Standards and Specifications for Geodetic Control Networks

Federal Geodetic Control Committee

Rear Adm. John D. Bossler, Chairman

Rockville, Maryland

September 1984

Reprinted October 1990

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Preface

This single publication is designed to replace both "Classification, Standards of Accuracy and General Specifications of Geodetic Control Surveys," issued February 1974, and "Specifications to Support Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys," issued June 1980. Because requirements and methods for acquisition of geodetic control are changing rapidly, this publication is being released in loose-leaf format so that it can be updated more conveniently and efficiently. Recipients of this publication wishing to receive updated information should complete and mail the form below. Comments on the contents and format of the publication are welcomed and should be addressed to:

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1. Introduction

The Government of the United States makes nationwide surveys, maps, and charts of various kinds. These are necessary to support the conduct of public business at all levels of government, for planning and carrying out national and local projects, the development and utilization of natural resources, national defense, land management, and monitoring crustal motion. Requirements for geodetic control surveys are most critical where intense development is taking place, particularly offshore areas, where surveys are used in the exploration and development of natural resources, and in delineation of state and international boundaries.

State and local governments and industry regularly cooperate in various parts of the total surveying and mapping program. In surveying and mapping large areas, it is first necessary to establish frameworks of horizontal, vertical, and gravity control. These provide a common basis for all surveying and mapping operations to ensure a coherent product. A reference system, or datum, is the set of numerical quantities that serves as a common basis. Three National Geodetic Control Networks have been created by the Government to provide the datums. It is the responsibility of the National Geodetic Survey (NGS) to actively maintain the National Geodetic Control Networks (appendix A).

These control networks consist of stable, identifiable points tied together by extremely accurate observations. From these observations, datum values (coordinates or gravity) are computed and published. These datum values provide the common basis that is so important to surveying and mapping activities.

As stated, the United States maintains three control networks. A horizontal network provides geodetic latitudes and longitudes in the North American Datum reference system; a vertical network furnishes elevations in the National Geodetic Vertical Datum reference system; and a gravity network supplies gravity values in the U.S. absolute gravity reference system. A given station may be a control point in one, two, or all three control networks.

It is not feasible for all points in the control networks to be of the highest possible accuracy. Different levels of accuracy are referred to as the "order" of a point. Orders are often subdivided further by a "class" designation. Datum values for a station are assigned an order (and class) based upon the appropriate classification standard for each of the three control networks. Horizontal and vertical standards are defined in reasonable conformance with past practice. The recent development of highly accurate absolute gravity instrumentation now allows a gravity reference standard. In the section on "Standards," the classification standards for each of the control networks are described, sample computations performed, and monumentation requirements given.

Control networks can be produced only by making very accurate measurements which are referred to identifiable control points. The combination of survey design, instrumentation, calibration procedures, observational techniques, and data reduction methods is known as a measurement system. The section on "Specifications" describes important components and states permissible tolerances for a variety of measurement systems.

Clearly, the control networks would be of little use if the datum values were not published. The section entitled "Information" describes the various products and formats of available geodetic data.

Upon request, the National Geodetic Survey will accept data submitted in the correct formats with the proper supporting documentation (appendix C) for incorporation into the national networks. When a survey is submitted for inclusion into the national networks, the survey measurements are processed in a quality control procedure that leads to their classification of accuracy and storage in the National Geodetic Survey data base. To fully explain the process we shall trace a survey from the planning stage to admission into the data base. This example will provide an overview of the standards and specifications, and how they work together.

The user should first compare the distribution and accuracy of current geodetic control with both immediate and long-term needs. From this basis, requirements for the extent and accuracy of the planned survey are determined. The classification standards of the control networks will help in this formulation. Hereafter, the requirements for the accuracy of the planned survey will be referred to as the "intended accuracy" of the survey. A measurement system is then chosen, based on various factors such as: distribution and accuracy of present control; region of the country; extent, distribution, and accuracy of the desired control; terrain and accessibility of control; and economic factors.

Upon selection of the measurement system, a survey design can be started. The design will be strongly dependent upon the "Network Geometry" specifications for that measurement system. Of particular importance is the requirement to connect to previously established control points. If this is not done, then the survey cannot be placed on the national datum. An adequate number of existing control point connections are often required in the specifications in order to ensure strong network geometry for other users of the control, and to provide several closure checks to help measure accuracy. NGS can certify the results of a survey only if it is connected to the national network.

Situations will arise where one cannot, or prefers not to, conform to the specifications. NGS may downgrade the classification of a survey based upon failure to adhere to the measurement system specifications if the departure degrades the precision, accuracy, or utility of the survey. On the other hand, if specification requirements for the desired level of accuracy are exceeded, it may be possible to upgrade a survey to a higher classification.

Depending upon circumstances, one may wish to go into the field to recover old control and perform reconnaissance and site inspection for the new survey. Monumentation may be performed at this stage. Instruments should be checked to conform to the "Instrumentation" specifications, and to meet the "Calibration Procedures" specifications. Frequent calibration is an excellent method to help ensure accurate surveys.

In the field, the "Field Procedures" specifications are used to guide the methods for taking survey measurements. It must be stressed that the "Field Procedures" section is not an exhaustive account of how to perform observations. Reference should be made also to the appropriate manuals of observation methods and instruments.

