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Classification, Standards of Accuracy, and General Specific-ations of Geodetic Control Surveys

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Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys

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Introduction

The Government of the United States makes nationwide surveys, maps, and charts of various kinds which must be referenced to national datums. These are necessary to provide basic information for the conduct of public business at all levels of government, for planning and carrying out national and local projects, for programs relating to the development and utilization of natural resources, for National defense, and for development of the country. Requirements for geodetic control surveys are most critical where intense development is taking place; included are offshore areas, where the surveys are used in the development and exploitation of the marine resources and in the delineation of state and international seaward boundaries.

State and local governments and industry regularly cooperate in various parts of the total surveying and mapping program. In making surveys and maps of large areas, it is first necessary to establish frameworks of horizontal and vertical control surveys. These provide a common basis for all surveying and mapping operations, and so ensure a coherent product.

Geodetic surveys of large areas are affected by and must take into account the curvature of the earth, astronomic observations, and gravity determinations.[1] Geodetic surveys, executed with high precision, are used to control mapping and charting operations as well as engineering projects. "Geodetic survey" and "control survey" are terms used almost interchangeably.

Control surveys are of two types: horizontal and vertical. Horizontal control surveys determine latitudes and longitudes referenced to a national datum and provide the basis for rectangular coordinate systems. Horizontal geodetic surveys are adjusted to the mathematical figure of the earth applicable to the national datum. Vertical control surveys determine elevations referred to a national datum that has been referenced to tidal measurements. Vertical geodetic surveys are adjusted with respect to the geoid, an equipotential surface of the earth approximated by mean sea level. These surveys provide permanently marked and properly described stations.

Horizontal control is established by triangulation, trilateration, and traverse procedures. Triangulation is a system of joined or overlapping triangles in which the length of an occasional side, known as a base line, is measured and the other sides are computed from angles measured at the triangle vertices. Trilateration is a method of surveying in which the lengths of the triangle sides are measured. Traverse is a method of surveying in which a sequence of lengths and directions of lines between points on the earth are measured and used in determining positions of the points.

Vertical control is established by leveling of a high order of accuracy. It provides elevations of marked points along lines that form closed circuits and is accomplished by measuring differences in elevation between consecutive bench marks.

These classifications and standards have been prepared by the Federal Geodetic Control Committee (FGCC) and have been reviewed by the American Society of Civil Engineers, the American Congress on Surveying and Mapping, and the American Geophysical Union. The opinions of other organizations and individuals were also requested and received. After consideration of all comments, the original draft was revised in this, the present form.

These new classifications and standards replace those approved March 1, 1957 (and referred to in Exhibit C to the Office of Management and Budget Circular A-16 dated October 10, 1958). The classic First-, Second-, and Third-Order nomenclatures have been retained. However, classes within the orders have been revised to reflect a requirement for greater flexibility in designing surveys and in recognition of rapidly changing requirements for higher accuracy surveys. Improvements in the technology in recent years make these changes desirable and practical.

[1] The standards of accuracy for gravity determinations and observations of astronomic latitude and longitude are not contained herein as they depend on the particular application involved; they are described in separate publications such as Coast and Geodetic Survey Special Publications No. 237, "Manual of Geodetic Astronomy, Determination of Longitude, Latitude and Azimuth," 1947, GPO, Washington, D.C.

The specifications in the attached tables show the permissible tolerances on the indicated quantities as a function of order and class; these must be very closely followed to insure that the overall standards are achieved. Detailed specifications have been prepared by the Federal Geodetic Control Committee to supplement this publication. Some important although seemingly minor factors which do not fit into the tables could cause a survey to fail to attain the required closures even though the specified requirements were met. It is emphasized that closure is not the sole criterion for classifying a survey into a particular order, as the closure is only part of the requirements and must be considered together with the other specifications in classification.

These classifications and standards are a directive for surveys which are to be considered a part of the National Geodetic Control Networks. Densification and extension of control is also provided by analytic photogrammetric triangulation and satellite systems (e.g., Doppler). It is highly desirable that these and all other geodetic or precise engineering surveys be properly referenced to the National Networks and adhere to these standards whenever possible.

