SURVEY ORDERS OF ACCURACY

TYPE OF WORK	ORDER OF SURVEY			
	FIRST	SECOND	THIRD	LOWER
MAPPING (LARGE AND HIGH-DENSITY AREAS)	▨	▨		
PRIMARY CONTROL	▨	▨		
MAJOR STRUCTURES	▨	▨		
MINOR STRUCTURES		▨		
CENTERLINE SURVEY (HIGH-DENSITY URBAN AREA)		▨		
FINAL LOCATION SURVEY			▨	
PRELIMINARY LOCATION SURVEY			▨	▨
ADVANCE PLANNING SURVEY				▨

TABLE 1.—STANDARDS FOR THE CLASSIFICATION OF GLODETIC CONTROL AND PRINCIPAL RECOMMENDED USES

Horizontal Control

Classification	*First-Order*	*Second-Order*		*Third-Order*	
		Class I	*Class II*	*Class I*	*Class II*
Relative accuracy between directly connected adjacent points (at least)	1 part in 100,000	1 part in 50,000	1 part in 20,000	1 part in 10,000	1 part in 5,000
Recommended uses	Primary National Network. Metropolitan Area Surveys. Scientific Studies	Area control which strengthens the National Network. Subsidiary metropolitan control.	Area control which contributes to, but is supplemental to, the National Network.	General control surveys referenced to the National Network. Local control surveys.	

Vertical Control

Classification	*First-Order*		*Second-Order*		*Third-Order*
	Class I	*Class II*	*Class I*	*Class II*	
Relative accuracy between directly connected points or benchmarks (standard error)	0.5 mm $\sqrt{K}$	0.7 mm $\sqrt{K}$	1.0 mm $\sqrt{K}$ (K is the distance in kilometers between points.)	1.3 mm $\sqrt{K}$	2.0 mm $\sqrt{K}$
Recommended uses	Basic framework of the National Network and metropolitan area control. Regional crustal movement studies. Extensive engineering projects. Support for subsidiary surveys.		Secondary framework of the National Network and metropolitan area control. Local crustal movement studies. Large engineering projects. Tidal boundary reference. Support for lower order surveys.	Densification within the National Network. Rapid subsidence studies. Local engineering projects. Topographic mapping.	Small-scale topographic mapping. Establishing gradients in mountainous areas. Small engineering projects. May or may not be adjusted to the National Network.

TABLE 2.—CLASSIFICATION, STANDARDS OF ACCURACY, AND GENERAL SPECIFICATIONS FOR HORIZONTAL CONTROL

TRIANGULATION

Classification	*First-Order*	*Second-Order*		*Third-Order*	
		Class I	*Class II*	*Class I*	*Class II*
Recommended spacing of principal stations	Network stations seldom less than 15 km. Metropolitan surveys 3 km to 8 km and others as required.	Principal stations seldom less than 10 km. Other surveys 1 km to 3 km or as required.	Principal stations seldom less than 5 km or as required.	As required	As required
Strength of figure					
R_1 between bases					
Desirable limit	20	60	80	100	125
Maximum limit	25	80	120	130	175
Single figure					
Desirable limit					
R_1	5	10	15	25	25
R_2	10	30	70	80	120
Maximum limit					
R_1	10	25	25	40	50
R_2	15	60	100	120	170
Base measurement					
Standard error [1]	1 part in 1,000,000	1 part in 900,000	1 part in 800,000	1 part in 500,000	1 part in 250,000
Horizontal directions [2]					
Instrument	0".2	0."2	0".2 or 1".0	1".0	1".0
Number of positions	16	16	8 or 12	4	2
Rejection limit from mean	4"	4"	5" or 5"	5"	5"
Triangle closure					
Average not to exceed	1".0	1".2	2".0	3".0	5".0
Maximum seldom to exceed	3".0	3".0	5".0	5".0	10".0
Side checks					
In side equation test, average correction to direction not to exceed	0".3	0".4	0".6	0".8	2"
Astro azimuths [3]					
Spacing-figures	6-8	6-10	8-10	10-12	12-15
No. of obs./night	16	16	16	8	4
No. of nights	2	2	1	1	1
Standard error	0".45	0".45	0".6	0".8	3".0
Vertical angle observations [4]					
Number of and spread between observations	3 D/R—10"	3 D/R—10"	2 D/R—10"	2 D/R—10"	2 D/R—20"