Computational checks can be found in the "Field Procedures" as well as in the "Office Procedures" specifications, since one will probably want to perform some of the computations in the field to detect blunders. It is not necessary for the user to do the computations described in the "Office Procedures" specifications, since they will be done by NGS. However, it is certainly in the interest of the user to compute these checks before leaving the field, in case reobservations are necessary. With the tremendous increase in programmable calculator and small computer technology, any of the computations in the "Office Procedures" specifications could be done with ease in the field.

At this point the survey measurements have been collected, together with the new description and recovery notes of the stations in the new survey. They are then placed into the formats specified in the Federal Geodetic Control Committee (FGCC) publications *Input Formats and Specifications of the National Geodetic Survey Data Base*. Further details of this process can be found in appendix C, "Procedures for Submitting Data to the National Geodetic Survey."

The data and supporting documentation, after being received at NGS, are processed through a quality control procedure to make sure that all users may place confidence in the new survey points. First, the data and documentation are examined for compliance with the measurement system specifications for the intended accuracy of the new survey. Then office computations are performed, including a minimally constrained least squares adjustment. (See appendix B for details.) From this adjustment, accuracy measures can be computed by error propagation. The accuracy classification thus computed is called the "provisional accuracy" of the survey.

The provisional accuracy is compared to the intended accuracy. The difference indicates the departure of the accuracy of the survey from the specifications. If the difference is small, the intended accuracy has precedence because a possible shift in classification is not warranted. However, if the difference is substantial, the provisional accuracy will supersede the intended accuracy, either as a downgrade or an upgrade.

As the final step in the quality control procedure, the variance factor ratio computation using established control, as explained in the section on "Standards," is determined for the new survey. If this result meets the criteria stated there, then the survey is classified in accordance with the provisional accuracy (or intended accuracy, whichever has precedence).

Cases arise where the variance factor ratio is significantly larger than expected. Then the control network is at fault, or the new survey is subject to some unmodeled error source which degrades its accuracy. Both the established control measurements and the new survey measurements will be scrutinized by NGS to determine the source of the problem. In difficult cases, NGS may make diagnostic measurements in the field.

Upon completion of the quality control check, the survey measurements and datum values are placed into the data base. They become immediately available for electronic retrieval, and will be distributed in the next publication cycle by the National Geodetic Information Branch of NGS.

A final remark bears on the relationship between the classification standards and measurement system specifications. Specifications are combinations of rules of thumb and studies of error propagation, based upon experience, of how to best achieve a desired level of quality. Unfortunately, there is no guarantee that a particular standard will be met if the associated specifications are followed. However, the situation is ameliorated by a safety factor of two incorporated in the standards and specifications. Because of this safety factor, it is possible that one may fail to meet the specifications and still satisfy the desired standard. This is why the geodetic control is not automatically downgraded when one does not adhere to the specifications. Slight departures from the specifications can be accommodated. In practice, one should always strive to meet the measurement system specifications when extending a National Geodetic Control Network.

2. Standards

The classification standards of the National Geodetic Control Networks are based on accuracy. This means that when control points in a particular survey are classified, they are certified as having datum values consistent with all other points in the network, not merely those within that particular survey. It is not observation closures within a survey which are used to classify control points, but the ability of that survey to duplicate already established control values. This comparison takes into account models of crustal motion, refraction, and any other systematic effects known to influence the survey measurements.

The NGS procedure leading to classification covers four steps:

1. The survey measurements, field records, sketches, and other documentation are examined to verify compliance with the specifications for the intended accuracy of the survey. This examination may lead to a modification of the intended accuracy.
2. Results of a minimally constrained least squares adjustment of the survey measurements are examined to ensure correct weighting of the observations and freedom from blunders.
3. Accuracy measures computed by random error propagation determine the provisional accuracy. If the provisional accuracy is substantially different from the intended accuracy of the survey, then the provisional accuracy supersedes the intended accuracy.
4. A variance factor ratio for the new survey combined with network data is computed by the Iterated Almost Unbiased Estimator (IAUE) method (appendix B). If the variance factor ratio is reasonably close to 1.0 (typically less than 1.5), then the survey is considered to check with the network, and the survey is classified with the provisional (or intended) accuracy. If the variance factor ratio is much greater than 1.0 (typically 1.5 or greater), then the survey is considered to not check with the network, and both the survey and network measurements will be scrutinized for the source of the problem.

2.1 Horizontal Control Network Standards

When a horizontal control point is classified with a particular order and class, NGS certifies that the geodetic latitude and longitude of that control point bear a relation of specific accuracy to the coordinates of all other points in the horizontal control network. This relation is expressed as a distance accuracy, 1:a. A distance accuracy is the ratio of the relative positional error of a pair of control points to the horizontal separation of those points.