Horizontal Control

First-order (Primary Horizontal Control)

The primary framework for National Horizontal Control Network consists of arcs of triangulation as well as trilateration and traverse, spaced about 100 kilometers apart in each direction. To maintain satisfactory mathematical consistency within the contained area networks between these arcs, this primary framework should have an accuracy of at least 1 part in 100,000. The study of gradual and secular ground creep movements in the earth's crust in areas subject to seismic or tectonic activity, the testing of defense and scientific equipment, and use in high-precision engineering projects require control of this same accuracy. These surveys that develop the National Network, prepare for metropolitan expansion, and serve these scientific and engineering purposes are designated First-Order.

Second-Order, Class I (Secondary Horizontal Control)

This class includes the area networks between the First-Order arcs and detailed surveys in very high value land areas. Surveys of this class strengthen the National Network and are adjusted as part of the network. Thus, this class also includes the basic framework for further densification. The internal closures of this class of survey should indicate an accuracy of at least 1 part in 50,000.

Second-Order, Class II (Supplemental Horizontal Control)

The demands for reliable horizontal control surveys in areas which are not in a high state of development or where no such development is anticipated in the near future justify the need for this classification. This class is used to establish control along the coastline, inland waterways, and interstate highways and is recommended for controlling extensive land subdivision and construction. The control contributes to the National Network and is published as part of the network. The minimum accuracy allowable in Class II of Second-Order is 1 part in 20,000.

Third-Order Class I and Class II (Local Horizontal Control)

Surveys of this order are used to establish control for local improvements and developments, topographic and hydrographic surveys, or for such other projects for which they provide sufficient accuracy. This order of survey is based on higher order control, carefully connected to the National Network, and also should be permanently marked and adequately described. Spires, stacks, standpipes, flag poles, and other identifiable objects located to this accuracy also have significant value for many surveying and engineering projects. The work should be performed with sufficient accuracy to satisfy the standards listed in the tables.

Although the specifications for the triangle closure and side checks are better than the minimum required for the standards, the specifications are logical and obtainable with judicious procedures; adherence to the standards is recommended.

Standards for surveys below Third-Order are not included in these specifications.

Table 1.—Standards for the Classification of Geodetic 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 $\sqrt{K}$	1.3 mm $\sqrt{K}$	2.0 mm $\sqrt{K}$
			(K is the distance in kilometers between points.)		
	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 Obser./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 (5) (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.
Geometric configuration (6)					
Minimum angle contained within, not less than	25°	25°	20°	20°	15°
Length measurement					
Standard error (1)	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 (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
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
Closure in position (5) 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

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 (2)					
Instrument	0″.2	0″.2 or 1″.0	0″.2 or 1″.0	1″.0	1″.0
Number of observations	16	8 or 12*	6 or 8*	4	2
Rejection limit from mean	4″	4″ or 5″	4″ or 5″	5″	5″
Length measurements		* May be reduced to 8 and 4, respectively, in metropolitan areas.			
Standard error (1)	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 (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 stations between known elevations	4-6	6-8	8-10	10-15	15-20
Astro azimuths					
Number of courses between azimuth checks (7)	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 (8)	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″ per station or 15″ $\sqrt{N}$	8″ per station or 30″ $\sqrt{N}$
Position closure (5)(8) after azimuth adjustment	0.04m $\sqrt{K}$ or 1:100,000	0.08 $\sqrt{K}$ 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

NOTE (1)

The standard error is to be estimated by

$$\sigma_m = \sqrt{\frac{\sum v^2}{n\,(n-1)}}$$

where σ_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.

"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.

* See page 267 of Coast and Geodetic Survey Special Publication No. 247,

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 0.2×10^{-3}gpu[1].

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.

[1] 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 (1)	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 (2) 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 (3) 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 $\sqrt{K}$

NOTE (1)

See text for discussion of instruments.

NOTE (2)

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.