Number of figures between known elevations	4-6	6-8	8-10	10-15	15-20
Closure in length (also position when applicable) after angle and side conditions have been satisfied, should not exceed	1 part in 100,000	1 part in 50,000	1 part in 20,000	1 part in 10,000	1 part in 5,000

TRILATERATION

Recommended spacing of principal stations	Network stations seldom less than 10 km. Other surveys seldom less than 3 km.	Principal stations seldom less than 10 km. Other surveys seldom less than 1 km.	Principal stations seldom less than 5 km For some surveys a spacing of 0.5 km between stations may be satisfactory.	Principal stations seldom less than 0.5 km.	Principal stations seldom less than 0.25 km.
Geometric configuration					
Minimum angle contained within, not less than	25°	25°	20°	20°	15°
Length measurement					
Standard error	1 part in 1,000,000	1 part in 750,000	1 part in 450,000	1 part in 250,000	1 part in 150,000
Vertical angle observations					
Number of and spread between observations	3 D/R—10"	3 D/R—10"	2 D/R—10"	2 D/R—10"	2 D/R—20"
Number of figures between known elevations	4-6	6-8	8-10	10-15	15-20
Astro azimuths					
Spacing-figures	6-8	6-10	8-10	10-12	12-15
No. of obs./night	16	16	16	8	4
No. of nights	2	2	1	1	1
Standard error	0".45	0".45	0".6	0".8	3".0
Closure in position after geometric conditions have been satisfied should not exceed	1 part in 100,000	1 part in 50,000	1 part in 20,000	1 part in 10,000	1 part in 5,000

See notes (1)-(8), p. 7.

TABLE 2.—Continued

TRAVERSE

Classification	*First-Order*	*Second-Order*		*Third-Order*	
		Class I	*Class II*	*Class I*	*Class II*
Recommended spacing of principal stations	Network stations 10-15 km Other surveys seldom less than 3 km.	Principal stations seldom less than 4 km except in metropolitan area surveys where the limitation is 0.3 km.	Principal stations seldom less than 2 km except in metropolitan area surveys where the limitation is 0.2 km.	Seldom less than 0.1 km in tertiary surveys in metropolitan area surveys. As required for other surveys.	
Horizontal directions or angles [a]					
Instrument	0".2	0".2 or 1".0	0".2 or 1".0	1".0	1".0
Number of observations	16	8 or 12[a]	6 or 8[a]	4	2
Rejection limit from mean	4"	4" or 5"	4" or 5"	5"	5"
Length measurements					
Standard error [b]	1 part in 600,000	1 part in 300,000	1 part in 120,000	1 part in 60,000	1 part in 30,000
Reciprocal vertical angle observations [c]					
Number of and spread between observations	3 D/R—10"	3 D/R—10"	2 D/R—10"	2 D/R—10"	2 D/R—20"
Number of stations between known elevations	4-6	6-8	8-10	10-15	15-20
Astro azimuths					
Number of courses between azimuth checks [f]	5-6	10-12	15-20	20-25	30-40
No. of obs./night	16	16	12	8	4
No. of nights	2	2	1	1	1
Standard error	0".45	0".45	1".5	3".0	8".0
Azimuth closure at azimuth check point not to exceed [f]	1".0 per station or 2" $\sqrt{N}$	1".5 per station or 3" $\sqrt{N}$. Metropolitan area surveys seldom to exceed 2".0 per station or 3" $\sqrt{N}$	2".0 per station or 6" $\sqrt{N}$. Metropolitan area surveys seldom to exceed 4".0 per station or 8" $\sqrt{N}$	3".0 per station or 10" $\sqrt{N}$. Metropolitan area surveys seldom to exceed 6".0 per station or 15" $\sqrt{N}$	8" per station or 30" $\sqrt{N}$
Position closure [f] [g] after azimuth adjustment	0.04m $\sqrt{K}$ or 1:100,000	0.08m $\sqrt{K}$ or 1:50,000	0.2m $\sqrt{K}$ or 1:20,000	0.4m $\sqrt{K}$ or 1:10,000	0.8m $\sqrt{K}$ or 1:5,000

[a] May be reduced to 8 and 4, respectively, in metropolitan areas.

NOTE (1)

The standard error is to be estimated by

$$e_m = \sqrt{\frac{\Sigma v^2}{n(n-1)}}$$

where e_m is the standard error of the mean, v is a residual (that is, the difference between a measured length and the mean of all measured lengths of a line), and n is the number of measurements.