Table 2.1—Distance accuracy standards

Classification	*Minimum distance accuracy*
First-order	1:100,000
Second-order, class I	1: 50,000
Second-order, class II	1: 20,000
Third-order, class I	1: 10,000
Third-order, class II	1: 5,000

A distance accuracy, 1:a, is computed from a minimally constrained, correctly weighted, least squares adjustment by:

$$a = d/s$$

where

a = distance accuracy denominator

s = propagated standard deviation of distance between survey points obtained from the least squares adjustment

d = distance between survey points

The distance accuracy pertains to all pairs of points (but in practice is computed for a sampling of pairs of points). The worst distance accuracy (smallest denominator) is taken as the provisional accuracy. If this is substantially larger or smaller than the intended accuracy, then the provisional accuracy takes precedence.

As a test for systematic errors, the variance factor ratio of the new survey is computed by the Iterated Almost Unbiased Estimator (IAUE) method described in appendix B. This computation combines the new survey measurements with existing network data, which are assumed to be correctly weighted and free of systematic error. If the variance factor ratio is substantially greater than unity then the survey does not check with the network, and both the survey and the network data will be examined by NGS.

Computer simulations performed by NGS have shown that a variance factor ratio greater than 1.5 typically indicates systematic errors between the survey and the network. Setting a cutoff value higher than this could allow undetected systematic error to propagate into the national network. On the other hand, a higher cutoff value might be considered if the survey has only a small number of connections to the network, because this circumstance would tend to increase the variance factor ratio.

In some situations, a survey has been designed in which different sections provide different orders of control. For these multi-order surveys, the computed distance accuracy denominators should be grouped into sets appropriate to the different parts of the survey. Then, the smallest value of a in each set is used to classify the control points of that portion, as discussed above. If there are sufficient connections to the network, several variance factor ratios, one for each section of the survey, should be computed.

Horizontal Example

Suppose a survey with an intended accuracy of first-order (1:100,000) has been performed. A series of propagated distance accuracies from a minimally constrained adjustment is now computed.

Line	*s* *(m)*	*d* *(m)*	*1:a*
1-2	0.141	17,107	1:121,326
1-3	0.170	20,123	1:118,371
2-3	0.164	15,505	1: 94,543
...	.	.	.
...	.	.	.
...	.	.	.

Suppose that the worst distance accuracy is 1:94,543. This is not substantially different from the intended accuracy of 1:100,000, which would therefore have precedence for classification. It is not feasible to precisely quantify "substantially different." Judgment and experience are determining factors.

Now assume that a solution combining survey and network data has been obtained (as per appendix B), and that a variance factor ratio of 1.2 was computed for the survey. This would be reasonably close to unity, and would indicate that the survey checks with the network. The survey would then be classified as first-order using the intended accuracy of 1:100,000.

However, if a variance factor of, say, 1.9 was computed, the survey would not check with the network. Both the survey and network measurements then would have to be scrutinized to find the problem.

Monumentation

Control points should be part of the National Geodetic Horizontal Network only if they possess permanence, horizontal stability with respect to the Earth's crust, and a horizontal location which can be defined as a point. A 30-centimeter-long wooden stake driven into the ground, for example, would lack both permanence and horizontal stability. A mountain peak is difficult to define as a point. Typically, corrosion resistant metal disks set in a large concrete mass have the necessary qualities. First-order and second-order, class I, control points should have an underground mark, at least two monumented reference marks at right angles to one another, and at least one monumented azimuth mark no less than 400 m from the control point. Replacement of a temporary mark by a more permanent mark is not acceptable unless the two marks are connected in timely fashion by survey observations of sufficient accuracy. Detailed information may be found in C&GS *Special Publication* 247, "Manual of geodetic triangulation."

2.2 Vertical Control Network Standards

When a vertical control point is classified with a particular order and class, NGS certifies that the orthometric elevation at that point bears a relation of specific accuracy to the elevations of all other points in the vertical control network. That relation is expressed as an elevation difference accuracy, b. An elevation difference accuracy is the relative elevation error between a pair of control points that is scaled by the square root of their horizontal separation traced along existing level routes.

Table 2.2—Elevation accuracy standards

Classification	*Maximum elevation difference accuracy*
First-order, class I	0.5
First-order, class II	0.7
Second-order, class I	1.0
Second-order, class II	1.3
Third-order	2.0

An elevation difference accuracy, b, is computed from a minimally constrained, correctly weighted, least squares adjustment by

$$b = S/\sqrt{d}$$

where

d = approximate horizontal distance in kilometers between control point positions traced along existing level routes.

S = propagated standard deviation of elevation difference in millimeters between survey control points obtained from the least squares adjustment. Note that the units of b are $(mm)/\sqrt{(km)}$.

The elevation difference accuracy pertains to all pairs of points (but in practice is computed for a sample). The worst elevation difference accuracy (largest value) is taken as the provisional accuracy. If this is substantially larger or smaller than the intended accuracy, then the provisional accuracy takes precedence.

As a test for systematic errors, the variance factor ratio of the new survey is computed by the Iterated Almost Unbiased Estimator (IAUE) method described in appendix B. This computation combines the new survey measurements with existing network data, which are assumed to be correctly weighted and free of systematic error. If the variance factor ratio is substantially greater than unity, then the survey does not check with the network, and both the survey and the network data will be examined by NGS.

Computer simulations performed by NGS have shown that a variance factor ratio greater than 1.5 typically indicates systematic errors between the survey and the network. Setting a cutoff value higher than this could allow undetected systematic error to propagate into the national network. On the other hand, a higher cutoff value might be considered if the survey has only a small number of connections to the network, because this circumstance would tend to increase the variance factor ratio.