NOTE (3)

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

For Second-Order leveling, parallel plate or similar micrometers on the instruments are not required but are desirable. Otherwise, three-wire geodetic spirit or automatic levels with horizontal sensitivity of 0.5 seconds of arc are recommended. Stadia should be read for keeping the sight lengths balanced and for adjustment purposes. The rod scale should be accurate overall to 0.2 mm. For Third-Order leveling, it is necessary to read only the middle wire when using the three-wire geodetic spirit level.

National Networks of Geodetic Control

There is a continuing basic program for establishing, upgrading, and maintaining of the National Geodetic Control Networks described in these classifications to provide adequate spacing as well as sufficient strength and accuracy to meet the needs and satisfy the requirements of engineers and scientists engaged in the development and conservation of the resources of the United States. The accuracy and spacing of the National Network control must be based on the most stringent requirements to be placed upon it; this accuracy should be the best achievable considering economic advantage and the capabilities of instruments and technology.

Horizontal Control Network

National overall accuracy is derived through the establishment of a fundamental backbone of the high-precision traverses, with accuracies of 1:1,000,000 integrated with satellite triangulation. Primary horizontal control (First-Order, accuracy of 1:100,000) establishes the principal network with arcs or traverses at a spacing not in excess of 100 km. Secondary horizontal control (Second-Order, Class I, accuracy of 1:50,000), together with supplemental work (Second-Order, Class II, accuracy of 1:20,000) breaks down the principal network and strengthens the whole. Local horizontal control (Third-Order, Class I, accuracy of 1:10,000, and Third-Order, Class II, accuracy of 1:5,000) is referenced to the network. To meet these accuracy criteria and for optimum utilization of the network, approximate station spacing, in general, along First-Order arcs is 15 km, with a breakdown to 10 km for Second-Order, Class I and 5 km for Second-Order, Class II. In areas of high land value, the station spacing for First-Order is a maximum of 8 km and Second-Order, Class I, 3 km. Second-Order, Class II and all Third-Order, Class I and Class II are as required for local usage.

In addition to the above spacing of stations, control shall be established at all airports, towns of 2,000 or more population, colleges, and at a 6- to 8-km spacing along coastlines and interstate highways. Although wider spacing may suffice for federal topographic mapping, closer spacing is required for surveys of property, highways, transmission lines, reclamation projects, and numerous other engineering activities. Such stations should be situated so they are readily available to local engineers and surveyors. Frequency, stability, recoverability, and accessibility are factors to be considered when emplacing marks (including underground marks, reference marks, and witness posts when appropriate).

Nationwide High Precision Traverses

These traverses provide scale for the worldwide satellite triangulation network and upgrade the scale and orientation of the National Network of Horizontal Control. They consist of a series of high-precision length, angle, and astronomic azimuth determinations running approximately east-west and north-south through the conterminous states, forming somewhat rectangular loops. Smaller loops and spur traverses are added to connect satellite triangulation stations and areas of special interest.

Standards of accuracy for high-precision traverses are not given herein. Supporting specifications approved by the Federal Geodetic Control Committee outline procedures indicating the care required to obtain the approximate 1 part in 1,000,000 accuracy.

The high precision traverses provide a geodetic reference framework of continental extent which, when remeasured in the future, will provide data for studies of deformation of the earth's crust, including continental drift and spreading.

Triangulation, Trilateration, Traverse, and Bases

Methods of establishment of horizontal control are triangulation, trilateration, and traverses, either separately or in combination. This publication does not differentiate between the methods used. Appropriate instrumentation and procedures are to be selected to satisfy the standards in the tables and to obtain the precision required.

The general availability of electronic distance-measuring equipment has practically eliminated the use of taping procedures for the measurement of base lines or traverse lengths. Accuracies are comparable or superior to those obtained with invar tapes.

Vertical Control Network

In leveling, inasmuch as survey errors propagate at least as the one-half power of the distance surveyed, and because of the great continental distances in the United States, the precision of the primary network measurements must be of high order.

The national vertical control network provides for this by a framework of high-precision basic control supporting a secondary network, which in turn supports area control of a density convenient for users.

