3.5 Geodetic Leveling

Geodetic leveling is a measurement system comprised of elevation differences observed between nearby rods. Geodetic leveling is used to extend vertical control.

Network Geometry

Order Class	First I	First II	Second I	Second II	Third
Bench mark spacing not more than (km)	3	3	3	3	3
Average bench mark spacing not more than (km)	1.6	1.6	1.6	3.0	3.0
Line length between network control points not more than (km)	300[a]	100[a]	50[a]	50[a]	25[b]
Minimum bench mark ties	6	6	4	4	4

[a] Electronic Digital/Bar-Code Leveling Systems, 25 km

[b] Electronic Digital/Bar-Code Leveling Systems, 10 km

As specified in above table, new surveys are required to tie to existing network bench marks at the beginning and end of the leveling line. These network bench marks must have an order (and class) equivalent to or better than the intended order (and class) of the new survey.

First-order surveys are required to perform valid check connections to a minimum of six bench marks, three at each end. All other surveys require a minimum of four valid check connections, two at each end.

A valid "check connection" means that the observed elevation difference agrees with the published adjusted elevation difference within the tolerance limit of the new survey. Checking the elevation difference between two bench marks located on the same structure, or so close together that both may have been affected by the same localized disturbance, is not considered a proper check.

In addition, the survey is required to connect to any network control points within 3 km of its path. However, if the survey is run parallel to existing control, then the following table specifies the maximum spacing of extra connections between the survey and the existing control.

When using Electronic Digital/Bar-Code Leveling Systems for area projects, there must be at least 4 contiguous loops and the loop size must not exceed 25 km. *(Note: This specification may be amended at a future date after sufficient data have been evaluated and it is proven that there are no significant uncorrected systematic errors remaining in Electronic Digital/Bar-Code Leveling Systems.)*

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* NGS' analyses of the data will be the final determination if the data meet the desired FGCS order and class standards.

Surveys Run Parallel to Existing Control Network

Distance, survey to control network	Maximum spacing of extra connections (km)
less than 0.5 km	5
0.5 km to 2.0 km	10
2.0 km to 3.0 km	20

Instrumentation

Order Class	First I	First II	Second I	Second II	Third
Leveling instrument					
Minimum repeatability of line of sight	0.25"[c]	0.25"[c]	0.50"[c]	0.50"[d]	1.00"
Leveling rod construction	IDS[g]	IDS[g]	IDS[e] or ISS	ISS	Wood or Metal
Instrument and rod resolution (combined)					
Least count(mm)	0.1[c]	0.1[c]	0.5-1.0[c,f]	1.0[d]	1.0[d]

IDS -- Invar, double-scale
ISS -- Invar, single-scale

[c] For Electronic Digital/Bar-Code Leveling Systems, 0.40" and 0.01 mm.

[d] For Electronic Digital/Bar-Code Leveling Systems, 0.80" and 0.1 mm.

[e] If optical micrometer is used.

[f] 1.0 mm if 3-wire method; 0.5 mm if optical micrometer.

[g] For Electronic Digital/Bar-Code Leveling Systems, Invar, single-scale.

Leveling rods must be one piece. A turning point consisting of a steel turning pin with a driving cap should be utilized. If a steel pin cannot be driven, then a turning plate ("turtle") weighing at least 7 kg should be substituted. In situations allowing neither turning pins nor turning plates (sandy or marshy soils), a long wooden stake with a double-headed nail should be driven to a firm depth.

According to at least one manufacturer's specifications, the electronic digital leveling instrument should not be exposed to direct sunlight. The manufacturer recommends using an umbrella in bright sunlight.

Calibration Procedures

Order Class	First I	First II	Second I	Second II	Third
Leveling instrument					
Maximum collimation error, single line of sight (mm/m)	0.05	0.05	0.05	0.05	0.10
Maximum collimation error, reversible compensator-type instruments, mean of two lines of sight (mm/m)	0.02	0.02	0.02	0.02	0.04
Time interval between collimation error determinations not longer than (days)					
Reversible compensator	7	7	7	7	7
Other types	1	1	1	1	7[h]
Maximum angular difference between two lines of sight, reversible compensator	40"	40"	40"	40"	60"
Leveling rod					
Minimum scale calibration standard	N[i]	N[i]	N[i]	M	M
Time interval between scale calibrations (yr)	3	3	--	--	--
Leveling rod bubble verticality maintained to within	10'	10'	10'	10'	10'

N -- U.S. National standard
M -- Manufacturer's standard

[h] For Electronic Digital/Bar-Code Systems, collimation error determinations are required at the beginning of each day (0.05 mm/m = 10 arc seconds). Collimation data must be recorded with the leveling data and the daily updated value must be used during the daily data capture.

[i] For Electronic Digital/Bar-Code Rods, until the U.S. National Standard Testing Procedure is implemented, manufacturer's scale calibration standard is acceptable, provided the data used during the calibration are furnished in digital format.

Compensator-type instruments should be checked for proper operation at least every 2 weeks of use. Rod calibration should be repeated whenever the rod is dropped or damaged in any way. Rod levels should be checked for proper alignment once a week. The manufacturer's calibration standard should, as a minimum, describe scale behavior with respect to temperature.