In some situations, a survey has been designed in which different sections provide different orders of control. For these multi-order surveys, the computed elevation difference accuracies should be grouped into sets appropriate to the different parts of the survey. Then, the largest value of b in each set is used to classify the control points of that portion, as discussed above. If there are sufficient connections to the network, several variance factor ratios, one for each section of the survey, should be computed.

Vertical Example

Suppose a survey with an intended accuracy of second-order, class II has been performed. A series of propagated elevation difference accuracies from a minimally constrained adjustment is now computed.

Line	*S (mm)*	*d (km)*	*b (mm)/√(km)*
1-2	1.574	1.718	1.20
1-3	1.743	2.321	1.14
2-3	2.647	4.039	1.32
...	.	.	.
...	.	.	.
...	.	.	.

Suppose that the worst elevation difference accuracy is 1.32. This is not substantially different from the intended accuracy of 1.3 which would therefore have precedence for classification. It is not feasible to precisely quantify "substantially different." Judgment and experience are determining factors.

Now assume that a solution combining survey and network data has been obtained (as per appendix B), and that a variance factor ratio of 1.2 was computed for the survey. This would be reasonably close to unity and would indicate that the survey checks with the network. The survey would then be classified as second-order, class II, using the intended accuracy of 1.3.

However, if a survey variance factor ratio of, say, 1.9 was computed, the survey would not check with the network. Both the survey and network measurements then would have to be scrutinized to find the problem.

Monumentation

Control points should be part of the National Geodetic Vertical Network only if they possess permanence, vertical stability with respect to the Earth's crust, and a vertical location that can be defined as a point. A 30-centimeter-long wooden stake driven into the ground, for example, would lack both permanence and vertical stability. A rooftop lacks stability and is difficult to define as a point. Typically, corrosion resistant metal disks set in large rock outcrops or long metal rods driven deep into the ground have the necessary qualities. Replacement of a temporary mark by a more permanent mark is not acceptable unless the two marks are connected in timely fashion by survey observations of sufficient accuracy. Detailed information may be found in *NOAA Manual NOS NGS* 1, "Geodetic bench marks."

2.3 Gravity Control Network Standards

When a gravity control point is classified with a particular order and class, NGS certifies that the gravity value at that control point possesses a specific accuracy.

Gravity is commonly expressed in units of milligals (mGal) or microgals (μGal) equal, respectively, to (10^{-5}) meters/sec^2, and (10^{-8}) meters/sec^2. Classification order refers to measurement accuracies and class to site stability.

Table 2.3—Gravity accuracy standards

Classification	*Gravity accuracy (μGal)*
First-order, class I	20 (subject to stability verification)
First-order, class II	20
Second-order	50
Third-order	100

When a survey establishes only new points, and where only absolute measurements are observed, then each survey point is classified independently. The standard deviation from the mean of measurements observed at that point is corrected by the error budget for noise sources in accordance with the following formula:

$$c^2 = \sum_{i+1}^{n} \frac{(x_i - x_m)^2}{n - 1} + e^2$$

where
c = gravity accuracy
x_i = gravity measurement
n = number of measurements

$$x_m = (\sum_{i=1}^{n} x_i)/n$$

e = external random error

The value obtained for c is then compared directly against the gravity accuracy standards table.

When a survey establishes points at which both absolute and relative measurements are made, the absolute determination ordinarily takes precedence and the point is classified accordingly. (However, see Example D below for an exception.)

When a survey establishes points where only relative measurements are observed, and where the survey is tied to the National Geodetic Gravity Network, then the gravity accuracy is identified with the propagated gravity standard deviation from a minimally constrained, correctly weighted, least squares adjustment.

The worst gravity accuracy of all the points in the survey is taken as the provisional accuracy. If the provisional accuracy exceeds the gravity accuracy limit set for the intended survey classification, then the survey is classified using the provisional accuracy.

As a test for systematic errors, the variance factor ratio of the new survey is computed by the Iterated Almost Unbiased Estimator (IAUE) method described in appendix B. This computation combines the new survey measurements with existing network data which are assumed to be correctly weighted and free of systematic error. If the variance factor ratio is substantially greater than unity, then the survey does not check with the network, and both the survey and the network data will be examined by NGS.

Computer simulations performed by NGS have shown that a variance factor ratio greater than 1.5 typically indicates systematic errors between the survey and the network. Setting a cutoff value higher than this could allow undetected systematic error to propagate into the national network. On the other hand, a higher cutoff value might be considered if the survey has only a minimal number of connections to the network, because this circumstance would tend to increase the variance factor ratio.

In some situations, a survey has been designed in which different sections provide different orders of control. For these multi-order surveys, the computed gravity accuracies should be grouped into sets appropriate to the different parts of the survey. Then, the largest value of c in each set is used to classify the control points of that portion, as discussed above. If there are sufficient connections to the network, several variance factor ratios, one for each part of the survey, should be computed.

Gravity Examples

Example A. Suppose a gravity survey using absolute measurement techniques has been performed. These points are then unrelated. Consider one of these survey points.

