UNIT 10

THE GLOBAL POSITIONING SYSTEM

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Introduction

The Global Positioning System (GPS) has led to a revolution in the land surveying profession. The GPS technology is being employed in a variety of surveying applications while the technology is still evolving. At present there are only nationally accepted procedures/methodologies for performing static GPS surveys. Newer methodologies have been identified, e. g., pseudostatic and fast/rapid static, for which procedures are just beginning to be developed and universally accepted.

As the cost of hardware continues to decrease, surveyors will discover the benefits associated with employing the GPS technology in a variety of survey operations. Since the technology and its applications are still evolving, the land surveyor must keep abreast of these evolutionary changes.

Questions about GPS are just beginning to appear on Land Surveyor licensing examinations. This unit and the sources it cites are only a few of the available materials about GPS. Professional surveyors can expect more to become available. Methods being tested today may become the standards and specifications of tomorrow. These changes in methodology will probably be reflected on future Land Surveyor examinations.

Remember that the GPS technology is in its evolutionary phase. Surveyors must follow the changes in the use of the technology to determine how and if it can best be applied to their survey projects. GPS is not the solution to all survey problems, but can probably aid survey practices in proportion to the time put into understanding it.

Performance Expected on the Exams

Since this is a new technology there is a degree of uncertainty about the types of questions that might appear on the exams. However, knowledge of a variety of GPS issues such as those listed below should provide a sound basis for understanding the technology and for success with questions that might appear on exams in the future.

Interpret the Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques as published by the Federal Geodetic Control Subcommittee (FGCS).

Plan a small GPS project given certain criteria.

Explain the basic concepts of using a satellite-based system for land surveying and geodesy.

Name and explain the main GPS methodologies, including their uses and limitations.

Differentiate between GPS issues directed to surveying versus those directed to navigation.

Explain the overall issues which can affect the successful completion of a GPS project, including designing redundancy into the project and addition of control stations (both horizontal and vertical) to strengthen the project.

Key Terms

FGCC standards and specifications

Static surveying

Kinematic surveying

Pseudo-static surveying

Fast or rapid static surveying

Pseudorange measurements
(primarily navigation)

Carrier-phase measurements
(primarily surveying)

P-code measurements

Epoch

Point positioning

Relative positioning

Differential positioning (see below)

Redundancy

Dilution of precision
(DOP, especially PDOP and GDOP)

Loss of lock/cycle slip

Multipath

Antenna swap

Selective availability (SA)

Anti-spoofing (AS)

Orthometric height (elevation)

Geoid height

Ellipsoid height

NOTE: Differential and relative positioning techniques were somewhat synonymous in earlier satellite tracking terminology. However, the term "differential" more appropriately describes the technique of determining the position of an unknown station by transmitting correction factors determined in real time at a known GPS station to the unknown station. These same correction factors are then applied to the unknown station.

Video Presentation Outline

History of Satellite Surveying

The 1960s: The Beginnings of Satellite Surveying Technologies

The 1970s: Doppler Technology

The 1980s: Evolution of Doppler to GPS

- Orbits
- Number of satellites
- Transmitting frequency
- Receiver design allowing simultaneous tracking
- Frequency standards

Technology Overview

- GPS receivers measure the time from signal generation at the satellite to signal arrival at the receiver.
- Point positioning involves station coordinate determination at a single station with a single receiver.
- Relative positioning involves GPS surveys with multiple receivers over known and unknown stations.

Positioning Methodologies

Accuracies – FGCC (now FGCS) Standards and Guidelines

Survey Categories	Order	Minimum Geometric Accuracy Standard (95 Percent Confidence Level)		
		Base Error	Line-length Dependent Error	
		e (cm)	p (ppm)	a (1:a)
Global-regional geodynamics; deformation measurements	AA	0.3	0.01	1:100,000,000
National Geodetic Reference System, "primary" networks; regional-local geodynamics; deformation measurements	A	0.5	0.1	1:10,000,000
National Geodetic Reference System, "secondary" networks; connections to the "primary" NGRS network; local geodynamics; deformation measurements; high-precision engineering surveys	B	0.8	1	1:1,000,000
National Geodetic Reference System (terrestrial based); dependent control surveys to meet mapping, land information, property, and engineering requirements	1	1.0	10	1:100,000
	2-I	2.0	20	1:50,000
	2-II	3.0	50	1:20,000
	3	5.0	100	1:10,000