The term "standard error" used here is computed under the assumption that all errors are strictly random in nature. The true or actual error is a quantity that cannot be obtained exactly. It is the difference between the true value and the measured value. By correcting each measurement for every known source of systematic error, however, one may approach the true error. It is mandatory for any practitioner using these tables to reduce to a minimum the effect of all systematic and constant errors so that real accuracy may be obtained. (See page 267 of Coast and Geodetic Survey Special Publication No. 247, "Manual of Geodetic Triangulation," Revised edition, 1959, for definition of "actual error.")

NOTE (2)

The figure for "Instrument" describes the theodolite recommended in terms of the smallest reading of the horizontal circle. A position is one measure, with the telescope both direct and reversed, of the horizontal direction from the initial station to each of the other stations. See FGCC "Detailed Specifications" for number of observations and rejection limits when using transits.

NOTE (3)

The standard error for astronomic azimuths is computed with all observations considered equal in weight (with 75 percent of the total number of observations required on a single night) after application of a 5-second rejection limit from the mean for First- and Second-Order observations.

NOTE (4)

See FGCC "Detailed Specifications" on "Elevation of Horizontal Control Points" for further details. These elevations are intended to suffice for computations, adjustments, and broad mapping and control projects, not necessarily for vertical network elevations.

NOTE (5)

Unless the survey is in the form of a loop closing on itself, the position closures would depend largely on the constraints or established control in the adjustment. The extent of constraints and the actual relationship of the surveys can be obtained through either a review of the computations, or a minimally constrained adjustment of all work involved. The proportional accuracy or closure (i.e. 1/100,000) can be obtained by computing the difference between the computed value and the fixed value, and dividing this quantity by the length of the loop connecting the two points.

NOTE (6)

See FGCC "Detailed Specifications" on "Trilateration" for further details.

NOTE (7)

The number of azimuth courses for First-Order traverses are between Laplace azimuths. For other survey accuracies, the number of courses may be between Laplace azimuths and/or adjusted azimuths.

NOTE (8)

The expressions for closing errors in traverses are given in two forms. The expression containing the square root is designed for longer lines where higher proportional accuracy is required.

The formula that gives the smallest permissible closure should be used.

N is the number of stations for carrying azimuth.
K is the distance in kilometers.

Vertical Control

First-Order

Leveling of this order is used in developing the basic framework of the national vertical net in the United States (Basic Nets A and B) so that few points in the country will be more than 50 km from an established First-Order bench mark. All lines close upon First-Order leveling to form circuits. The lines are divided into sections 1 to 2 km in length, and each section is leveled forward and backward. The difference in the two levelings must not exceed 3.0 mm $(K)^{1/2}$ for Class I (Basic Net A), or 4.0 mm $(K)^{1/2}$ for Class II (Basic Net B), where K is the distance in kilometers. The same criteria are recommended for use in establishing primary networks of leveling in metropolitan areas, except that the lines should be closely spaced.

Actual gravity values at the bench marks are needed to compute geopotential differences. If the gravity is not already available with the required accuracy, it shall be measured at sufficient number of bench marks so that the gravity uncertainty computed for any interval will not affect the accuracy of the geopotential difference by more than 0.2 x 10^{-3}gpu[8].

Second-Order, Class I

Leveling of this class should be used in developing the secondary net of the national vertical network and in densifying precise control in metropolitan areas. The leveling should connect to leveling of equal or greater accuracy to form closed circuits. All lines should be divided into sections 1 to 2 km in length, and each section should be run forward and backward, the two runnings of a section not to differ more than 6 mm $(K)^{1/2}$, where K is the length of the section in kilometers.

Second-Order, Class II

This class should be used in subdividing loops of First-Order and Second-Order, Class I leveling to establish general area coverage. The leveling should form closed circuits with leveling of equal or greater accuracy. and should rarely extend more than 50 km unsupported in this manner. Single-run leveling for short distances is acceptable, but for distances greater than 25 km double-run leveling is recommended. For double-run leveling, the line should be divided into sections of 1 to 3 km, and the forward and backward running of each section should differ by not more than 8 mm $(K)^{1/2}$, where K is the distance in kilometers.

Third-Order

Third-Order leveling may be used in subdividing loops of First- and Second-Order leveling, where additional control is required for local development. Third-Order lines may be single-run, but must always be loops or circuits closed upon lines of equal or higher order with a check of 12 mm $(K)^{1/2}$, or better, where K is the length of the line in kilometers. It is recommended that single-run lines be limited to 10 km in length, and double-run, to 25 km. Exceptions would be control for topographic mapping at a scale of 1:24,000 or smaller, and leveling in mountainous areas, where accuracy requirements may permit Third-Order lines 50 km long.