Assume $n = 750$

$$\sum_{i=1}^{750} (x_i - x_m)^2 = .169 \text{ mGal}^2$$

$$e = 5\ \mu\text{Gal}$$

$$c^2 = \frac{0.169}{750-1} + (.005)^2$$

$$c = 16\ \mu\text{Gal}$$

The point is then classified as first-order, class II.

Example B. Suppose a relative gravity survey with an intended accuracy of second-order (50 μGal) has been performed. A series of propagated gravity accuracies from a minimally constrained adjustment is now computed.

Station	*Gravity standard deviation (μGal)*
1	38
2	44
3	55
.	.
.	.
.	.

Suppose that the worst gravity accuracy was 55 μGal. This is worse than the intended accuracy of 50 μGal. Therefore, the provisional accuracy of 55 μGal would have precedence for classification, which would be set to third-order.

Now assume that a solution combining survey and network data has been obtained (as per appendix B) and that a variance factor of 1.2 was computed for the survey. This would be reasonably close to unity, and would indicate that the survey checks with the network. The survey would then be classified as third-order using the provisional accuracy of 55 μGal.

However, if a variance factor of, say, 1.9 was computed, the survey would not check with the network. Both the survey and network measurements then would have to be scrutinized to find the problem.

Example C. Suppose a survey consisting of both absolute and relative measurements has been made at the same points. Assume the absolute observation at one of the points yielded a classification of first-order, class II, whereas the relative measurements produced a value to second-order standards. The point in question would be classified as first-order, class II, in accordance with the absolute observation.

Example D. Suppose we have a survey similar to Case C, where the absolute measurements at a particular point yielded a third-order classification due to an unusually noisy observation session, but the relative measurements still satisfied the second-order standard. The point in question would be classified as second-order, in accordance with the relative measurements.

Monumentation

Control points should be part of the National Geodetic Gravity Network only if they possess permanence, horizontal and vertical stability with respect to the Earth's crust, and a horizontal and vertical location which can be defined as a point. For all orders of accuracy, the mark should be imbedded in a stable platform such as flat, horizontal concrete. For first-order, class I stations, the platform should be imbedded in stable, hard rock, and checked at least twice for the first year to ensure stability. For first-order, class II stations, the platform should be located in an extremely stable environment, such as the concrete floor of a mature structure. For second and third-order stations, standard bench mark monumentation is adequate. Replacement of a temporary mark by a more permanent mark is not acceptable unless the two marks are connected in timely fashion by survey observations of sufficient accuracy. Detailed information is given in *NOAA Manual NOS NGS* 1, "Geodetic bench marks." Monuments should not be near sources of electromagnetic interference.

It is recommended, but not necessary, to monument third-order stations. However, the location associated with the gravity value should be recoverable, based upon the station description.

3. Specifications

3.1 Introduction

All measurement systems regardless of their nature have certain common qualities. Because of this, the measurement system specifications follow a prescribed structure as outlined below. These specifications describe the important components and state permissible tolerances used in a general context of accurate surveying methods. The user is cautioned that these specifications are not substitutes for manuals that detail recommended field operations and procedures.

The observations will have spatial or temporal relationships with one another as given in the "Network Geometry" section. In addition, this section specifies the frequency of incorporation of old control into the survey. Computer simulations could be performed instead of following the "Network Geometry" and "Field Procedures" specifications. However, the user should consult the National Geodetic Survey before undertaking such a departure from the specifications.

The "Instrumentation" section describes the types and characteristics of the instruments used to make observations. An instrument must be able to attain the precision requirements given in "Field Procedures."

The section "Calibration Procedures" specifies the nature and frequency of instrument calibration. An instrument must be calibrated whenever it has been damaged or repaired.

The "Field Procedures" section specifies particular rules and limits to be met while following an appropriate method of observation. For a detailed account of how to perform observations, the user should consult the appropriate manuals.

Since NGS will perform the computations described under "Office Procedures," it is not necessary for the user to do them. However, these computations provide valuable checks on the survey measurements that could indicate the need for some reobservations. This section specifies commonly applied corrections to observations, and computations which monitor the precision and accuracy of the survey. It also discusses the correctly weighted, minimally constrained least squares adjustment used to ensure that the survey work is free from blunders and able to achieve the intended accuracy. Results of the least squares adjustment are used in the quality control and accuracy classification procedures. The adjustment performed by NGS will use models of error sources, such as crustal motion, when they are judged to be significant to the level of accuracy of the survey.

3.2 Triangulation

Triangulation is a measurement system comprised of joined or overlapping triangles of angular observations supported by occasional distance and astronomic observations. Triangulation is used to extend horizontal control.

Network Geometry

Order *Class*	*First*	*Second* *I*	*Second* *II*	*Third* *I*	*Third* *II*
Station spacing not less than (km)	15	10	5	0.5	0.5
Average minimum distance angle† of figures not less than	40°	35°	30°	30°	25°
Minimum distance angle† of all figures not less than	30°	25°	25°	20°	20°
Base line spacing not more than (triangles)	5	10	12	15	15
Astronomic azimuth spacing not more than (triangles)	8	10	10	12	15

† Distance angle is angle opposite the side through which distance is propagated.