Note: For ease of computation and understanding, it is assumed that the accuracy for each component of a vector base line measurement is equal to the linear accuracy standard for a single-dimensional measurement at the 95 percent confidence level. Thus, the linear one-standard deviation(s) is computed by:

$$s = \pm [\sqrt{e^2} + ((0.1d)(p))^2]/1.96.$$

Where **d** is the length of the base line in kilometers.

Table 10-1. *FGCC Accuracy Standards.*

General Survey Requirements:

- Elevation cutoff
- Tracking epoch
- Number of satellites
- Satellite configuration (dilution of precision)
- Site selection (elimination of multipath)

Static Positioning

Kinematic Positioning

Pseudo-kinematic/Pseudo-static

Project Planning

Vertical Control with GPS

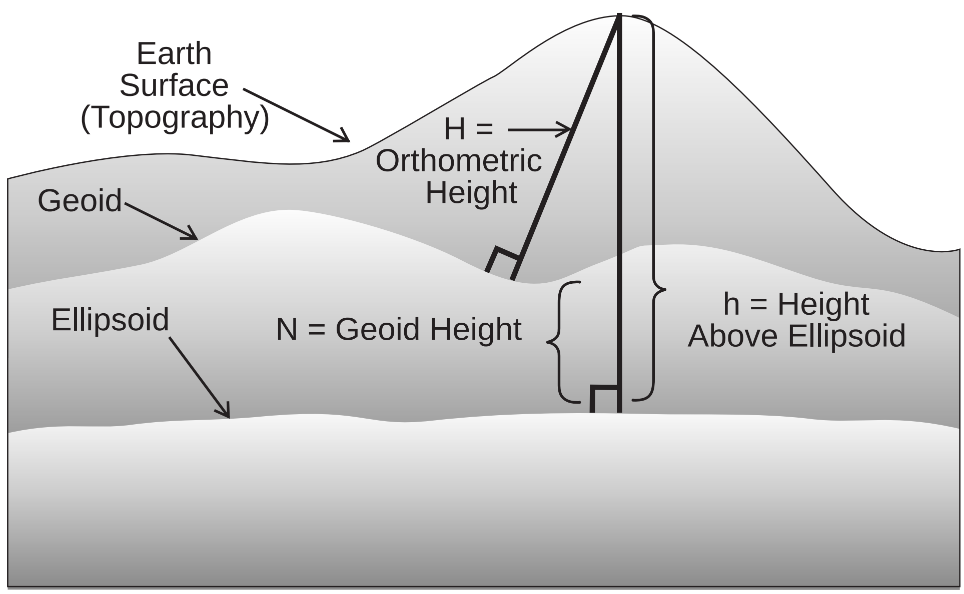


Figure 10-1. *Orthometric, ellipsoid, and geoid heights.*

GPS Provides Ellipsoid Heights

$$h = N + H$$

Where:

h = ellipsoid height
N = geoid height
H = orthometric height (elevation)

- Relative differences between GPS points can be determined with a high degree of precision.
- Absolute differences in elevation between GPS points can only be determined within 3 to 5 cm.

The California High Precision Geodetic Network (HPGN)

- The HPGN consists of about 250 stations observed to FGCS Order B accuracy (base error, 8mm + 1:1,000,000).
- Most stations are in the state highway corridors and readily accessible.
- The HPGN was constrained to about 20 California VLBI stations which are part of a worldwide network.
- The coordinates of these stations are referred to as NAD83 (1991.35).
- The pre-HPGN coordinates, NAD83 (1986), will be revised. This will probably happen in early 1993. The HPGN project helped to make the NGRS in California even more accurate.