The framework consists of two interrelated systems, designated as Basic Nets A and B, covering the country. Basic Net A is composed of lines of First-Order, Class I leveling, forming more or less rectangular circuits 100 to 300 km across, and is the fundamental reference system. Basic Net B is composed of lines of First-Order, Class II leveling, subdividing the circuits of Net A to provide an overall spacing of 50 to 100 km. The Secondary Network consisting of lines of Second-Order, Class I leveling spaced 25 to 50 km apart densifies the national network. The more closely spaced Second-Order, Class II area control is referenced to the network.

The surface of our continent is constantly changing because of tectonic and other physical forces. Large areas are undergoing subsidence owing to removal of ground water or petroleum resources, regions are still emerging from glacier recession, elevations are changing because of natural movement of the earth's crust, and seismic activity is continuous. Engineers and planners need up-to-date elevations to cope with new water levels and crustal changes.

One of the most important factors in the development of a control level net is to establish marks that will remain stable. In some areas, the causes of ground movement are so deep-seated that it is difficult to establish a mark that will remain stable indefinitely. The usual practice is to establish, at 1- to 3-km intervals along lines of First- or Second-Order leveling, bench mark disks set in concrete posts, stable structures, and outcropping bedrock. or secured to rods and pipes driven to refusal (or a stable stratum). At each intersection of lines of the basic framework, a cluster of three "super" marks is established; this cluster consists of deep isolated-pipe marks or marks in bedrock. Intersections of lines of the Secondary Network are marked by clusters of three driven-rod marks. In both cases, the next adjacent regular bench mark on each level line is the driven-rod or outcropping rock type. This pattern permits, to a degree, a check on the stability of marks for future extensions.

Earth Movement Surveys

Surveys for the measurement of horizontal and vertical movements of the earth's crust are undertaken in areas of known or suspected subsidence or seismic activity, where the safety of the inhabitants and the economy of the region are involved. These surveys consist of periodically repeated precise measurements to provide information relative to crustal distortions and strain buildup for use in geophysical studies and in engineering design and maintenance. Similar surveys, particularly vertical, are required in areas of subsidence caused by withdrawal of underground resources. These repeat surveys are necessary to maintain the quality of the networks and to correlate between changes in local mean sea level and crustal distortion. The economic and engineering impact, and the rate of movement, dictate the period between surveys.

Table 4.—National Geodetic Networks

HORIZONTAL

Classification	Nationwide high precision traverses—Satellite Control	*First-Order*	*Second-Order* *Class I*	*Second-Order* *Class II*	*Third-Order* *Class I*	*Third-Order* *Class II*
Network component	Basic horizontal framework (control establishes the National Network)	Primary horizontal network (control develops the National Network)	Secondary horizontal control (control strengthens the National Network)	Supplemental horizontal control (Control contributes to the National Network)	Local horizontal control (control is referenced to the National Network)	
Nominal accuracy or precision between adjacent points	I part in 1,000,000	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 density of control	Traverses and satellite stations at 900-1200 km. Stations at 15 km. to limit of technical and geometric restraints	Arcs not in excess of 100 km. Stations at 12-20 km. Urban control 3-8 km.	Stations at 10-13 *km*. Urban control 1-3 km.	As required	As required	

VERTICAL

Classification	*First-Order* *Class I*	*First-Order* *Class II*	*Second-Order* *Class I*	*Second-Order* *Class II*	*Third-Order*
Network component	Basic Vertical Network A (control establishes the National Network)	Basic Vertical Network B (control establishes the National Network)	Secondary Vertical Network (Control develops the National Network)	Supplemental Vertical Control (Control contributes to the National Network)	Local vertical control
Nominal accuracy *between points**	1.5 mm$\sqrt{K}$	2 mm $\sqrt{K}$	3 mm $\sqrt{K}$	4 mm $\sqrt{K}$	6 mm $\sqrt{K}$
Recommended density of *lines*	100-300 km	50-100 km.	25-50 km	10-25 km	As needed

* One-half of permissable closure

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