The new survey is required to tie to at least four network control points spaced well apart. These network points must have datum values equivalent to or better than the intended order (and class) of the new survey. For example, in an arc of triangulation, at least two network control points should be occupied at each end of the arc. Whenever the distance between two new unconnected survey points is less than 20 percent of the distance between those points traced along existing or new connections, then a direct connection should be made between those two survey points. In addition, the survey should tie into any sufficiently accurate network control points within the station spacing distance of the survey. These network stations should be occupied and sufficient observations taken to make these stations integral parts of the survey. Nonredundant geodetic connections to the network stations are not considered sufficient ties. Nonredundantly determined stations are not allowed. Control stations should not be determined by intersection or resection methods. Simultaneous reciprocal vertical angles or geodetic leveling are observed along base lines. A base line need not be observed if other base lines of sufficient accuracy were observed within the base line spacing specification in the network, and similarly for astronomic azimuths.

Instrumentation

Only properly maintained theodolites are adequate for observing directions and azimuths for triangulation. Only precisely marked targets, mounted stably on tripods or supported towers, should be employed. The target should have a clearly defined center, resolvable at the minimum control spacing. Optical plummets or collimators are required to ensure that the theodolites and targets are centered over the marks. Microwave-type electronic distance measurement (EDM) equipment is not sufficiently accurate for measuring higher-order base lines.

Order *Class*	*First*	*Second* *I*	*Second* *II*	*Third* *I*	*Third* *II*
Theodolite, least count	0.2"	0.2"	1.0"	1.0"	1.0"

Calibration Procedures

Each year and whenever the difference between direct and reverse readings of the theodolite depart from 180° by more than 30", the instrument should be adjusted for collimation error. Readjustment of the cross hairs and the level bubble should be done whenever their misadjustments affect the instrument reading by the amount of the least count.

All EDM devices and retroreflectors should be serviced regularly and checked frequently over lines of known distances. The National Geodetic Survey has established specific calibration base lines for this purpose. EDM instruments should be calibrated annually, and frequency checks made semiannually.

Field Procedures

Theodolite observations for first-order and second-order, class I surveys may only be made at night. Reciprocal vertical angles should be observed at times of best atmospheric conditions (between noon and late afternoon) for all orders of accuracy. Electronic distance measurements need a record at both ends of the line of wet and dry bulb temperatures to ±1°C, and barometric pressure to ±5 mm of mercury. The theodolite and targets should be centered to within 1 mm over the survey mark or eccentric point.

Order *Class*	*First*	*Second* *I*	*Second* *II*	*Third* *I*	*Third* *II*
Directions					
Number of positions	16	16	8 or 12†	4	2
Standard deviation of mean not to exceed	0.4"	0.5"	0.8"	1.2"	2.0"
Rejection limit from the mean	4"	4"	5"	5"	5"
Reciprocal Vertical Angles (along distance sight path)					
Number of independent observations direct/reverse	3	3	2	2	2
Maximum spread	10"	10"	10"	10"	20"
Maximum time interval between reciprocal angles (hr)	1	1	1	1	1
Astronomic Azimuths					
Observations per night	16	16	16	8	4
Number of nights	2	2	1	1	1
Standard deviation of mean not to exceed	0.45"	0.45"	0.6"	1.0"	1.7"
Rejection limit from the mean	5"	5"	5"	6"	6"
Electro-Optical Distances					
Minimum number of days	2*	2*	1	1	1
Minimum number of measurements/day	2§	2§	2§	1	1
Minimum number of concentric observations/measurement	2	2	1	1	1
Minimum number of offset observations/measurement	2	2	2	1	1
Maximum difference from mean of observations (mm)	40	40	50	60	60
Minimum number of readings/observation (or equivalent)	10	10	10	10	10
Maximum difference from mean of readings (mm)	‡	‡	‡	‡	‡
Infrared Distances					
Minimum number of days	—	2*	1	1	1
Minimum number of measurements	—	2§	2§	1	1
Minimum number of concentric observations/measurement	—	1	1	1	1
Minimum number of offset observations/measurement	—	2	1	1	1
Maximum difference from mean of observations (mm)	—	5	5	10	10
Minimum number of readings/observation (or equivalent)	—	10	10	10	10
Maximum difference from mean of readings (mm)	—	‡	‡	‡	‡
Microwave Distances					
Minimum number of measurements	—	—	—	2	1
Minimum time span between measurements (hr)	—	—	—	8	—

Order Class	First	Second I	Second II	Third I	Third II
Maximum difference between measurements (mm)	—	—	—	100	—
Minimum number of concentric observations/measurement	—	—	—	2**	1**
Maximum difference from mean of observations (mm)	—	—	—	100	150
Minimum number of readings/observation (or equivalent)	—	—	—	20	20
Maximum difference from mean of readings (mm)	—	—	—	‡	‡

† 8 if 0.2", 12 if 1.0" resolution.
* two or more instruments.
§ one measurement at each end of the line.
‡ as specified by manufacturer.
** carried out at both ends of the line.

Measurements of astronomic latitude and longitude are not required in the United States, except perhaps for first-order work, because sufficient information for determining deflections of the vertical exists. Detailed procedures can be found in Hoskinson and Duerksen (1952).