The Latest Methodologies

- Rapid static
- GPS control of photogrammetry

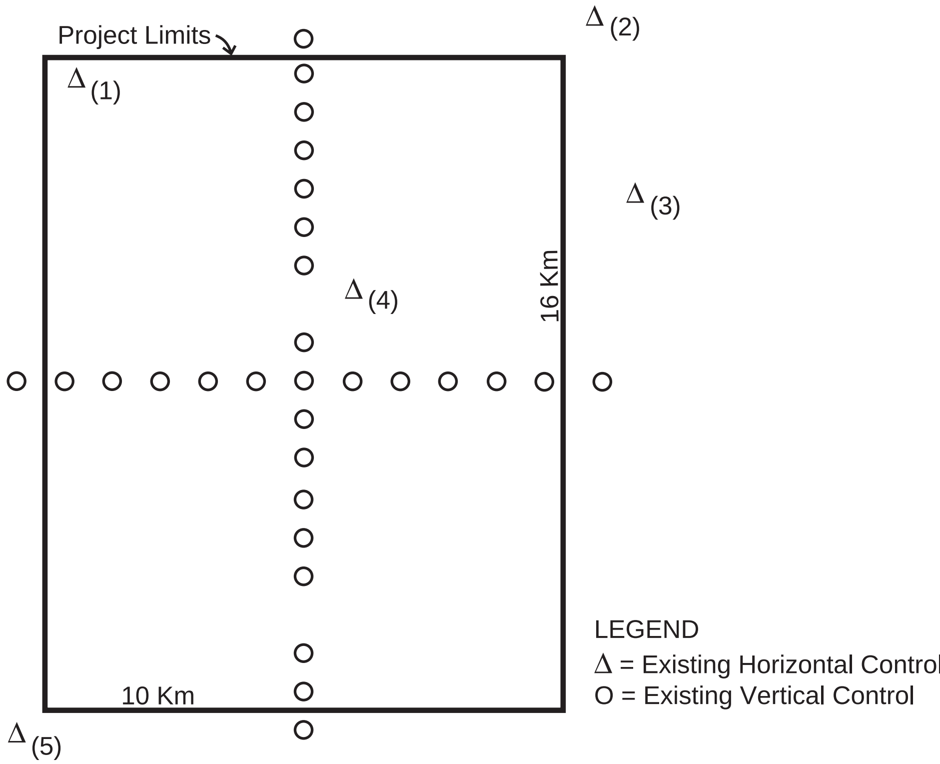
Steps to Completion of a GPS Project

1. Define the scope of the project.
2. Determine accuracy requirements, by FGCS specifications.
3. Determine project requirements, i.e., station spacing.
4. Design the project layout.
5. Research station information for existing horizontal and vertical control stations.

6. Determine suitability of existing control for GPS observations, and select those stations which are required to meet FGCS standards for the project.
7. Select sites for new project stations ensuring clear access to satellite signals and no multipath problems, set new survey monuments, and prepare station descriptions.
8. Determine number and type of receivers (single or dual frequency; P-code, etc) required to meet project specifications.
9. Plan observing schedules (accounting for satellite availability, station observation time) to ensure redundancy per FGCS specifications.
10. Conduct GPS observations, complete observation log, take station rubbing and verify final station description.
11. Download data from GPS receivers and make back-up copy.
12. Receive and process data at central processing location.
13. Review all data for completeness.
14. Perform minimal constrained adjustment.
15. Review results for problem vectors or outliers.
16. Reobserve problem vector lines, if necessary.
17. Perform constrained adjustment and review results.
18. Incorporate precise ephemeris data if appropriate.
19. Prepare final report with all pertinent sketches/maps, schedules, stations held fixed (including coordinates and elevations used), software packages used (TRIMNET, TRIMVEC, GEOLAB, GPPS, etc.), station description package, final adjustment report, and coordinates.

Sample Test Questions

1. A team of surveyors is required to design a GPS project for the city of Germantown. The project limits are about 10 km x 16 km (about 160 sq km). The project requires establishment of First Order control (FGCS) at 2 km spacing around the periphery and throughout the project limits. There is a line of levels (vertical control) running through the middle of the city in east-west and north-south directions. The vertical control bench marks are spaced about 1-1/2 km along the two lines. There are five First Order horizontal control stations in the vicinity of the city. The layout of the project limits is indicated below with existing vertical control (bench marks) and horizontal control indicated.



