respect to the benchmark should be measured (± 3 meters) and recorded on the Field Records and Encoding Form, in case the site is required for use as a regional gravity station.

d. Ties to the International Gravity Standardization Net. Ties to the IGSN are the first step in the expansion of a base net. The purpose of these ties is to establish a datum and scale for the proposed net.

(1) Direct Establishment of Scale. Two or more specially selected gravimeters, one having a previously established calibration factor in terms of the IGSN, will be used to observe ties to the IGSN. If possible, two IGSN stations encompassing the total gravity range to be covered will be observed in order to provide scale for the proposed gravity survey. See figure 3-3.

(2) Indirect Establishment of Scale. If it is impractical to tie to two IGSN stations, the tie is observed twice with two gravimeters. This type of tie does not provide a direct method of establishing the scale for the proposed survey area, but the scale can be determined by using a gravimeter that has had its calibration factor determined from the IGSN. Whenever a long tie is observed, it is recommended that intermediate stations be observed to determine gravimeter drift accurately. See figure 3-4.

e. Net Design. The first consideration in a network design is the tie to the IGSN, as explained in section 4d above. This tie provides for a scale adjustment to the IGSN system and also makes possible future calibration of locally used gravimeters. Two or more gravimeters are used to observe the net, at least one of which has a previously determined IGSN scale correction. Sufficient ties between net stations and sufficient observations must be included in the net to assure the required accuracy. Loops should be planned so they form closed circuits. Ideally, the proposed network should be analyzed with the help of a computer program, which can predict propagated error with respect to starting stations and between net stations.

5. REGIONAL SURVEYS

Regional surveys are performed to map the gravity field to some specified accuracy and resolution.

a. Station Density. The spacing between gravity stations determines the resolution of the gravity field. Requirements for density will be stated in the instructions furnished for each project.

b. Station Distribution. The requirement for a uniform station distribution that meets the density requirement must be modified so as to define the gravity field high and low features. The gravity field is generally correlated with topography; therefore, a representative sampling is accomplished by locating stations on both hills and valleys.

c. Terrain Effect. Local terrain effects must be avoided when choosing a station site, to prevent errors in the gravity field definition. Stations must be located at least 300 meters from abrupt topographic features such as escarpments, canyons, river channels, mounds, and holes.

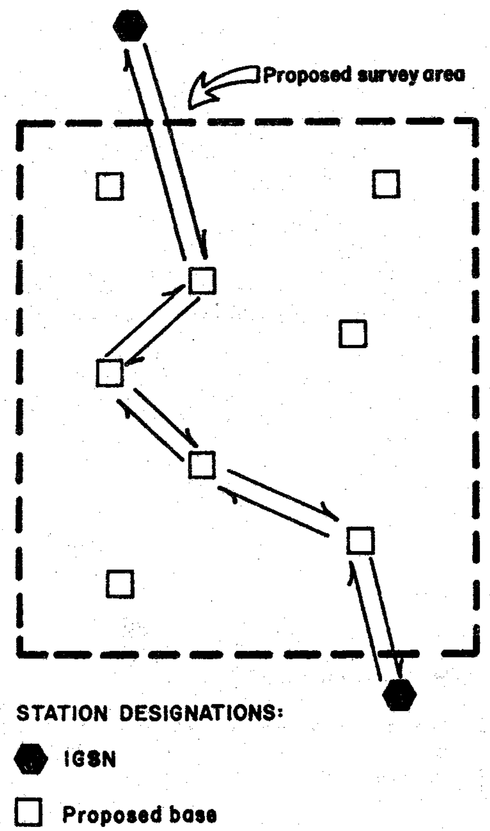


Figure 3-3.

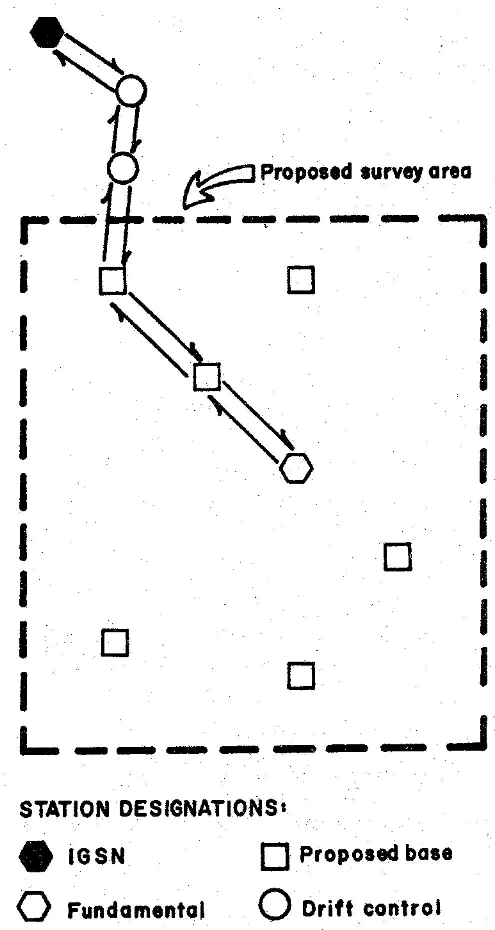


Figure 3-4.

d. Base Reference. All regional loops must originate and terminate at a designated base station. Under no circumstances will a regional loop originate or terminate on a regional station.

e. Loop Sequence. Regional stations are established by use of either the modified ladder or the line sequence loop method of observation. The modified ladder sequence method is preferred because the reobservation of stations within the loop will provide instrumental drift rate and determine any tares that may have occurred during the survey. In order to determine instrumental drift rate, at least one station per day will be reobserved for each loop. The reobservations will be distributed within the loop, so as to provide uniform time intervals with the closing base observation. The survey should be planned on a day-to-day basis that will allow interties to stations in previously established loops. Also, the last station observed in the previous day's loop should be reobserved and included in a new loop sequence.

6. HORIZONTAL AND VERTICAL CONTROL

a. Characteristically, regional gravity points established in areas of large-scale mapping are located at map-identifiable features that have published elevations. The following are typical of points that may be used, provided the elevations meet the accuracy requirements of the particular gravity survey:

(1) Bench marks of first through third order

(2) Temporary bench marks

(3) Vertical angle bench marks (elevations usually determined for triangulation, traverse stations, and supplementary vertical control for picture points)

(4) Spot elevations, referred to either as checked spot elevations, established in the field by closed spirit leveling, trigonometric leveling, or closed-circuit barometric leveling; or as unchecked spot elevations, determined by unchecked field survey methods, such as side shots on stadia lines, unchecked vertical angles, barometric leveling, and repeated photogrammetric readings. Spot elevations are established at well-defined cultural and relief features such as road forks and intersections, railroad crossings, buildings, stream crossings and forks, summits of hills, mountains and mountain passes, water surfaces of lakes and ponds, bottoms of depressions, etc.

b. Contour Interpolation.

(1) Elevations can also be determined by contour interpolation, provided that one-half the contour interval is equal to or less than the maximum allowable error for the point anomaly error requirement.

(2) Valid horizontal positions can be obtained for gravity stations

located at map-identifiable points by scaling methods from large-scale maps that satisfy the accuracy requirements.

(3) Position and elevation data not available from map sources must be obtained from an appropriate field survey. The specifications for these surveys will generally be stated in the project instructions for the specific gravity survey.

CHAPTER 4

OBSERVATION AND RECORDING PROCEDURES

1. GENERAL

The observation procedures in this chapter have been developed for use with the LaCoste and Romberg geodetic gravimeter.

2. LOOP VALIDITY

A valid loop consists of a set of observations made by one observer only. This is necessary to eliminate parallax and other observer peculiarities. The gravimeter must also have been at operating temperature for at least 6 hours before commencing the survey and must remain at operating temperature for the duration of the loop.

3. OBSERVATION PROCEDURE

a. Gravimeter Placement. The gravimeter may be placed directly on any smooth, hard, level surface for observing. On rough or nonlevel surfaces, such as soil or gravel, the leveling plate must be used; it must be firmly seated to eliminate any movement while observations are being made.

b. Leveling. Immediately on arrival at a station, the gravimeter must be leveled and rough nulled. Rough nulling is accomplished by bringing the beam off the stops but not necessarily to the reading line. The rough null condition should exist for approximately 5 minutes while station descriptions, etc., are written. The observer must keep the sun from shining on the gravimeter top, because the heat can cause distortion of the level vial assembly. If the observer has to leave the immediate vicinity of the gravimeter, the beam must be clamped and the gravimeter returned to its carrying case. The case lid must be kept closed to prevent the gravimeter from being tipped by the wind.

c. Nulling. The gravimeter is nulled by approaching the reading line from the down-scale (left) side to the up-scale (right) side. The null position is the coincidence of the left edge of the beam with the reading line, as shown in figure 4-1. If the observer overshoots the reading line, the dial must be offset 180° down-scale and the reading line again approached, so as to eliminate any backlash in the dial gear system.

d. Observation Validity. A valid observation at a station consists of two consecutive nulls, no more than 4 minutes apart, that agree to 0.01 counter unit.

4. RECORDING PROCEDURE

Field data is recorded on the Land Gravity Field Record and Encoding Form. See chapter 6.

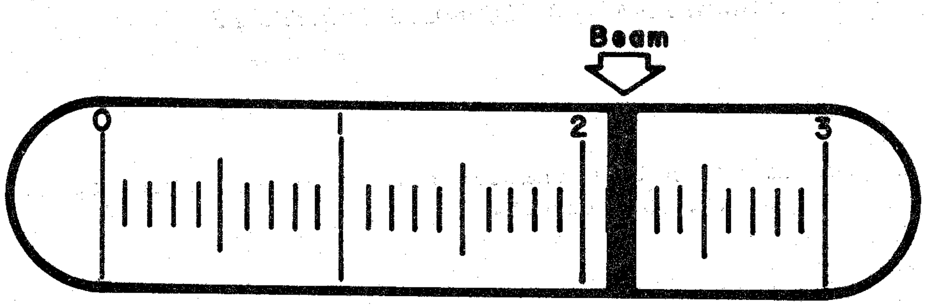


Figure 4-1. Eyepiece scale.

a. Recording Dial and Counter Readings. When the gravimeter is nulled, the observation is recorded from the counter and dial. The last digit of the counter is 0.1 unit, and each numbered unit on the dial is also 0.1 unit. The dial is read to 0.001 unit by estimating the last decimal to eliminate round-off error. Care must be taken in recording the counter reading; in certain instances it may indicate 1.0 unit too high, because it is anticipating the next unit. For example, a value of 3590.995 may read as follows: Counter, 3591.0; Dial, .995. Therefore, it is recommended that the dial reading be recorded first. Then the counter reading can be checked by turning the dial slightly counterclockwise (down-scale) to see if the counter reading changes. After the last reading is recorded and the counter double-checked against the recorded reading, the gravimeter beam is clamped and the gravimeter stored in the carrying case.

b. Station Naming Procedures.