Office Procedures

Order Class	First	Second I	Second II	Third I	Third II
Triangle Closure					
Average not to exceed	1.0"	1.2"	2.0"	3.0"	5.0"
Maximum not to exceed	3"	3"	5"	5"	10"
Side Checks					
Mean absolute correction by side equation not to exceed	0.3"	0.4"	0.6"	0.8"	2.0"

A minimally constrained least squares adjustment will be checked for blunders by examining the normalized residuals. The observation weights will be checked by inspecting the postadjustment estimate of the variance of unit weight. Distance standard errors computed by error propagation in this 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 which account for the following:

semimajor axis of the ellipsoid ....(a = 6378137 m)
reciprocal flattening of the ellipsoid ....(1/f = 298.257222)
mark elevation above mean sea level........................(known to ± 1 m)
geoid heights ....(known to ± 6 m)
deflections of the vertical ....(known to ± 3")
geodesic correction
skew normal correction
height of instrument
height of target
sea level correction
arc correction
geoid height correction
second velocity correction
crustal motion

3.3 Traverse

Traverse is a measurement system comprised of joined distance and theodolite observations supported by occasional astronomic observations. Traverse is used to densify horizontal control.

Network Geometry

Order Class	First	Second I	Second II	Third I	Third II
Station spacing not less than (km)	10	4	2	0.5	0.5
Maximum deviation of main traverse from straight line	20°	20°	25°	30°	40°
Minimum number of bench mark ties	2	2	2	2	2
Bench mark tie spacing not more than (segments)	6	8	10	15	20
Astronomic azimuth spacing not more than (segments)	6	12	20	25	40
Minimum number of network control points	4	3	2	2	2

The new survey is required to tie to a minimum number of network control points spaced well apart. These network points must have datum values equivalent to or better than the intended order (and class) of the new survey. Whenever the distance between two new unconnected survey points is less than 20 percent of the distance between those points traced along existing or new connections, then a direct connection must be made between those two survey points. In addition, the survey should tie into any sufficiently accurate network control points within the station spacing distance of the survey. These ties must include EDM or taped distances. Nonredundant geodetic connections to the network stations are not considered sufficient ties. Nonredundantly determined stations are not allowed. Reciprocal vertical angles or geodetic leveling are observed along all traverse lines.

Instrumentation

Only properly maintained theodolites are adequate for observing directions and azimuths for traverse. Only precisely marked targets, mounted stably on tripods or supported towers, should be employed. The target should have a clearly defined center, resolvable at the minimum control spacing. Optical plummets or collimators are required to ensure that the theodolites and targets are centered over the marks. Microwave-type electronic distance measurement equipment is not sufficiently accurate for measuring first-order traverses.

Order Class	First	Second I	Second II	Third I	Third II
Theodolite, least count	0.2"	1.0"	1.0"	1.0"	1.0"

Calibration Procedures

Each year and whenever the difference between direct and reverse readings of the theodolite depart from 180° by more than 30", the instrument should be adjusted for collimation error. Readjustment of the cross hairs and the level bubble should be done whenever their misadjustments affect the instrument reading by the amount of the least count.

All electronic distance measuring devices and retroreflectors should be serviced regularly and checked frequently over lines of known distances. The National Geodetic Survey has established specific calibration base lines for this purpose. EDM instruments should be calibrated annually, and frequency checks made semiannually.

Field Procedures

Theodolite observations for first-order and second-order, class I surveys may be made only at night. Electronic distance measurements need a record at both ends of the line of wet and dry bulb temperatures to ±1°C and barometric pressure to ±5 mm of mercury. The theodolite, EDM, and targets should be centered to within 1 mm over the survey mark or eccentric point.

Order Class	First	Second I	Second II	Third I	Third II
Directions					
Number of positions	16	8 or 12†	6 or 8*	4	2
Standard deviation of mean not to exceed	0.4"	0.5"	0.8"	1.2"	2.0"
Rejection limit from the mean	4"	5"	5"	5"	5"
Reciprocal Vertical Angles (along distance sight path)					
Number of independent observations direct/reverse	3	3	2	2	2
Maximum spread	10"	10"	10"	10"	20"
Maximum time interval between reciprocal angles (hr)	1	1	1	1	1
Astronomic Azimuths					
Observations per night	16	16	12	8	4
Number of nights	2	2	1	1	1
Standard deviation of mean not to exceed	0.45"	0.45"	0.6"	1.0"	1.7"
Rejection limit from the mean	5"	5"	5"	6"	6"
Electro-Optical Distances					
Minimum number of measurements	1	1	1	1	1
Minimum number of concentric observations/measurement	1	1	1	1	1
Minimum number of offset observations/measurement	1	1	—	—	—
Maximum difference from mean of observations (mm)	60	60	—	—	—
Minimum number of readings/observation (or equivalent)	10	10	10	10	10
Maximum difference from mean of readings (mm)	§	§	§	§	§
Infrared Distances					
Minimum number of measurements	1	1	1	1	1
Minimum number of concentric observations/measurement	1	1	1	1	1
Minimum number of offset observations/measurement	1	1	1‡	—	—
Maximum difference from mean of observations (mm)	10	10	10‡	—	—
Minimum number of readings/observation	10	10	10	10	10
Maximum difference from mean of readings (mm)	§	§	§	§	§
Microwave Distances					
Minimum number of measurements	—	1	1	1	1
Minimum number of concentric observations/measurement	—	2**	1**	1**	1**
Maximum difference from mean of observations (mm)	—	150	150	200	200
Minimum number of readings/observation	—	20	20	10	10
Maximum difference from mean of readings (mm)	—	§	§	§	§

† 8 if 0.2", 12 if 1.0" resolution.
* 6 if 0.2", 8 if 1.0" resolution.
§ as specified by manufacturer.
‡ only if decimal reading near 0 or high 9's.
** carried out at both ends of the line.