A. What minimum combination of horizontal control stations best fits the project requirements?

1. 1, 2, and 4
2. 1, 2, and 3
3. 5, 4, and 2
4. 1, 3, and 5

B. What is the best minimum combination of vertical control stations (bench marks), if any, required for the project?

1. No bench marks are required as the client only requires First Order horizontal control.
2. Four bench mark ties well dispersed throughout the project area.
3. Four bench mark ties to any four bench marks.
4. One bench mark tie in the center of the project.

C. What will be the approximate total number of stations (including network ties) in the project?

1. 44
2. 54
3. 61
4. 58

D. What is the error which can be expected between any two adjacent stations in the city network (at the two sigma or 95% confidence level)?

1. 1.0 cm
2. 2.2 cm
3. 3.0 cm
4. 5.0 cm

2. You are required to plan a GPS project which has a total of 40 stations. The required accuracy level for the project is First Order. The project will be accomplished using static relative positioning techniques.

   You have decided that the breakdown of the stations in the project are:

   new stations = 30
   existing horizontal control stations = 4
   existing vertical control stations = 6

   You have five suitable receivers available for the project.

   What is the minimum number of observing sessions required for the project? Show all work and appropriate FGCS specifications.

3. Are GPS heights a) orthometric heights or, b) ellipsoid heights?

4. What additional element is required to relate the orthometric height to the ellipsoid height?

5. A. How many non-trivial base lines are there in a single three station GPS session?

   B. How many trivial base lines are there in the same session?

6. What is the most likely way to avoid multipath problems?

7. Can the effects of refraction of the GPS signal through the ionosphere be removed by single frequency receivers?

8. Why is the Dilution of Precision factor important in GPS planning?

9. What is the minimum number of satellites required for most GPS applications?

10. What effect does selective availability have on the GPS signal?

Answer Key

1A. 4. According to the FGCS Standards and Specifications (pg. 15, Table 2), the location of network control should be not less than three "quadrants" relative to the center of the project. Either or both of the remaining two stations (stations 2 and 4) could be added to the network to increase the reliability and add redundancy to the network.

1B. 2. The dispersion of the bench marks throughout the project ensures a better determination of the overall accuracy of the project. According to the FGCS Standards and Specifications, bench mark ties are required for all surveys.

1C. 3. The project calls for stations around the periphery and throughout the city at 2 km spacing. Stations are at 2 km spacing at all grid intersections, therefore, 6 (at 0, 2, 4, 6, 8, and 10 km) x 9 (at 0, 2, 4, 6, 8, 10, 12, 14, and 16 km) = 54 stations at grid intersections. Thus: 54 new stations, plus 4 vertical control tie stations, plus 3 horizontal control tie stations equal a total of 61 stations.

1D. 2. The answer can be read directly from the graph on page 9 of the FGCS guidelines or by computation from the formula:

$$\sigma = \sqrt{e^2 + ((0.1)(p)(d))^2}$$

Where:

σ = maximum allowable error in cm at the 95% confidence level;
e = base error in cm;
d = distance in km between adjacent stations;
p = the minimum geometric relative position accuracy standard in parts per million at the 95% confidence level (see Table 1, page 6).

In this First Order project e = 1.0 cm, d = 2 km, and p = 10.

Substituting in the formula:

$$\sigma = \sqrt{1.0 + ((0.1)(10)(2))^2}$$
$$= 2.2 \text{ cm}$$

Thus, at the 95% confidence level, we can expect an error no greater than 2.2 cm for the stations spaced at 2 km and following First Order specifications.

2. The first step is to determine the total number of station occupations required. Table 4 on page 21 of the FGCS guidelines suggests the following:

   - 10% of all stations are occupied 3 times. Thus 4 stations (10% of 40 stations) must be occupied 3 times. This is a total of 12 occupations.

   - 100% of all vertical stations must be occupied twice. Thus 6 bench marks must be occupied twice. This is a total of 12 occupations.

   - 25% of all horizontal control stations must be occupied twice. Thus 1 horizontal station must be occupied twice. This is a total of 2 occupations.