Order Class	First I	First II	Second I	Second II	Third
Minimal observation method	micrometer[j]	micrometer[j]	micrometer[j] or 3 wire	3-wire[j]	center wire[j]
Section running[k]	DR, DS, or MDS	DR, DS, or MDS	DR	DR	DR
Difference of forward and backward sight lengths never to exceed: per setup (m)	2	5	5	10	10
per section (m)	4	10	10	10	10
Maximum sight length (m)[l]	50	60	60	70	90
Minimum ground clearance of line of sight (m)	0.5	0.5	0.5	0.5	0.5
Even number of setups when not using leveling rods with detailed calibration	yes	yes	yes	yes	---
Determine temperature gradient for the vertical range of the line of sight at each setup	yes	yes	yes	---	---
Maximum section misclosure (mm)	$3\sqrt{D}$	$4\sqrt{D}$	$6\sqrt{D}$	$8\sqrt{D}$	$12\sqrt{D}$
Maximum loop misclosure (mm)	$4\sqrt{E}$	$5\sqrt{E}$	$6\sqrt{E}$	$8\sqrt{E}$	$12\sqrt{E}$
3-wire method					
Reading check (difference between top and bottom intervals) for one setup not to exceed (tenths of rod units)	---	---	2	2	3
Read rod 1 first in alternate setup method	---	---	yes	yes	yes
Micrometer single-difference method					
Reading check (difference between low and high scale) for one setup not to exceed (micrometer units)	---	---	3	4	5
Read rod 1 first in alternate setup method	---	---	yes	yes	yes

(continued)

Order Class	First I	First II	Second I	Second II	Third
Electronic Digital/Bar-Code method					
Δh_1 - Δh_2 for one setup not to exceed (mm) for MDS procedure	0.30	0.30	0.60	0.70	1.30
Use multiple reading option to obtain each observation - minimum number of readings[m]	3	3	3	3	3
Double-scale rods, DS procedure					
Low-high scale elevation difference for one setup not to exceed (mm)					
With reversible compensator	0.40	1.00	1.00	2.00	2.00
Other instrument types:					
Half-centimeter rods	0.25	0.30	0.60	0.70	1.30
Full-centimeter rods	0.30	0.30	0.60	0.70	1.30

DS -- Double Simultaneous procedure; see summary of observing sequences
MDS - Modified, Double Simultaneous procedure; see summary of observing sequences
DR -- Double-Run
SP -- SPur, must be less than 25 km, must be double-run
D --- shortest one-way length of section in km
E --- length of loop in km

[j] Electronic Digital/Bar-Code method permitted.

[k] For establishing a height of a new bench mark, double-run procedures must be used. Single-run methods can be used to relevel existing work provided the new work meets the allowable section misclosure.

[l] Maximum sight length permitted unless the manufacturer recommends a maximum sight length which is less.

[m] If the standard deviation of the mean exceeds 0.1 mm, continue making readings until it is less than 0.1 mm or repeat observation.

Double-run leveling may always be used, but single-run leveling procedures can only be used where it can be evaluated using published height values, i.e., the difference in published height values can be substituted for the backward running. DS and MDS procedures are recommended for all single-run leveling, but single-difference procedures are permitted.

Rods must be leap-frogged between setups (alternate setup method). The date, beginning and ending times, cloud coverage, air temperature (to the nearest degree), temperature scale, and average wind speed should be recorded for each section, plus any changes in the date, instrumentation, observer, or time zone.

When using the DS and MDS procedures, the instrument need not be off leveled/releveled between observing the high and low scales when using an instrument with a reversible compensator. The low-high scale difference tolerance for a reversible compensator is used only for the control of blunders.

Summary of Observing Sequences
(Required for first-order; optional for other orders)

DS Procedures With double-scale rods, the following observing sequence should be used:	MDS Procedures With bar-coded scale rods, the following observing sequence should be used:
backsight, low-scale	backsight
backsight, stadia	backsight distance, standard error
foresight, low-scale	foresight
foresight, stadia	foresight, distance, standard error
off-level/relevel or reverse compensator	off-level/relevel
foresight, high-scale	foresight, standard error
backsight, high-scale	backsight, standard error

Office Procedures

Order Class	First I	First II	Second I	Second II	Third
Section misclosures					
(backward and forward) Algebraic sum of all corrected section misclosures of a leveling line not to exceed (mm)	$3\sqrt{L}$	$4\sqrt{L}$	$6\sqrt{L}$	$8\sqrt{L}$	$12\sqrt{L}$
Section misclosure not to exceed (mm)	$3\sqrt{D}$	$4\sqrt{D}$	$6\sqrt{D}$	$8\sqrt{D}$	$12\sqrt{D}$
Loop misclosures					
Algebraic sum of all corrected misclosures not to exceed (mm)	$4\sqrt{E}$	$5\sqrt{E}$	$6\sqrt{E}$	$8\sqrt{E}$	$12\sqrt{E}$
Loop misclosure not to exceed (mm)	$4\sqrt{E}$	$5\sqrt{E}$	$6\sqrt{E}$	$8\sqrt{E}$	$12\sqrt{E}$

L -- shortest one-way length of leveling line in km
D -- shortest one-way length of section in km
E -- length of loop in km

The normalized residuals from a minimally constrained least squares adjustment will be checked for blunders. The observation weights will be checked by inspecting the post adjustment estimate of the variance of unit weight. Elevation difference standard errors computed by error propagation in a correctly weighted least squares adjustment will indicate the provisional accuracy classification. A survey variance factor ratio will be computed to check for systematic error. The least squares adjustment will use models that account for:

- gravity effect or orthometric correction
- rod scale errors
- rod (Invar) temperature
- refraction--need latitude and longitude accurate to at least 6" or (preferably) vertical temperature difference observations between 0.5 and 2.5 m above the ground
- earth tides and magnetic field
- collimation error[n]
- crustal motion

[n] For Electronic Digital/Bar-Code Leveling Systems, collimation data must be recorded with leveling data and updated value must be used during data capture.