(1) Base Stations. Base stations are generally named after the city (or nearest city) in which they are located. Since numerous gravity stations are located within a given city or locale, a letter designation will be assigned by the home office after the station name to designate the type of location. The following is used as a guide in assigning letters to new bases:

A = Absolute site
B = Universities
C = Public buildings
D = Other buildings (hotels, etc.) and places in town
E = Out of town, on highways, etc.
F = Military installation
J = Airport
K = Other transportation buildings, railroad stations, etc.
L = Harbor sites

(2) A second letter designator will be assigned to differentiate stations located at the same site (i.e., "JB" would be the second site established at an airport).

(3) Regional Gravity Stations. All regional gravity stations will be assigned a unique number that consists of the observer's initials (three letters maximum), the loop number, and the station number. Loops are numbered consecutively starting with 1 for each observer. Stations are numbered consecutively starting with 1 for each loop or line.

Example: Station PCE-3-12
PCE = Observer's initials
3 = Loop or line number
12 = 12th station of loop or line number 3

(4) Other Systems. Other station numbering systems may be used; however, the loop or line must be positively identified for each station in order to provide rapid access to the raw data.

c. Base Station Description. Base stations should be described in accordance with the instructions in chapter 6. Since most gravity base stations are not monumented, it is important that the surveyor take a photograph of the base station showing the exact spot where the reading was made and any features that will assist in a speedy recovery of the base station. In addition, draw a detailed and accurate diagram of the immediate area of the base and the roads or streets leading to it. Include in the description directions for reaching the base station, with addresses referenced to principal streets and highways.

d. Regional Station Description. A gravity description form is provided mainly as a recovery aid for regional gravity stations and for additional office checks to discover positional errors. This form should never be used to describe base stations. See chapter 6 for instructions on its use.

CHAPTER 5

EQUIPMENT

1. GENERAL

These instructions have been written specifically for the LaCoste and Romberg Model G geodetic gravimeter because of its wide use and acceptance in establishing base networks on a worldwide basis. If another type of gravimeter is used, the appropriate instruction manual should be a part of the project specifications.

2. CARE, MAINTENANCE, AND PROPER HANDLING OF GRAVIMETERS

a. Surveyor's Responsibility. Gravimeters are delicate instruments capable of producing very accurate relative gravity measurements if properly used and maintained. A dirty, poorly maintained gravimeter usually results in poor survey data. Like other delicate geodetic survey instruments, the gravimeter and its accessories must be kept clean and in good operating condition at all times. All gravity surveyors must read the LaCoste and Romberg instruction manual and thoroughly understand all adjusting procedures; only those adjustments described in the instruction manual are to be performed by surveyors.

b. Preventive Maintenance. The following maintenance procedures are to be followed by all surveyors:

(1) Eyepiece. Keep the eyepiece clean and free of dust. It may be cleaned with optical tissue or soft, lint-free cloth. When removing the eyepiece, be very careful to keep dust out of the optical tube.

(2) Leveling Screws. Remove and clean the gravimeter leveling screws once a month, or as often as necessary when operating in a dusty environment. The screws may be cleaned with a stiff brush and solvents such as alcohol, lighter fluid, or naphtha. A dry lubricant such as graphite should be applied to the screws after they are cleaned. The leveling screw holding nuts attached to the gravimeter case may be cleaned with a cotton swab dipped in a solvent. Care must be taken in turning the leveling screws, which are made of aluminum, to prevent damage to the screw threads.

(3) Gravimeter Dial Tension. In order to null the gravimeter precisely and rapidly, the dial tension must be correct. To check for correct dial tension, turn the dial 360° in each direction to feel for binding or changes in the tension. In addition, turn the dial no more than 10 dial divisions to see if the dial has a tendency to creep back in the opposite direction. If the dial is binding or the tension changes or creeps back, the tension clip must be removed, cleaned, and reshaped to make contact on its entire surface with the brass collar; then the clip must be adjusted for the correct tension. In addition, the leather shoe on the tension clip must be

checked for wear. When replacing the dial on the measuring screw shaft, the operator must ensure that the bottom of the dial is not touching the top of the tension clip; otherwise, the dial will bind on the tension clip and will prevent accurate, smooth nulling of the gravimeter.

(4) Gravimeter Cable. One of the most frequent field malfunctions of gravimeters is the direct result of mishandling the power cable attached to the gravimeter case. Never lift the gravimeter from the carrying case by the cable; straighten any kinks carefully to prevent breaking it.

(5) Carrying Case. The aluminum gravimeter carrying case is designed for carrying the gravimeter, batteries, and accessories; the case also protects the gravimeter from bumps. If it is not cleaned periodically, the carrying case can accumulate a considerable amount of dust and dirt, which could damage the leveling screws or other parts of the instrument.

3. GRAVIMETER LEVEL AND SENSITIVITY CHECKS

a. Level Check. The gravimeter's long level (parallel to the counter) and cross level (perpendicular to the counter) should be checked according to the instructions given in the LaCoste and Romberg instruction manual. The accuracy of the survey depends on keeping the levels properly adjusted. The long and cross levels are interrelated, and any deviation from their optimum positions will change the gravimeter's sensitivity and reading line.

b. Sensitivity Checks. The gravimeter's sensitivity is changed by adjusting the long level. The ideal sensitivity is 10 eyepiece divisions per one revolution of the dial. The manufacturer recommends that sensitivity be kept between 8 and 12 eyepiece divisions per one dial revolution. If the sensitivity is low, there is a slight loss in reading accuracy, but the beam response is faster. Conversely, if the sensitivity is high, more accurate readings should be obtainable; however, the beam response is slower. Any significant shift in sensitivity also causes a shift in reading line position.

(1) Sensitivity should be checked daily while international ties and base nets are being observed. (Do not make adjustments to the levels during the course of a tie unless something has happened to cause the levels to become seriously out of adjustment.) Make a note on the top margin of the Field Record and Encoding Form as shown in the example below:

Sensitivity checked: 10:9, 27 March 1974
(10 dial units (1 dial revolution) = 9 eyepiece divisions)

When checking sensitivity, be sure to eliminate all backlash by turning the dial at least one-half revolution counterclockwise beyond the lower stop. For regional surveys, the operator should check the levels frequently until familiar with the instrument and its behavior. After gaining experience with an instrument, the operator may find it sufficient to check the levels weekly, recording each level check in the field book.

(2) If the sensitivity check indicates that an adjustment is needed, both levels and the reading line should be checked. A decrease in sensitivity will shift the reading line up-scale (to the right). Conversely, an increase in sensitivity will shift the reading line down-scale (to the left).

4. GRAVIMETER OPERATING TEMPERATURE

The operator should become familiar with the operating temperature for the gravimeter being used and be alert for detectable changes in temperature. Except in extreme weather, when the ambient temperature can affect the stem of the thermometer, there should be practically no visible change in the thermometer reading. If the temperature goes down and the lights are dim, it is an indication of low battery voltage. If environmental temperatures are the same as or near the gravimeter's operating temperature, the gravimeter thermostat will behave erratically, making it difficult or impossible to null the gravimeter accurately. It is recommended that the gravimeter be provided adequate ventilation in areas having temperatures at 38°C (100°F) or higher. <u>Never leave a gravimeter in a closed vehicle when the environmental temperature is 30°C (86°F) or higher or when there is strong sunshine.</u> Under these conditions the temperature inside a vehicle can reach 49°C (120°F) or more, which would affect the gravimeter's thermostat and result in erratic drift. Gravimeters exposed to low temperatures accompanied by a moderate to strong breeze will sometimes display erratic drift behavior. It is a good practice to protect gravimeters from sudden environmental changes and to shield them from strong wind and cold temperatures. In addition, gravimeters must be given sufficient time to adjust to the ambient temperature to give the best results.

5. GRAVIMETER ACCESSORIES

<u>a. Charger-Eliminator (for Gulton-Sonotone Batteries).</u> Gravimeter operators should read and understand the instructions in the LaCoste and Romberg instruction manual dealing with the charger-eliminator before using the unit. The charger-eliminator is to be used only in an adequately ventilated environment, especially when on the eliminator mode, because the unit generates a considerable amount of heat. The charger-eliminator should never be left in the gravimeter carrying case while being used.

(1) Unplug the battery charging cable from the charger-eliminator when it is not in use. Failure to do so may result in an accidental shorting of the cable prongs and will cause severe damage to the charger-eliminator.

(2) The charger-eliminator is capable of operating at 110 or 220 volts AC at 60 or 50 Hz. When operating in areas using 220 volts AC, turn the voltage selector switch fully counterclockwise before plugging the unit in. If the voltage selector switch is not turned fully to the lowest number on the scale when the unit is plugged into a 220-volt outlet, a fuse will blow. To prevent this, use the following procedure when operating in areas using 220 volts:

(a) Turn the voltage selector fully counterclockwise (lowest number on scale).

(b) Plug in the unit.

(c) Turn the voltage selector until the voltage meter dial indicates 110 to 115 volts; do not go past 130 volts or the fuse will blow.

b. Gulton Batteries. Surveyors must read and understand the charging and maintenance instructions that are applicable to the batteries being used. The primary causes of battery failure are excessive overcharging and dirty terminals. Overcharging will permanently damage a battery; therefore, operators are cautioned to be extremely careful in charging the batteries. Battery terminals should be inspected periodically and dismantled to see if there are any deposits. Clean the terminals and holding nuts with a stiff, nonmetallic brush and soap and water. Apply a light coat of Vaseline to the terminal straps and nuts to prevent corrosion. All batteries must be kept fully charged. A reading of 13 or more volts indicates that the battery is fully charged and ready for field use, but any lesser voltage indicates that the battery is not fully charged or that the battery has a dead cell. After being charged, a battery with a dead cell sometimes registers 12 volts; however, this charge will last a very short time and will result in a dead battery during survey operations. Therefore, it is important to check individual cells periodically to see that they are registering the proper voltage. Sometimes a cell will appear dead because of corrosion between the cell strap and holding nut. The corrosion sometimes cannot be seen until the nut and strap are removed; therefore, it is good practice to inspect the battery terminals periodically. Gulton battery cells are equipped with a safety valve. Under no circumstances will the valve be opened by surveyors. Gulton batteries do not require refilling with water.

c. Gel/Cell Batteries. Gel/Cell batteries are completely sealed and do not require periodic maintenance. Use only the Gel/Cell charger-eliminator to charge Gel/Cell batteries. Charging them with a LaCoste and Romberg Gulton battery charger-eliminator will ruin them. The Gel/Cell charger-eliminator may be used to charge a battery and to provide power to the gravimeter at the same time. In areas using 220 volts AC, the voltage selector switch on the Gel/Cell charger-eliminator must be set on 230 before the unit is plugged in. Failure to do this will result in a blown fuse. If a fuse is blown, it must be replaced with an identical fuse. A slow-blow fuse must never be used because this could cause severe damage to the unit.