   - 30% of all new stations must be occupied twice. Thus 9 new stations (30% of 30 new stations) must be occupied twice. This is a total of 18 occupations.

   - This leaves a total of 20 stations which are occupied once. This total is arrived at by subtracting 4 stations requiring 3 occupations, 1 horizontal station requiring 2 occupations, 6 bench marks requiring 2 occupations, and 9 new stations requiring 2 occupations, or, 40 - (4 + 1 + 6 + 9), or, 20.

     Thus, the total occupations are:

3 occupations:	12	
2 occupations:	12	(bench marks)
	2	(horizontal control)
	18	(new stations)
1 occupation:	20	
TOTAL OCCUPATIONS:	64	

   The total number of sessions is 13 (12.8) since there are 5 receivers and 64 occupations (64/5).

   REMINDER: It would be wise to consider occupying at least 1 and possibly 2 of the existing horizontal control points 3 times. 4 stations have to be occupied 3 times. Selecting 1 or 2 existing stations adds redundancy and helps strengthen the project reliability without increasing the total number of sessions.)

3. GPS heights are ellipsoid heights. GPS heights are measured to a mathematical surface, the ellipsoid, the surface of which acts as the zero reference for GPS heights.

4. The geoid (or geoidal) height is the element which relates the ellipsoid height to the orthometric height, or elevation. The relationship of the ellipsoid height to the orthometric height is given by the formula:

   $$N = h - H$$

   Where:

   N = geoid height
   h = ellipsoid height
   H = orthometric height

5. A. There are 2 non-trivial base lines.

   B. There is 1 trivial base line.

6. Multipath, the reception of a GPS signal via two or more paths, can best be eliminated by selecting sites which have no obstructions above 15 degrees from the horizon and which have no nearby (say ±50 feet) smaller obstructions such as road signs.

7. No. The removal of the ionospheric effects can be accomplished by dual frequency receivers. Single frequency receivers can be used on projects with short base lines since the effects of the ionosphere can be considered the same over small areas.

8. The Dilution of Precision (DOP) factor, a mathematical computation, provides information about how well the desired accuracy in a GPS project can be achieved. It is a measure of the geometry of the satellite constellation. The more favorable the satellite distribution in the sky, the lower will be the DOP factor. In general, surveys should not be performed with a DOP, especially PDOP or GDOP, above about 6.0 (the lower the value the better the projected accuracy).

9. Static, pseudo-static, and fast or rapid static require a minimum of 4 satellites, although 5 satellites are recommended for the latter 2 methods. Kinematic surveys generally require 5 satellites.

10. Selective Availability, implemented by the Department of Defense which maintains the GPS constellation, has the effect of reducing the accuracy

one can obtain in a GPS position. Selective Availability, or SA, falsifies the time of signals being broadcast by the GPS satellites. SA usually only affects real time GPS computations. Most GPS surveys are computed after the field surveys are completed, and the effects of SA can be eliminated.

NOTE: The references cited in the reference section provide other and more in-depth coverage of these issues.

References

__________, *Geometric Geodetic Accuracy Standards and Specifications for using GSP Relative Positioning Techniques:* Federal Geodetic Control Committee, Version 5.0: May 11, 1988, reprinted with corrections: August 1, 1989.

__________, *Geodesy for the Layman:* NOAA, 1983.

The above publications are available from:

National Geodetic Information Center
N/CG174, Rockwall Bldg., Room 24
National Geodetic Survey, NOAA
Rockville, MD 20852

__________, *GPS: A Guide for the Next Utility:* Trimble Navigation Ltd., 1989.

__________, *GPS Field Surveyors Guide: A Field Guidebook for Static Surveying:* Trimble Navigation Ltd., 1991.

__________, *GPS Field Surveyors Guide: A Field Guidebook to Dynamic Surveying:* Trimble Navigation Ltd., 1992.

Leick, Alfred, *GPS Satellite Surveying:* John Wiley & Sons, 1990.

Wells, David, editor, *Guide to GPS Positioning*, Canadian GPS Associates, 1986.

NOTE: These two books provide significantly more technical information about the GPS technology.