Leveling of Lower Order

Trigonometric leveling, barometric leveling, and fly leveling may be considered as Fourth-Order, or less; standards for these surveys are not included in these classifications. Elevations are normally published as part of other data.

Instruments and Procedures

For First-Order leveling, an automatic or tilting level with parallel plate micrometer, or equivalent, should be used. It should have horizontal sensitivity of 0.25 second of arc, or better, and should have high-quality optics that will permit repeat reading of 0.2 mm on a geodetic rod at a distance of 50 m under normal atmospheric conditions. The instrument should remain stable in a moderate breeze (up to 20 km/h), and should be temperature compensated. The rod should be composed of an invar scale under tension on a wood or metal frame equipped with a bull's-eye bubble. The scale should be accurate overall to 0.1 mm. The rods are used in pairs, each rod alternating as the forward and backward rod, and the same rod is always read first regardless of position. That is, one rod will be used for the back readings on odd-numbered instrument stations, and for the forward readings on even-numbered stations. The lengths of sights should not exceed the criteria given in table 3, and should be shortened if refraction or scintillation is troublesome. Balancing of forward and backward sights also shall conform to the limits given in table 3.

[8] 1 geopotential unit (gpu) = 1 kilogalmeter (10^5 cm^2 sec^{-2})

TABLE 3.—CLASSIFICATION, STANDARDS OF ACCURACY, AND GENERAL SPECIFICATIONS FOR VERTICAL CONTROL

Classification	First-Order Class I, Class II	Second-Order Class I	Second-Order Class II	Third-Order
Principal uses Minimum standards; higher accuracies may be used for special purposes	Basic framework of the National Network and of metropolitan area control Extensive engineering projects Regional crustal movement investigations Determining geopotential values	Secondary control of the National Network and of metropolitan area control Large engineering projects Local crustal movement and subsidence investigations Support for lower-order control	Control densification, usually adjusted to the National Net. Local engineering projects Topographic mapping Studies of rapid subsidence Support for local surveys	Miscellaneous local control; may not be adjusted to the National Network. Small engineering projects Small-scale topo. mapping Drainage studies and gradient establishment in mountainous areas
Recommended spacing of lines National Network	Net A; 100 to 300 km *Class I* Net B; 50 to 100 km *Class II*	Secondary Net; 20 to 50 km	Area Control; 10 to 25 km	As needed
Metropolitan control;	2 to 8 km	0.5 to 1 km	As needed	As needed
other purposes	As needed	As needed	As needed	As needed
Spacing of marks along lines	1 to 3 km	1 to 3 km	Not more than 3 km	Not more than 3 km
*Gravity requirement**	0.20×10^{-3}gpu	....	....	....
Instrument standards	Automatic or tilting levels with parallel plate micrometers; invar scale rods	Automatic or tilting levels with optical micrometers or three-wire levels; invar scale rods	Geodetic levels and invar scale rods	Geodetic levels and rods
Field procedures	Double-run; forward and backward, each section	Double-run; forward and backward, each section	Double- or single-run	Double- or single-run
Section length	1 to 2 km	1 to 2 km	1 to 3 km for double-run	1 to 3 km for double-run
Maximum length of sight	50 m Class *I*; 60 m *Class II*	60 m	70 m	90 m
Field procedures† Max. difference in lengths Forward & backward sights per setup	2 m Class *I*; 5 m *Class II*	5 m	10 m	10 m
per section (cumulative)	4 m Class *I*; 10 m *Class II*	10 m	10 m	10 m
Max. length of line between connections	Net A: 300 km Net B: 100 km	50 km	50 km double-run 25 km single-run	25 km double-run 10 km single-run
Maximum closures‡ Section; fwd. and bkwd.	3 mm $\sqrt{K}$ Class *I*; 4 mm $\sqrt{K}$ Class *II*	6 mm $\sqrt{K}$	8 mm $\sqrt{K}$	12 mm $\sqrt{K}$
Loop or line	4 mm $\sqrt{K}$ Class *I*; 5 mm $\sqrt{K}$ Class *II*	6 mm $\sqrt{K}$	8 mm $\sqrt{K}$	12 mm $\sqrt{K}$

* See text for discussion of instruments.

† The maximum length of line between connections may be increased to 100 km for double run for Second-Order, Class II, and to 50 km for double run for Third-Order in those areas where the First-Order control has not been fully established.

‡ Check between forward and backward runnings where K is the distance in kilometers.