6. EQUIPMENT PROBLEMS DURING SURVEYS

a. General. Most of the equipment problems encountered by surveyors are caused by poor or improper equipment maintenance and careless practices. However, equipment will fail on occasion, and batteries have a limited life span. The following instructions are provided to help surveyors recognize and correct equipment failures.

b. Corrective Actions by Surveyors. LaCoste and Romberg gravimeter maintenance and adjustment instructions are provided in sections 2, 3, and 4 (chap. 5). The following actions can be taken by surveyors in the field to correct malfunctions:

(1) Gravimeter Bumped or Dropped (clamped or unclamped). Read the gravimeter for 15 minutes at 2-minute intervals to see if the reading is changing by more than 0.03 mgal between readings. This would indicate that the gravimeter is recovering from a tare. In addition, any significant change in gravity from a previously observed nearby station indicates that a tare has occurred. In this case, return to the previously observed station to read the gravimeter. If the readings at this station are within ± 1.0 mgal, record the reobserved value, check the levels, and if no adjustment is required, continue the survey. If the tare is larger than ± 1.0 mgal, abort the loop or line. A tare of ± 5.0 mgals indicates that the gravimeter's sensing system has been subjected to a physical change. In this case, check the gravimeter's levels thoroughly and adjust them (preferably in a stable environment), and observe the drift rate of the gravimeter for a period of 1 hour to determine the rate of recovery (after small tares, gravimeters have a tendency to drift back to the original state). If the drift is high but linear, survey work can continue. Tares of 50 mgals or more indicate that the sensing element may have been severely damaged. The gravimeter in this case may require checking and repair by factory-trained personnel.

(2) Gravimeter off Heat. This malfunction is usually due to battery failure, to a loose power cable connection, or to failure and shorting of the power cable. Check the gravimeter periodically during travel between stations to prevent loss of survey data. The following procedures will be followed in case of power loss to the gravimeter:

(a) Check the battery by turning the gravimeter light on. If it is very dim, the battery is faulty and should be replaced.

(b) Check the vehicle cable connection if used. Check the connector plug and vehicle cable battery terminal connection at the vehicle battery.

(3) Gravimeter Back on Heat. After the malfunction has been corrected and the power is restored, the gravimeter must be allowed time to come back to operating temperature and to stabilize the sensing system before the survey can proceed. Note that gravimeters reach their operating temperature within a relatively short time (5 minutes if the gravimeter has cooled off 5°C); however, if the gravimeter was off heat for 30 minutes, it will probably need 1 or 2 hours to be stable enough for regional field work. Read the gravimeter every 5 minutes after the malfunction has been corrected and after the gravimeter has reached operating temperature. Survey operations (regional only) may be resumed after two consecutive readings, 5 minutes apart, are within ± 0.02 mgal. On a base net survey the gravimeter must be allowed sufficient recovery time, and the loop may be continued after making a reobservation on the last station observed.

CHAPTER 6

INSTRUCTIONS FOR THE USE OF RECORDING AND DESCRIPTION FORMS

1. GENERAL

The Field Record and Encoding Form was designed primarily for automated data processing of land gravity field observations. The description form provides a record for recovering regional gravity stations in the field, for quality control of the survey, and for additional checks in the office.

2. DESCRIPTION

The Field Record and Encoding Form and Gravity Description Form are printed on pressure-sensitive NCR paper and come in sets of three. The Field Record and Encoding Form has space to provide accuracy codes for ϕ, λ, and h coordinates. Both forms are packaged in a hard-cover notebook with inserts placed between sets and separating the two forms. The notebook is kept by the surveyor, who will insert new forms as required.

3. RECORDING INSTRUCTIONS

a. Land Gravity Field Record and Encoding (DMAHTC Form 8353-1 May 79). See figure 6-1.

(1) General

(a) Fill out in ink with a medium or fine ballpoint pen. Felt-tip pens are not authorized. Use sufficient pressure to obtain three legible copies.

(b) Recording errors must be carefully lined out and the correct value placed in the same box, neatly and legibly. An alternative is to line out the entire entry and record on the following line.

(c) All coded letters must be printed in capitals as follows:

The number 0 is written 0.
The letter O is written Ø.
The number 1 is written 1.
The letter I is written I.
The letter Z is written Ƶ.

(d) Observe all decimal point locations given in the column headings. Never write the decimal point (see example 1). Numbers without decimal parts are filled in to the left of the indicated decimal on the form (see example 2).

Example 1. 0.69 is written $\boxed{}\boxed{}\overset{\bullet}{\boxed{6}}\boxed{9}$
Example 2. 69 is written $\boxed{6}\boxed{9}\boxed{}\boxed{}$

<u>Never</u> fill the blanks to the left with leading zeros.

(e) Columns requiring a plus or minus sign (+ or -) need only have minus signs coded; plus signs are understood.

(f) Code only one loop or line to a form.

(g) Additional station description forms may be used as required. Write the loop name on the heading of all the description forms.

(2) Recording Instructions. <u>Note</u>: For illustration purposes, the boxes and columns to be filled in have been numbered 1 through 20. These numbers appear only on the sample form (figure 6-1).

Item 1. Enter the project title, beginning with the first left-hand column.

Item 2. Enter the loop or line number.

Item 3. Enter the beginning date of the loop or line.

Item 4. Enter the name of the observer and the initials of the recorder (if different).

Item 5. Enter the name of the checker.

Item 6. Enter LR for LaCoste and Romberg (or WO for Worden) and the instrument's serial number. <u>Note</u>: Always write the type of gravimeter in columns 66 and 67. Write the number of the gravimeter so that the last digit falls in column 71.

Item 7. Enter the appropriate correction factor as given on the project instructions.

Item 8. Give the name of the starting and ending base and the anomaly station number in accordance with section 4<u>b</u> (chap. 4).

Item 9. Enter the sign and whole degrees, and enter the minutes to hundredths, if available. When the whole degrees of latitude are zero, the sign is coded in column 22. North is positive and south is negative.

Item 10. Enter the same as for latitude. When whole degrees of longitude are zero, the sign is coded in column 31. East is positive and west is negative.

Item 11. Enter the two-digit horizontal position accuracy code, which is derived from table 6-1. Although several types of horizontal surveys and map scales are included in the code, only those surveys and map scales providing the necessary accuracy requirements are used by surveyors.

LAND GRAVITY FIELD RECORD AND ENCODING

PAGE 1 OF 1 PAGES

1 SURVEY NAME/AREA	2 LOOP NAME	3 STARTING DATE	4 OBSERVER/RECORDER	5 CHECKER/COMMENTS	6 GRAVIMETER TYPE	NUMBER	7 CORR TO GMT, HRS	ANO	SEC
MASSACHUSETTS	RBB 3	8 JUN 69	BECK RBA	GAHAN	LR	61	4		
1 - 24	25 - 30	31 - 42	43 - 54	55 - 65	66 - 71		72 - 76	77-78	79-80

	8 STATION NAME	9 LATITUDE ± °	′	10 LONGITUDE ± °	′	11 EP	13 EM	12 ELEVATION	14 EH	15 DATE DAY	MO	YR	16 FIRST NULL HR	MIN	17 DIAL	18 SECOND NULL HR	MIN	19 DIAL	20
1	FITCHBURG J	43	1002	-72	01622	20	F	1031	14	8	6	69	7	48	3434804	7	52	3434802	
2	RBB3-01	43	1586	-71	58392	22	F	30	41	8	6	69	8	59	3402975	9	01	3402976	
3	RBB3-02	43	1322	-71	55222	22	F	1536	10	8	6	69	10	20	3428906	10	20	3428908	
4	RBB3-01	43	1586	-71	58392	22	F	30	41	8	6	69	11	39	3402987	11	40	3402987	
5	RBB3-03	43	1951	-72	06332	22	F	122	21	8	6	69	12	39	3382775	12	41	3382773	
6	RBB3-03	43	1951	-72	06332	22	F	122	21	8	6	69	13	30	3382742	13	30	3382742	
7	RBB3-04	43	2896	-72	07172	22	F	266	10	8	6	69	14	28	3409467	14	32	3409468	
8	RBB3-05	43	2075	-72	05882	22	F	92	21	8	6	69	15	39	3419644	15	41	3419646	
9	FITCHBURG J	43	1002	-72	01622	20	F	1031	14	8	6	69	16	59	3434882	17	00	3434881	
10																			
11																			
12																			
13																			
14																			
15																			
16																			
17																			
18																			
19																			
20																			

DMATC FORM 8353-1, FEB 73

SUPERSEDES TPC FORM 115-117, WHICH MAY BE USED

Figure 6-1.

Item 12. If the elevation is in feet, enter F; if in meters, enter M.

Item 13. Record as reported, noting decimal location.

Item 14. Enter the two-digit vertical control accuracy code, which gives the accuracy of the elevations. The code is derived from table 6-2. Only those elevations providing the required accuracies will be used by surveyors.

Item 15. Enter the calendar day; the month number, for example, February = 2; and the year, for example, 1974 = 74.

Item 16. Enter hours and minutes, using the 24-hour clock and the local time zone. Only one time zone will be used during a loop or line.

Item 17. Enter the gravimeter reading, noting decimal location.

Item 18. Same as item 16.

Item 19. Enter gravimeter reading.

Item 20. Leave blank.

b. Gravity Description (DMAHTC Form 8353-2 May 79). See figure 6-2.

(1) General

(a) Fill out in ink with a medium or fine ballpoint pen. Felt-tip pens are not authorized. Use sufficient pressure to obtain three legible copies.

(b) Errors will be carefully lined out and the correction written neatly and legibly.

(2) Recording Instructions

Item 1. Enter the project title.

Item 2. Enter the loop number in accordance with paragraph 4b(2) (chap. 4).

Item 3. Enter the starting date of the loop.

Item 4. Enter the surveyor's name and the recorder's initials (if different).

Item 5. Enter the name of the party chief.

Item 6. Enter the page number for the current loop.

Table 6-1. Horizontal Position Accuracy Codes

Type	Class	Data Source
		Horizontal Surveys
1	0	First- through third-order surveying
1	1	IPS
1	2	Nav Systems trilateration--Del Norte
		Maps
2	0	Scale > 1/24,000
2	1	1/24,000, 1/25,000
2	2	1/50,000, 1/62,500
2	3	1/100,000
2	4	1/250,000
2	5	< 1/250,000
		Photography
3	0	Scale > 1/1000
3	1	1/10,000 - 1/60,000
3	2	< 1/60,000
		Astronomic
4	0	

Item 7. Enter the proper designation for the gravity station.

Item 8. This block shows an example of a description for a gravity station at a checked spot elevation (CSE). It must include a sketch, brief written description, elevation with source, and map name.

Item 9. This is an example of a description for a gravity station at a monumented control point. Enter the control point designation, published elevation, height of the instrument, recovery note, and map name.

Item 10. This is an example of a gravity station at a contour interpolation point. It is done the same way as a checked spot elevation, except that the contour interval for the map is indicated.

c. Gravity Station Description (DMAHTC Form 8250-9 (GSS)). See figure 6-3.

(1) Because descriptions and sketches of gravity stations must be sufficient to recover the station, make them as complete as possible.

(2) Recording Instructions

Item 1. Enter the type of base network, such as National Base, State Base, etc.

Item 2. Enter the name of the station, taken from the locality. The letter designation will be assigned by the home office.

Item 3. Enter the country in which the station is located.

Item 4. Enter the state or province in which the station is located.

Item 5. Enter the full name of the nearest city, town, or village.

Item 6. Enter the geographic coordinate for latitude.

Item 7. Enter the geographic coordinate for longitude.

Item 8. Enter the elevation in meters, obtained from the best available source.

Item 9. Give the type of mark, such as brass disk, concrete pillar, etc. If there is no mark, enter "none."

Item 10. For a gravity mark, give the name of the agency. If the mark is a bench mark or triangulation mark, leave blank.

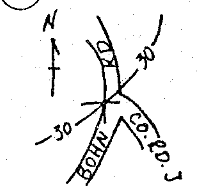
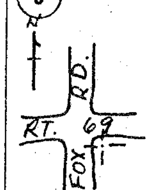
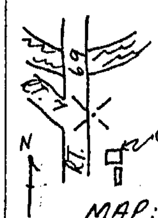
Item 11. Enter the name or designation of the gravity mark. For other marks, leave blank; they will be designated in boxes 14 and 17.

Table 6-2. Vertical Control Accuracy Codes

Type	Class	Data Source
		Vertical Surveys
1	0	First- through third-order leveling
1	1	Fourth-order or engineering leveling
1	2	Ground elevation meter (GEM), IPS
1	3	Vertical angles, trigonometric
1	4	Barometric
		Map, Checked Spot Elevation (CSE)
2	0	Contour interval < 10 ft/3 m
2	1	10-19 ft/3-6 m
2	2	20-39 ft/6-12 m
2	3	40-59 ft/12-18 m
2	4	60-79 ft/18-24 m
2	5	80-99 ft/24-29 m
2	6	≥ 100 ft/30 m
		Map, Unchecked Spot Elevation (USE)
3	0	Contour interval < 10 ft/3 m
3	1	10-19 ft/3-6 m
3	2	20-39 ft/6-12 m
3	3	40-59 ft/12-18 m
3	4	60-79 ft/18-24 m
3	5	80-99 ft/24-29 m
3	6	≥ 100 ft/30m
		Map, Contour Interpolation (CI)
4	0	Contour interval < 10 ft/3 m
4	1	10-19 ft/3-6 m
4	2	20-39 ft/6-12 m
4	3	40-59 ft/12-18 m
4	4	60-79 ft/18-24 m
4	5	80-99 ft/24-29 m
4	6	≥ 100 ft/30 m

GRAVITY DESCRIPTION

SURVEY NAME/AREA	LOOP NO.	DATE	OBSERVER/RECORDER	CH OF PARTY	PAGE
(1) MASSACHUSETTS	(2) RBB-3	(3) 8 JUN 69	(4) BECK	(5) J. S. BACH	(6) 1 OF 1

STATION (7) RBB 3-01	STATION RBB 3-02	STATION RBB 3-03
(10)  OBS. MADE AT W. SIDE OF "T" JCT OF BOHN RD. & CO. RD. J, 4 MI. NE OF BLUE MOUNDS ELEV. 30 FT. (CI) MAP C.I. = 10 FT. MAP: 15' BLUE MOUNDS QUAD	(9) USGS BM "153 1903" BM RECOVERED AS DESCRIBED H.I. = 0.0 FT. MAP: 15' BLUE MOUNDS QUAD	(8)  OB. MADE AT SE CORNER AT RD. LEVEL, AT JCT OF RT. 69 & FOX RD, 0.7 MI. SW OF FOXTOWN. ELEV. 122 FT. (CSE) MAP: 15' BLUE MOUNDS QUAD
STATION RBB 3-04	STATION RBB 3-05	STATION
USGS BM "27 JFK 1963" BM RECOVERED AS DESCRIBED H.I. = -0.5 FT. MAP: 15' BLUE MOUNDS QUAD	 OB. AT E. SIDE OF RT. 69 AT ℄ OF JCT WITH RT. 7. 1.5 MI. S. OF FOXTOWN. MAP: 15' BLUE MOUNDS QUAD	
STATION	STATION	STATION

DMAHTC FORM 8353-2
MAY 79
SUPERSEDES DMATC FORM 8353-2, JUL 73, WHICH MAY BE USED.

Figure 6-2.

Item 12. Enter the source of the latitude and longitude, such as a map, triangulation station, etc.

Item 13. Enter the source agency, such as USGS, NGS etc.

Item 14. Enter the name of the map, station designation, control list, etc.

Item 15. Enter the source of the elevation, such as bench mark, map, etc.

Item 16. Same as position source; refer to item 13.

Item 17. Enter the name of the map, bench mark, etc.

Item 18. This space is left blank except in those cases where the gravity station position or elevation is derived from a nearby bench mark or horizontal control station. In such cases, give the elevation of the gravity station, below or above, and the distance from the bench mark or control station. For example, "Gravity station is 4.5 meters north and 1.2 meters below BM." For cases where the elevation is obtained from a map, give the contour interval.

Item 19. Give a description of the station in this space. The description should consist of "to reach" information referenced to a readily found landmark, road intersection, etc., and a description of the location of the gravity station. When writing a "to reach" description, proceed from the most general to the most specific details of the immediate area.

Item 20. Attach to the lower left corner of the form a photograph showing the immediate location of the base and showing enough of the surroundings to facilitate quick recovery. Draw a descriptive diagram on the lower right corner, oriented with north toward the top of the form.

Item 21. Enter the individual's name who prepared the description or performed the recovery.

Item 22. Enter the agency to which the individual is assigned.

Item 23. Enter the date the station was established or recovered.

GRAVITY STATION DESCRIPTION	STATION TYPE: State Base (1)	STATION DESIGNATION: Great Falls JA (2)
COUNTRY: USA (3)	STATE/PROVINCE: Montana (4)	CITY: Great Falls (5)
LATITUDE: 47°29!05 N (6)	LONGITUDE: 111°21!30 W (7)	ELEVATION: 1118.00 m (8)
GRAVITY STATION MARK: None (9)	AGENCY/SOURCE: (10)	INSCRIPTION: (11)
POSITION REFERENCE: Map (12)	POSITION SOURCE: USGS 7.5' (13)	SOURCE DESIGNATION: Southwest Great Falls, MT, 1965 (14)
ELEVATION REFERENCE: Map (15)	ELEVATION SOURCE: USGS 7.5' (16)	SOURCE DESIGNATION: Southwest Great Falls, MT, 1965 (17)

POSITION/ELEVATION REMARKS

C.I.--20 feet (18)

DESCRIPTION

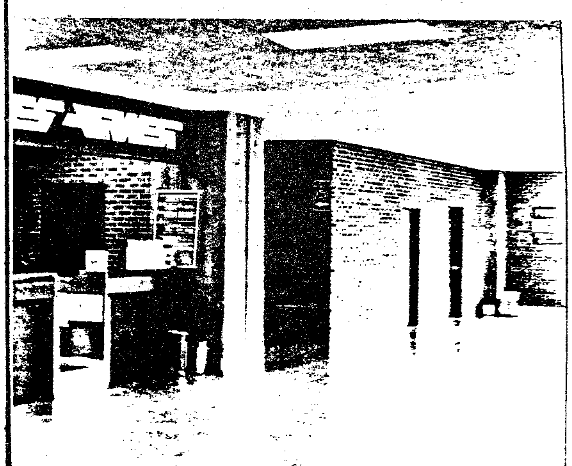
Station is west of Great Falls on Gore Hill at the International Airport, in the east side of the main lobby, east of the door to the police office, 0.61 meters south of the wall and 0.61 meters west of the wall at the base of the concrete pillar on the tile floor.

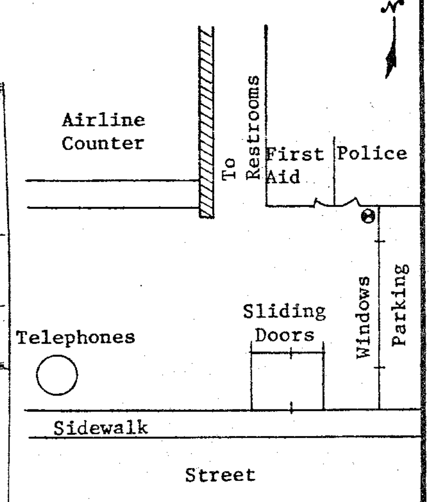
(19)

GSS CODE: 156E04

DIAGRAM/PHOTOGRAPH (20)

INTERNATIONAL AIRPORT





DATE OF PHOTO: Apr 79

DESCRIBED/RECOVERED BY	AGENCY	DATE
Grabowski (21)	DMAHTC/GSS (22)	April 79 (23)

DMAHTC FORM 8250-9 (GSS) MAR 79 Supersedes DMATC FORM 8250-9 (GSS), Oct 77, which will be used until stock is exhausted.

Figure 6-3.

CHAPTER 7

INSTRUCTIONS FOR FIELD GRAVITY COMPUTATIONS

1. GENERAL

Gravity field computations are only required for base net surveys, gravimeter checks, and in some cases for regional surveys to ascertain the accuracy requirements of the survey.

2. ITEMS REQUIRED FOR COMPUTATION

a. Gravity Survey Computation Form

b. Earth tide tables or computer predictions

c. Graph paper for solution of earth tides if the tables published by the European Association of Exploration Geophysicists are used

3. INSTRUCTIONS FOR USING GRAVITY SURVEY COMPUTATION FORM

Field computation instructions are referenced to the examples shown in figures 7-1 and 7-2. The instructions are keyed to the column headings on the form.

Item 1. Give the station designation and geographic position to the nearest degree.

Item 2. Write the date at the first station only. Write the local standard time, converting minutes to decimals of hours, using the conversion table provided in appendix B.

Item 3. ΔT is the time difference between each pair of successive stations. ΣT is the accumulated sum of ΔT's. At a layover drift station (see station RBB 3-03, for example) the accumulated sum is not required, since all layover static drift is eliminated from the total survey time.

Item 4. Enter the counter and dial reading from the field and encoding form.

GRAVITY SURVEY COMPUTATION

LOCATION: MASS., USA

PROJECT: LOOP RBB 3 MASSACHUSETTS SURVEY

STATION (1)	UNIVERSAL DATE (2)	UNIVERSAL TIME	Δ TIME (3)	Σ TIME	COUNTER READING (4)	DIAL RDG	COUNTER MGALS (5) / DIAL FACTOR MGALS/DU	OBSERVED MGALS	CORRECTIONS (6) 1	2	3	4	CORRECT MGALS (7)	Δ G MGALS (8)
FITCHBURG J	8 Jun 69	07.8	1.2	1.2	34	34.803	3529.11 / 1.03930	3565.28	+.13				3565.41	
RBB 3-01		09.0	1.3	2.5	34	02.976	″	3532.20	+.12		−.01		3532.31	
RBB 3-02		10.3	1.4	3.9	34	28.907	″	3559.15	+.11		−.02		3559.24	
RBB 3-01		11.7	1.0	4.9	34	02.987	″	3532.21	+.09		−.02		3532.27	
RBB 3-03		12.7			33	82.774	3425.19 / 1.03920	3511.21	+.07		−.03		3511.25	
RBB 3-03		13.5	1.0	5.9	33	82.742	″	3511.18	+.05	+.05	−.03		3511.25	
RBB 3-04		14.5	1.2	7.1	34	09.468	3529.11 / 1.03930	3538.95	+.04	+.05	−.04		3539.00	
RBB 3-05		15.7	1.3	8.4	34	19.645	″	3549.53	+.05	+.05	−.04		3549.59	
FITCHBURG J		17.0			34	34.882	″	3565.36	+.05	+.05	−.05		3565.41	

1. EARTH TIDE
2. DRIFT BETWEEN TRIPS
3. DRIFT DURING TRIPS
4. TARES

OBSERVER AND ORGANIZATION: Robert B. Beck

INSTRUMENT Type, No.: LRG 61

COMPUTED BY: G.A.H. — DATE: 9 Jun 69

CHECKED BY: R.B.B. — DATE: 10 Jun 69

DMAHTC FORM 8250-14 (GSS) MAR 79

Figure 7-1. AMS Form 4420-8. Gravity survey computation.

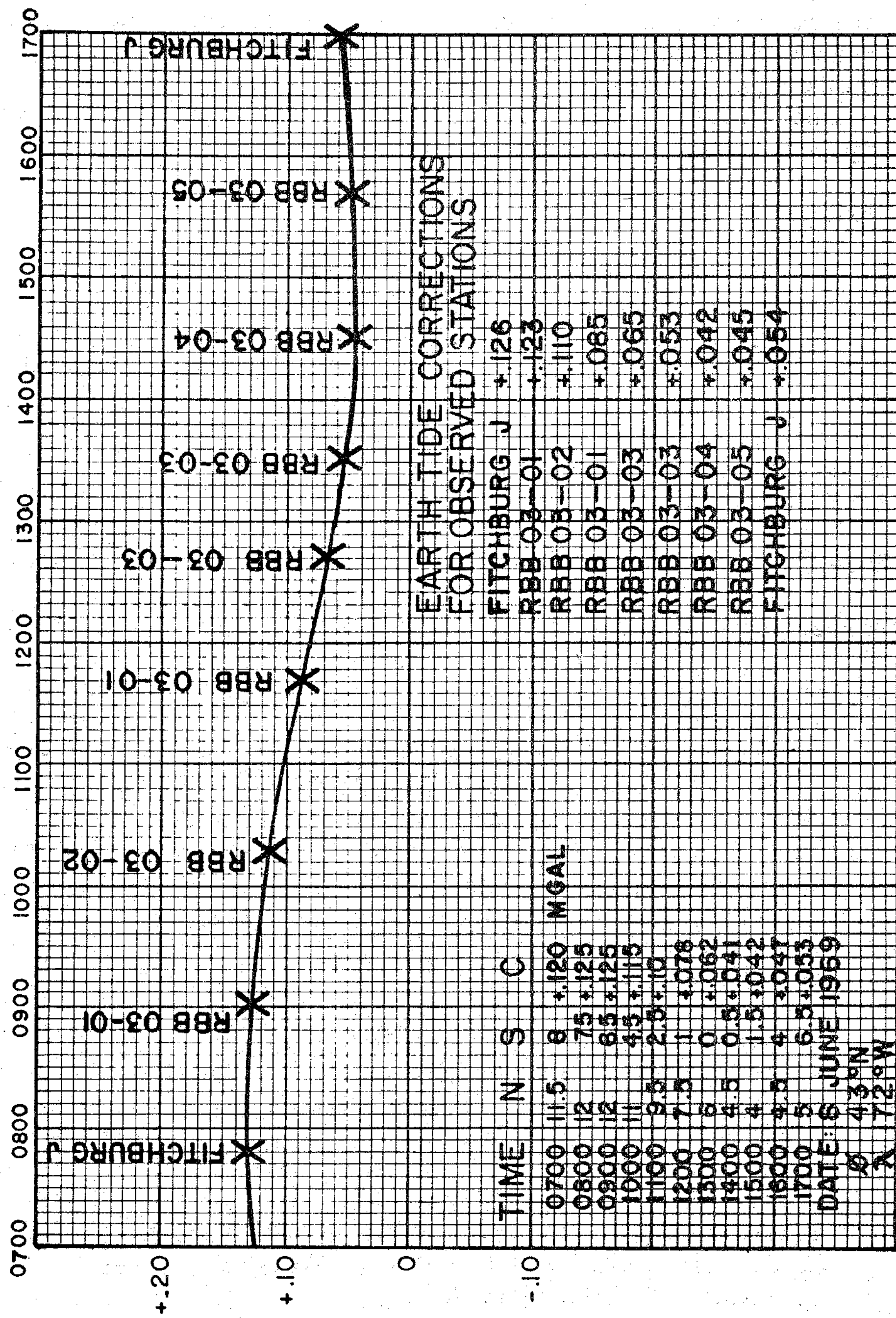


Figure 7-2. Sample graphical earth tide solution.

Item 5. Counter milligal/dial factors are obtained from the milligal conversion table provided with the gravimeter. By use of the table, the counter dial readings can be converted to milligals. Each instrument has its own calibration table, which is used as follows:

a. Using the counter reading value as the argument, proceed to the column on the table headed "Counter Reading." Go down the column to the nearest hundred value less than the counter reading. Read across to the column headed "Value in Milligals" and copy the number on the space provided on the form. Proceed across to the column headed "Factor for Interval" and copy this number in the appropriate place on the form.

Example:

Counter & Dial Reading for LRG 61	=	3434.803
Counter Reading on Table	=	3400.00
Value in Mgal from Table	=	3529.11
Factor for Interval	=	1.03930

b. To convert the counter dial reading to mgals, use the formula mgals = (counter reading - hundred value) (interval factor) + value in mgals, as in the following example:

$$(3434.803 - 3400.00)\ (1.03930) + 3529.11 = 3565.28 \text{ mgals}$$

Item 6. Corrections Columns

a. Earth Tide Corrections. If computer-generated, hourly earth tide predictions are available for the area, they may be entered in corrections column 1. Figure 7-2 provides a field example for the graphical computation of earth tides from the tables of the European Association of Exploration Geophysicists. The "P" correction provided in the tables is ignored unless the loop is 2 days or longer. Corrections for longitude are not necessary for field computational checks. The earth tide correction obtained from the table and the graph (figure 7-2) is entered in column 1.

b. Static Drift Correction. The gravimeter's drift characteristics are different when the gravimeter is under a static mode (i.e., overnight stop, lunch stop, etc.). This drift must be eliminated from the dynamic drift (drift while surveying). Referring to figure 7-1, the static drift for the layover station RBB 3-03 is ± 0.05 mgal. This is the difference between the two consecutive readings at station RBB 3-03. Notice that the earth tide correction is applied before subtracting the two readings.

Example:

1st reading RBB 3-03	=	3511.28
2nd reading RBB 3-03	=	3511.23
Drift correction	=	+ 0.05 mgal

The correction is applied in such a manner that the second drift reading is always corrected to agree with the first reading. Consequently, all readings obtained henceforth on this loop will be corrected by the same amount (see figure 7-1, column 2). All layover drift corrections (drift between trips) are entered in corrections column 2.

c. Dynamic Drift Correction (column 3). To compute dynamic drift, the earth tide and static drift (see 3g(2)) corrections are applied to the opening and closing observed mgals base readings. The readings are then differenced and divided by the time between the readings.

Example:

$$\frac{-0.05 \text{ mgal}}{8.4 \text{ hrs}} = -0.006 \text{ mgal/hr}$$

The drift rate is then multiplied by the ΣT at each of the stations within the loop (see figure 7-1).

Example:

Station RBB 3-05	7.1 hrs (-0.006)	=	-0.04 mgal
Station RBB 3-02	2.5 hrs (-0.006)	=	-0.02 mgal

d. Tare Correction (column 4). This column is not used.

Item 7. After all the indicated corrections have been applied to the observed mgals, the corrected mgal value is written in this column.

Item 8. ΔG Mgals (column 8). ΔG mgals are the differences between the initiating base station and all the other stations within the loop or line. ΔG provides a good way to check accuracy by comparing the ΔG of reobserved stations. In addition, ΔG values are used to change the gravimeter mgals values to absolute gravity values. ΔG values are added algebraically to the base gravity value to obtain absolute values for the other stations within the loop.

Example:

FITCHBURG J Gravity Value = 980 372.70 mgals

Station	ΔG/mgals	Absolute Gravity Value (mgals)
RBB 3-01	-33.10	980 339.60
RBB 3-02	- 6.17	980 366.53
RBB 3-01	-33.14	980 339.56
RBB 3-03	-54.16	980 318.54
RBB 3-04	-26.40	980 346.30
RBB 3-05	-15.82	980 356.88

CHAPTER 8

HIGH ACCURACY RELATIVE GRAVITY MEASUREMENTS

1. GENERAL

Microgravimetry, the science of measuring gravity within a few microgals (0.001 milligal), is in its infancy; therefore, these instructions are designated as preliminary. Additional developments in absolute gravity measurements, the establishment of high accuracy absolute and relative calibration lines, and improvements on gravimeters will require changes in survey methodology and procedures. It is expected that these instructions will be rewritten on a yearly basis as the state of the art in microgravimetry advances.

2. PRESENTLY OBTAINABLE ACCURACIES

a. DMAHTC/GSS modified Model G LaCoste and Romberg gravimeters have been able to obtain accuracies as high as ±0.010 milligal standard error 10μ gals over gravity intervals of about 300 milligals with at least four observations at each station.

b. For the purpose of these preliminary instructions, the accuracy requirements are ±0.020 milligal standard error with a minimum of four observations with each gravimeter. At least two gravimeters must be used per loop. The standard deviation for each measured interval between gravimeters must be ±0.020 milligal.

3. GRAVIMETER SELECTION

When high accuracy surveys are to be performed, the gravimeter must be carefully selected according to the following criteria:

a. Gravimeter Calibration Curve. The curve must be flat or as nearly flat as possible for the area of the survey. Circular error corrections must be less than ±0.005 milligal.

b. Field Calibration. The performance of the gravimeter over well-defined calibration lines must be evaluated.

c. Gravimeter Drift Rate. A gravimeter with a low and nearly linear drift will provide better accuracy. Gravimeters have short- and long-term drift characteristics. Therefore, a comprehensive analysis must be made of previous data obtained with the gravimeter to assist in gravimeter selection.

d. The gravimeter must be in perfect adjustment and be free of hysteresis.

Note: Gravimeter selection requires cooperative and coordinated effort between SQT, SQR, and SQA.

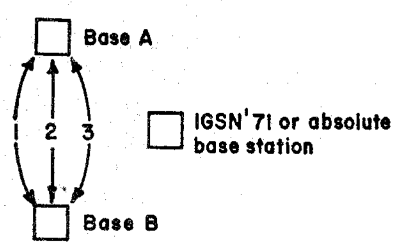
4. SURVEY PLANNING

a. Scale Conditions. Although individual gravimeters may provide excellent results, when compared with other gravimeters, these results may have differences between measured intervals greater than the allowable errors. This problem is caused by errors in the calibration curve or the table of dial factors and by the fact that the LaCoste and Romberg field calibration range's interval is in error by 1 part in 1300. To prevent this problem, one of the following procedures must be performed:

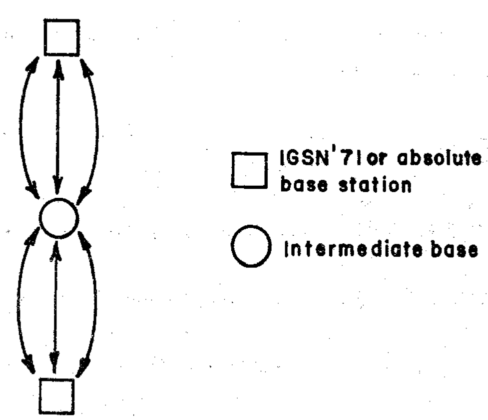
(1) Calibrate gravimeters over a standardized calibration range established with absolute measurements (accurate to ± 0.013 milligal standard error) and covering the gravity range of the area to be surveyed.

(2) Calibrate gravimeters over selected IGSN'71 base stations with error terms of less than the allowable error and encompassing the gravity range of the area to be surveyed.

(3) Survey loops to determine scale conditions must be surveyed in the following manner:



Intermediate stations may be established for drift control. If at all possible, loops should be completed in 1 day to avoid layover drift problems. If the base stations are too far apart to allow terminating the loop within a 1-day round trip, the loops must be observed as follows:



The standard deviation for a set of three readings at repeat stations shall be ±0.020 milligal or less after earth tide, linear drift, and applicable circular error corrections.

b. Site Selection and Accuracy Requirements. In many instances, DMAHTC/GSS is asked to provide a gravity value at a site located near the seashore or on piers and similar structures. Users must be advised that because of the problems involved in obtaining accurate earth tide corrections near the seashore, extreme ground water fluctuations, oceanic crustal loading, and unstable piers, the gravity values obtained may have errors of ±0.05 milligal or greater. Areas of known seismic activity such as California, Alaska, and Hawaii may have too much background noise, which will affect the accuracy of the survey. Large water table fluctuations will also introduce errors. The most accurate sites are those located on crystalline igneous rocks; however, even on this type of rock, microseismic activity may be present. Crystalline igneous rocks such as granites and basalts do provide a stable environment free from water table fluctuations and localized subsidence and certain freedom from the localized vibrations harmful to required accuracies. The following site selection criteria are to be used as guidelines in finding stable, accurate, and permanent gravity base stations:

(1) Buildings should be on bedrock, preferably igneous.

(2) Locate sites in the building's lowest level.

(3) Locate the station on an isolated pier, concrete floor, or other mineral type of floor.

(4) Locate the site away from vibration-introducing machinery such as elevators and escalators and at least 30 meters from power transformers or other machines causing large electromagnetic fields.

(5) The building must be a permanent structure such as a university building, observatory, etc., and located away from interstate highways or railroads.

(6) Accessibility to the site 7 days a week is preferred.

(7) The site, if at all possible, should have electric power, be climatically controlled, and have sufficient floor space for future absolute measurements.

It will probably be difficult to find a site that meets all these criteria, but particular attention must be given to criteria 4 and 5. If the site is to be located in an alluvial filled valley, it may be necessary to establish an excenter on bedrock (if within 60 miles of the site) to monitor localized crustal movements or water table fluctuations that may change the gravity value at the site.

c. Survey Planning. The most important factor in determining accuracy in gravity surveys, besides instrumentation and calibration, is redundancy of observations and maintenance of homogeneous gravimeter drift environment.

(1) Basic ties for the purpose of establishing a higher accuracy gravity value at a preselected site will be performed with the ladder sequence of observations. After the scale ties have been made or the gravimeter has been calibrated over a portion of a calibration line encompassing the same gravity range as the project area, starting (IGSN'71) bases will be selected. These bases will be selected according to the following criteria:

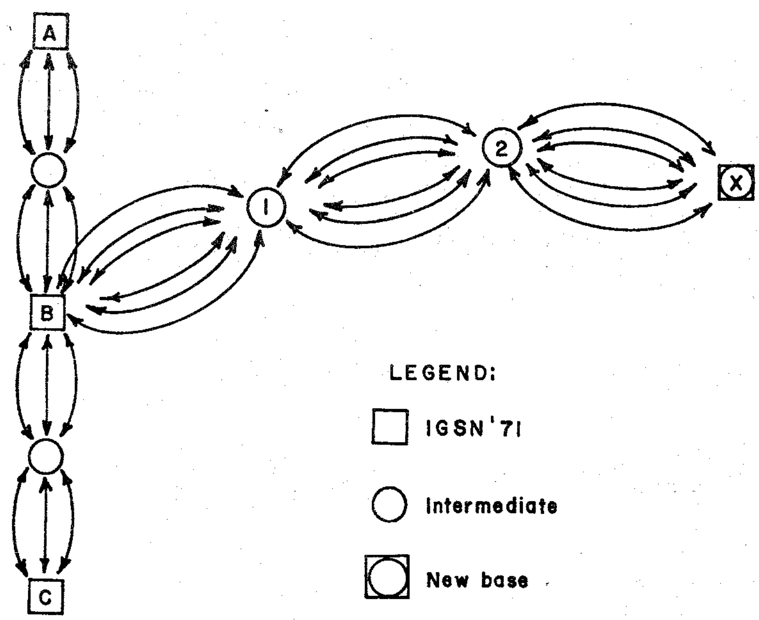
(a) Base stability

(b) High accuracy (at least ±0.013 milligal)

(c) Good accessibility

If two bases (IGSN'71) are selected, the bases will be tied together for a further check of IGSN'71.

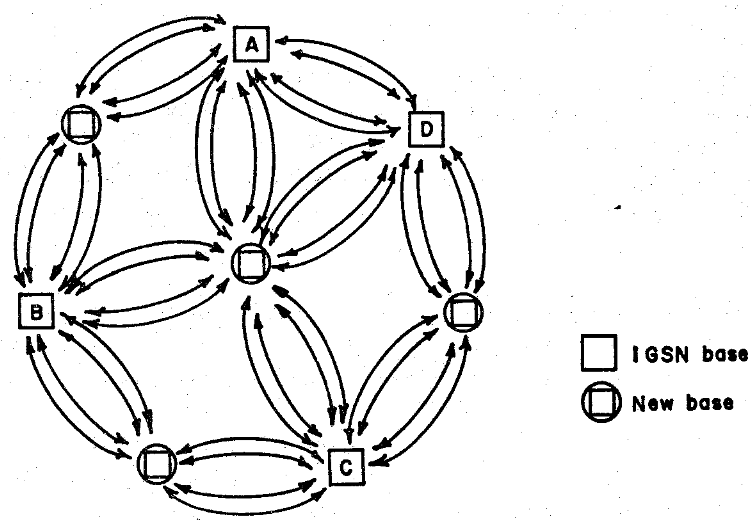
Originating bases should be no more than 200 milligals from the site to be observed. The following diagram is provided as a guideline in planning surveys:



In the example above, the station to be established (X) is too far away from the originating base B; therefore, intermediate stations have been located so that at least one round trip can be made per day between each site. The intermediate stations should be selected at stable, accessible, and permanent locations, since they may be incorporated into the IGSN'71 or a gravity base network.

The example shows four round trips between each station with one forward trip to the next station after completion of the round trips. In addition, on the return trip to the originating station B, an observation will be made at station 1.

(2) High Accuracy Gravity Networks. High accuracy gravity surveys will be surveyed in the same manner as described in paragraph 4c, with the loops forming a closed interconnected network as shown in the diagram below:



Scale conditions for the network illustrated above would be set by base stations A, B, C, D, and the gravimeter's most recent calibration. This network design provides excellent redundancy of observations, and a very strong least-squares adjustment solution would be possible. Such a network may be required to detect crustal movements, local subsidence, mass transfers, and other phenomena that may cause a change in gravity.

5. SURVEY PROCEDURES

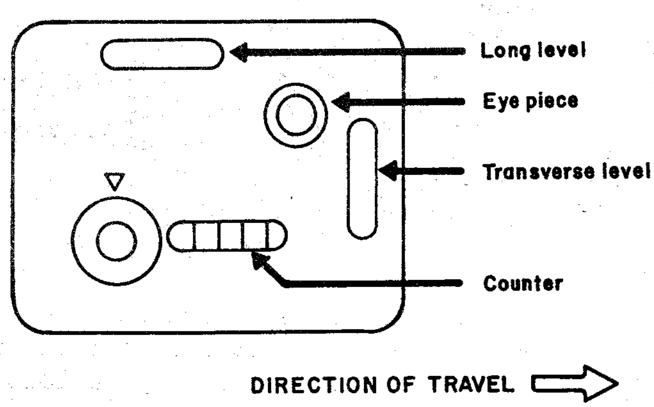
a. On arriving in the operational area, check and adjust the gravimeter levels and sensitivity. Set sensitivity to 1:10, and check and adjust it before commencing each loop.

b. Before commencing scale ties, turn the gravimeter screw 200 milligals past the highest reading to be encountered and 200 milligals below the lowest reading. Before commencing survey operations, turn the loop counter to half of the interval to be measured. For example:

Base Station A	980 760.200 milligals
Base Station B	980 460.200 milligals
Interval	300.000 milligals

The gravimeter is located at base station B and the counter reads 3500.000 counter units. Therefore, before departing station B, add 150 milligals to 3500.000 counter units by turning the counter until it reads 3650.000 counter units. This procedure tends to minimize the effects of hysteresis. In addition, before commencing the day's work, turn the screw about 100 counter units above and below the expected gravity range to be encountered during the loop. This procedure distributes the screw lubricant, eliminates dry spots, and also minimizes hysteresis.

c. Transportation of Gravimeters. Gravimeters must be transported in special isolation-equipped carrying cases. Carry the gravimeter so that the longitudinal axis faces the direction of travel, that is, in the same way the observer reads it, with the long level directly to the front and the traverse level to the right of the eyepiece.



Gravimeters being transported in automobiles must be strapped to the seat. If maximum accuracy is required, however, it is recommended that a gravimeter platform supported by isolators be used. Note that foam rubber is highly damped and that such a condition tends to increase vibration transmissibility. Therefore, foam rubber pads are not recommended for supporting gravimeters during transportation for high accuracy surveys. Gravimeters may be carried on the seats of jet aircraft. Multiengine propeller aircraft and helicopters are not recommended because they generate frequencies very harmful to gravimeters. The best method for transporting gravimeters while conducting high accuracy surveys is a vehicle properly equipped to minimize the frequencies that cause erratic drift. Drivers should avoid jackrabbit starts and panic stops and should drive at moderate speeds, avoiding potholes and other obstacles that may cause severe jolts to the vehicle. On gravel roads drive slowly enough to avoid creating secondary harmonic vibrations within the vehicle.

d. Gravimeter Orientation. To minimize local magnetic field disturbances, all gravimeters must be read with the operator facing north.

e. Reading Techniques. On arrival at a station, level and null the gravimeter within one eyepiece division on the down-scale side; clamp it and enter the necessary information on the recording form. Check the levels (relevel if required) and null the gravimeter by moving the beam always from the down-scale side toward the upper scale to avoid backlash. After nulling the gravimeter and checking for eyepiece and galvanometer agreement, record the reading carefully and clamp the gravimeter. Before commencing the next reading check the levels (and relevel if required), turn the dial counterclockwise 180°, unclamp and null the gravimeter again, and inspect the eyepiece for coincidence with the galvanometer. Two readings will be required no more than 3 minutes apart, and the readings must repeat to ± 0.005 counter units.

Appendix A

Gravity Glossary

NOTE: Terms are defined solely as they apply to the field of gravity surveys. Therefore, wording of the definitions may differ from the D D Dictionary of Military and Associated Terms (JCS Pub. 1) and from the D D Glossary of Mapping, Charting, & Geodetic Terms.

absolute gravity. The total acceleration due to gravity at a point, expressed in milligals.

absolute gravity measurements. Absolute gravity observations are made with pendulums or with a device in which a weight is dropped over a measured distance. Absolute gravity measurements give the total acceleration due to gravity at a point and have been used to establish gravimeter calibration bases and gravity values at widely spaced locations.

accelerometer. Any instrument capable of measuring acceleration. All gravimeters are accelerometers.

adjustment. A mathematical technique of arriving at the best estimate of an observed quantity when two or more observations of that quantity exist. Many types of criteria for best estimate exist.

air/sea gravimeter. (See platform gravimeter.)

analog converter. (Analog to digital converter, A/D converter) An electronic component that converts a voltage (analog signal) to a binary coded decimal (digital signal). A digital voltmeter performs this function. A required component in a platform gravimeter to record analog gravity signals on digital magnetic tape for later computer processing.

anomaly (gravity). The difference between a theoretical gravity model and observed gravity corrected for certain assumptions. (See free air anomaly, Bouguer anomaly, and model.)

base counter reading (BCR). The reading obtained from an air/sea gravimeter at a base station. This value (determined when the vessel is docked) corresponds to the gravity value at the docking pier.

base (gravity base reference station). A gravity station at which the absolute gravity value is known (usually derived by relative measurements). Strategically located base stations are required for regional gravity surveys in order to determine relative gravity values for the stations. (see fundamental gravity base.)

binary coded decimal (BCD). A number system code in which each decimal digit is represented by four binary digits. The system is used to create magnetic tapes for computer processing.

Bouguer anomaly. The type of gravity anomaly in which observed gravity is corrected for the attraction of crustal materials between sea level and the observation point at elevation "h," which is in addition to the free air correction. Bouguer anomalies are chiefly negative on land areas and, in general, the more negative the higher the elevation. Conversely, Bouguer anomalies at sea level or at sea have positive values as a general rule. Two types of Bouguer anomalies may be defined: simple and complete.

a. Simple Bouguer anomaly

$$A_b = g_o - (\gamma_\phi - f_a + S)$$

where

A_b = simple Bouguer anomaly
g_o = observed gravity
γ_ϕ = theoretical gravity at latitude ϕ
ϕ = latitude of observation
f_a = free air correction
S = slab correction, which is .1119 mgal/meter or .034 mgal/foot times the elevation, for an assumed crustal density of 2.67 g/cm^3. (See Bouguer correction.)

b. Complete Bouguer anomaly

$$A'_b = g_o - (\gamma_\phi - f_a + S - T)$$

where

A'_b = complete Bouguer anomaly
T = terrain correction, which is always positive and modifies the slab correction for the actual topography surrounding the observation point. In practice this correction is usally too expensive to implement.

Bouguer correction. The correction for crustal mass attraction between a gravity station and mean sea level. Assuming the crust to be a semi-infinite horizontal slab, the correction is:

$$S = 2\pi G \rho h \text{ mgal}$$

where

$G = 6.673 \times 10^{-5}\ cm^3\ g^{-1}\ sec^{-2}$ (gravitational constant)
ρ = assumed crustal density in g cm^{-3}
h = elevation of station in cm

This correction is then .0418 h mgal (h in meters) or .0127ρ h mgal (h in feet) and ρ is usually assumed to be 2.67 g cm^{-3}.

calibration.

a. The determination of systematic nonlinear response of a gravimeter, which is a laboratory procedure. (See calibration table.)

b. Common usage for a survey performed over known gravity intervals to determine a scale factor correction. (See scale factor.)

calibration line. A set of standard gravity stations used in calibration surveys.

calibration table. A set of values relating dial divisions to milligals for a particular gravimeter. The calibration table corrects for nonlinearities in the mechanics of the gravimeters.

complete Bouguer anomaly. (See Bouguer anomaly.)

course. The geodetic direction in which the vehicle carrying a platform gravimeter is moving.

drift. Mechanical or physical characteristics of a gravimeter that cause its reading level to change with time. Gravimeters have different drift rates for static or dynamic conditions. The drift rate of a gravimeter is usually assumed to be linear with respect to time. For the purpose of computations only "dynamic" drift is used. The practice of reobserving gravity stations in a line or loop is for the sole purpose of determining a drift correction. (See layover drift and tare.)

earth tide. The gravitational effects of the sun and moon on the gravitational acceleration at the earth's surface. A theoretical correction based on the celestial mechanics of the earth-moon-sun system is usually applied to the gravity observations. Earth tide correction can be as high as 0.3 mgal.

elevation. The height of a gravity station above or below mean sea level. Elevations are one of the most important parameters in obtaining accurate gravity anomalies for regional stations. Gravity changes approximately 0.3 mgal per meter of elevation.

Eötvös effect. A gravimeter observed while on a vehicle that has an east-west velocity component experiences an apparent gravity change proportional to the velocity. This is the Eötvös effect and must be corrected.

A simple expression for the correction is:

$$C_e = 7.5\ V_e \cos \phi$$

where

C_e = Eötvös correction in milligals
V_e = east-west velocity in knots
ϕ = latitude of observation

Eötvös unit. The geophysical unit of gravitational gradient, which is 10^{-6} mgal per centimeter.

excenter gravity base. An excenter gravity base is an auxiliary gravity base reference station established primarily to preserve an absolute gravity value for a city or an area in case the base station is destroyed. Several excenters are usually established in major cities. In order to avoid confusion in recovering an established gravity base station excenter, stations are given a letter suffix such as ROME E, WASHINGTON L, etc. "Excenter station" is a descriptive term and should never be used as part of the station description or name.

falling body experiment. A method of determining absolute gravity by timing the interval required for a body to fall through a given distance.

filtering. A technique of removing relatively short term variations from relatively long term variations of a gravity measurement.

free air anomaly. A type of gravity anomaly in which observed gravity is corrected for the decrease in gravity due to the elevation of the station above sea level. The constant for free air correction is 0.3086 mgal/meter or 0.09406 mgal/foot.

$$A_{fa} = g_o - (\lambda_\phi - f_a)$$

where

A_{fa} = free air anomaly
g_o = observed gravity
λ_ϕ = theoretical gravity at latitude ϕ
f_a = free air correction

fundamental gravity base station. A permanent base station in a country or region accurately tied to the world gravity datum by multiple relative measurements. The absolute gravity value for a fundamental gravity base station is usually used to determine relative gravity values for a country or region, and it is always held fixed in adjustments of base stations.

geodetic gravimeter. An instrument capable of measuring gravity differences over the whole gravity range of the earth.

gravimeter (gravity meter). An accelerometer designed to measure relative differences in the acceleration due to gravity between two locations. In principle, a gravimeter is simply an extremely sensitive weighing device.

gravity datum. A system of gravity stations determined by relative measurements and referenced to two or more absolute gravity stations, thus defining absolute gravity values at all stations and containing an inherent definition of the milligal (scale). All geodetic gravity surveys must be referenced to such a system.

interconnection. The condition in a gravity survey where all stations in question have a known observational relationship between them.

isostatic correction. A correction applied to a gravity value to take into account the assumed mass deficiency under topographic features for which a topographic correction is made.

latitude correction. When gravity anomalies for a small area are computed for geophysical exploration purposes only, a latitude correction is applied to observed gravity rather than subtracting theoretical gravity from the reduced observations. The latitude correction is the derivative with respect to latitude of the theoretical gravity formula and is $\psi = 0.8 \sin 2\phi$ mgal/km.

layover drift. The drift rate of a gravimeter varies according to the motion environment. Therefore, whenever an interruption occurs during a survey loop or line, readings must be made at the start of the interruption and just before the survey starts again. This way the static drift rate is eliminated from the loop or line computation and only the dynamic drift is used on the reduction. Layover drift readings are usually made for stops longer than one hour. (See also drift.)

least squares. A method of mathematical adjustment whereby the most probable result is derived by minimizing the sum of the squares of the deviations.

line. A gravity survey method whereby the survey is initiated at one base reference station and terminated at a different base reference station. Drift control in a line may be obtained from the misclosure on the closing base (after earth tide correction) or from reobserved gravity stations within the line. (See loop.)

loop. A method of observing gravity whereby stations are reoccupied for the purpose of determining the drift correction.

milligal. In geophysics, the convenient acceleration unit is a milligal (mgal), which is 10^{-3} gal. The physical unit of acceleration in the centimeter-gram-second (cgs) system is the cm sec^{-2}. This unit is called a gal, after Galileo. The average acceleration of gravity at the earth's surface is 980 gals.

model. A mathematical formula that describes a physical situation. The theoretical gravity formula is a model of the earth's gravity field.

national gravity base network. A system of primary gravity stations taken to define the gravity system for a country.

network. A series of gravity loops or lines that have been interconnected in such a manner that closed loops or circuits have been formed. Gravity base reference stations are established in a network format.

pendulum. A body so suspended as to swing freely to and fro under the influence of gravity and momentum. Gravity measurement with a pendulum depends on the fact that the period of a freely swinging pendulum is inversely proportional to the square root of a gravitational acceleration. Pendulums have been generally replaced by gravimeters.

platform gravimeter. Any gravimeter, fitted with a vertical erection system and circuitry suitable for filtering out short period accelerations, that may be used to observe gravity from a moving vehicle.

potential. Gravitational potential is defined as the energy required to move a mass from one point in a gravity field to another. Gravitational potential and acceleration may be related by a differential equation. The potential function is used in mapping the earth's gravity field with satellites.

principal facts. The list of final results of a gravity survey that contains latitude, longitude, elevation, and observed gravity for all stations concerned.

RC filter. A filter containing resistive and capacitive elements, usually in conjunction with an operational amplifier, used in platform gravimeters to remove unwanted high frequency signal components.

reduction. Generally, any and all computations performed to derive gravity values. Strictly, the method of corrections applied to observed gravity values to obtain various anomaly types.

relative gravity. The difference in the gravitational acceleration between two points. Gravimeters measure relative gravity.

scale. As used in gravimetry, the definition of the basic dimension, the milligal. Generally, an accurately determined gravity interval in a gravity network to which all gravity differences are adjusted so as to be in agreement is considered to define scale.

scale factor. A dimensionless coefficient that when applied to gravity differences will cause these differences to agree with another set of differences from which the factor is derived. The factor is used to eliminate systematic discrepancies in observations between gravimeters or gravity surveys.

shaft encoder. An electromechanical device that converts shaft rotation angle (analog signal) to a binary coded decimal (digital signal). Useful for certain applications in platform gravimeters.

simple Bouguer anomaly. (See Bouguer anomaly.)

stable platform. That portion of a platform gravimeter that senses the vertical and keeps the gravimeter axis aligned with same.

station. That physical location on the surface of the earth where an observation is made.

stationary. Refers to a gravimeter observation made while the instrument was at rest on the earth's surface.

supplementary elevation. In circumstances where a water, ice, or underground depth is involved in the anomaly computation, this is listed as a supplementary elevation.

system. A set of relative gravity values that are all related to two or more fundamental stations and that agree internally with respect to scale.

tare. An abrupt change in gravimeter reading level caused by a jolt, bump, or extreme enviromental change causing a mechanical readjustment of the sensing element. Some gravimeters are especially sensitive to vibrations encountered on board helicopters and fixed-wing aircraft, resulting in tares of several milligals in magnitude. If a tare does not cause permanent damage to a gravimeter, it may be corrected by reobserving the last station before the tare occurred to determine the amount of reading level change.

terrain correction (topographic correction). A correction taking into account the deviations of topography from the infinite slab assumed in the simple Bouguer correction.

theoretical gravity. A model of the earth's gravity field. One of the models used in geodesy is known as the International Gravity Formula of 1930. It is:

$$\lambda_{\phi} = 978.049^{*}(1 + 0.0052884 \sin^2\phi - 0.0000059 \sin^2 2\phi)$$

*Units in gals.

where

λ_{ϕ} = theoretical gravity at latitude ϕ
978.049 = assumed gravity at the equator

A more recent version of this formula may be found under world gravity datum.

track. In moving platform gravimetry, the representation of the location, direction, and speed of the vehicle.

underwater gravimeter. The sensing element of a conventional gravimeter is incorporated along with automatic leveling devices in a waterproof case and provision made for remote operation.

vibrating string gravimeter (VSG). A gravity sensor used in platform gravimeters in which the element is a vibrating wire-mass system the frequency of which is dependent on gravity.

Appendix B

Decimal Equivalents of the Sexagesimal System

SEXAGESIMAL	= DECIMAL	SEXAGESIMAL	= DECIMAL
.00 - .29	= .00	30.30 - 30.89	= .51
.30 - .89	.01	30.90 - 31.49	.52
.90 - 1.49	.02	31.50 - 32.09	.53
1.50 - 2.09	.03	32.10 - 32.69	.54
2.10 - 2.69	.04	32.70 - 33.29	.55
2.70 - 3.29	.05	33.30 - 33.89	.56
3.30 - 3.89	.06	33.90 - 34.49	.57
3.90 - 4.49	.07	34.50 - 35.09	.58
4.50 - 5.09	.08	35.10 - 35.69	.59
5.10 - 5.69	.09	35.70 - 36.29	.60
5.70 - 6.29	.10	36.30 - 36.89	.61
6.30 - 6.89	.11	36.90 - 37.49	.62
6.90 - 7.49	.12	37.50 - 38.09	.63
7.50 - 8.09	.13	38.10 - 38.69	.64
8.10 - 8.69	.14	38.70 - 39.29	.65
8.70 - 9.29	.15	39.30 - 39.89	.66
9.30 - 9.89	.16	39.90 - 40.49	.67
9.90 - 10.49	.17	40.50 - 41.09	.68
10.50 - 11.09	.18	41.10 - 41.69	.69
11.10 - 11.69	.19	41.70 - 42.29	.70
11.70 - 12.29	.20	42.30 - 42.89	.71
12.30 - 12.89	.21	42.90 - 43.49	.72
12.90 - 13.49	.22	43.50 - 44.09	.73
13.50 - 14.09	.23	44.10 - 44.69	.74
14.10 - 14.69	.24	44.70 - 45.29	.75
14.70 - 15.29	.25	45.30 - 45.89	.76
15.30 - 15.89	.26	45.90 - 46.49	.77
15.90 - 16.49	.27	46.50 - 47.09	.78
16.50 - 17.09	.28	47.10 - 47.69	.79
17.10 - 17.69	.29	47.70 - 48.29	.80
17.70 - 18.29	.30	48.30 - 48.89	.81
18.30 - 18.89	.31	48.90 - 49.49	.82
18.90 - 19.49	.32	49.50 - 50.09	.83
19.50 - 20.09	.33	50.10 - 50.69	.84
20.10 - 20.69	.34	50.70 - 51.29	.85
20.70 - 21.29	.35	51.30 - 51.89	.86
21.30 - 21.89	.36	51.90 - 52.49	.87
21.90 - 22.49	.37	52.50 - 53.09	.88
22.50 - 23.09	.38	53.10 - 53.69	.89
23.10 - 23.69	.39	53.70 - 54.29	.90
23.70 - 24.29	.40	54.30 - 54.89	.91
24.30 - 24.89	.41	54.90 - 55.49	.92
24.90 - 25.49	.42	55.50 - 56.09	.93
25.50 - 26.09	.43	56.10 - 56.69	.94
26.10 - 26.69	.44	56.70 - 57.29	.95
26.70 - 27.29	.45	57.30 - 57.89	.96
27.30 - 27.89	.46	57.90 - 58.49	.97
27.90 - 28.49	.47	58.50 - 59.09	.98
28.50 - 29.09	.48	59.10 - 59.69	.99
29.10 - 29.69	.49	59.70 - 60.00	1.00
29.70 - 30.29	.50		

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ATTN: AO (Ms. Bean) .... 1 cy

DMAAC
ATTN: STT (Mr. Decker) ...... 2 cy

DMAHTC
ATTN: GSG (Mr. Wilson) ...... 25 cy

DMAHTC Geodetic Survey Squadron
ATTN: SQT (Mr. Rowe) .... 823 cy

DMS
DMS - SD, CW3 NOLTA .... 25 cy

IAGS
ATTN: (CADDESS) .... 100 cy

IAGS LO .... 1 cy

AFIS/INOTB .... 2 cy
Bolling, AFB D.C. 20332

RADC
ATTN: (Mr. Chiarello) ... 1 cy
Griffiss, AFB N.Y. 13441

NCA/EIEUG .... 10 cy
Griffiss, AFB N.Y. 13441

1866 FCS/TE .... 5 cy
Scott, AFB IL. 62225

1 CEVG/RBDT .... 5 cy
Barksdale, AFB LA. 71110