Measurements of astronomic latitude and longitude are not required in the United States, except perhaps for first-order work, because sufficient information for determining deflections of the vertical exists. Detailed procedures can be found in Hoskinson and Duerksen (1952).

Office Procedures

Order Class	First	Second I	Second II	Third I	Third II
Azimuth closure at azimuth check point (seconds of arc)	$1.7\sqrt{N}$	$3.0\sqrt{N}$	$4.5\sqrt{N}$	$10.0\sqrt{N}$	$12.0\sqrt{N}$
Position closure after azimuth adjustment†	$0.04\sqrt{K}$ or 1:100,000	$0.08\sqrt{K}$ or 1:50,000	$0.20\sqrt{K}$ or 1:20,000	$0.40\sqrt{K}$ or 1:10,000	$0.80\sqrt{K}$ or 1:5,000

(N is number of segments, K is route distance in km)

† The expression containing the square root is designed for longer lines where higher proportional accuracy is required. Use the formula that gives the smallest permissible closure. The closure (e.g., 1:100,000) is obtained by computing the difference between the computed and fixed values, and dividing this difference by K.
Note: Do not confuse closure with distance accuracy of the survey.

A minimally constrained least squares adjustment will be checked for blunders by examining the normalized residuals. The observation weights will be checked by inspecting the postadjustment estimate of the variance of unit weight. Distance 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 which account for the following:

semimajor axis of the ellipsoid	(a = 6378137 m)
reciprocal flattening of the ellipsoid	(1/f = 298.257222)
mark elevation above mean sea level	(known to ± 1 m)
geoid heights	(known to ± 6 m)
deflections of the vertical	(known to ± 3")
geodesic correction	
skew normal correction	
height of instrument	
height of target	
sea level correction	
arc correction	
geoid height correction	
second velocity correction	
crustal motion	

3.4 Inertial Surveying

Inertial surveying is a measurement system comprised of lines, or a grid, of Inertial Surveying System (ISS) observations. These specifications cover use of inertial systems only for horizontal control.

Network Geometry

Order / *Class*	*Second* *I*	*Second* *II*	*Third* *I*	*Third* *II*
Station spacing not less than (km)	10	4	2	1
Maximum deviation from straight line connecting endpoints	20°	25°	30°	35°

Each inertial survey line is required to tie into a minimum of four horizontal network control points spaced well apart and should begin and end at network control points. These network control points must have horizontal datum values better than the intended order (and class) of the new survey. Whenever the shortest distance between two new unconnected survey points is less than 20 percent of the distance between those points traced along existing or new connections, then a direct connection should be made between those two survey points. In addition, the survey should connect to any sufficiently accurate network control points within the distance specified by the station spacing. The connections may be measured by EDM or tape traverse, or by another ISS line. If an ISS line is used, then these lines should follow the same specifications as all other ISS lines in the survey.

For extended area surveys by ISS, a grid of intersecting lines that satisfies the 20 percent rule stated above can be designed. There must be a mark at each intersection of the lines. This mark need not be a permanent monument; it may be a stake driven into the ground. For a position to receive an accuracy classification, it must be permanently monumented.

A grid of intersecting lines should contain a minimum of eight network points, and should have a network control point at each corner. The remaining network control points may be distributed about the interior or the periphery of the grid. However, there should be at least one network control point at an intersection of the grid lines near the center of the grid. If the required network points are not available, then they should be established by some other measurement system. Again, the horizontal datum values of these network control points must have an order (and class) better than the intended order (and class) of the new survey.

Instrumentation

ISS equipment falls into two types: analytic (or strapdown) and semianalytic. Analytic inertial units are not considered to possess geodetic accuracy. Semianalytic units are either "space stable" or "local level." Space stable systems maintain the orientation of the platform with respect to inertial space. Local level systems continuously torque the accelerometers to account for Earth rotation and movement of the inertial unit, and also torque the platform to coincide with the local level. This may be done on command at a coordinate update, or whenever the unit achieves zero velocity (Zero velocity UPdaTe, or "ZUPT"). Independently of the measurement technique, the recorded data may be filtered by an onboard computer. Because of the variable quality of individual ISS instruments, the user should test an instrument with existing geodetic control beforehand.

An offset measurement device accurate to within 5 mm should be affixed to the inertial unit or the vehicle.

Calibration Procedures

A static calibration should be performed yearly and immediately after repairs affecting the platform, gyroscopes, or accelerometers.

A dynamic or field calibration should be performed prior to each project or subsequent to a static calibration. The dynamic calibration should be performed only between horizontal control points of first-order accuracy and in each cardinal direction. The accelerometer scale factors from this calibration should be recorded and, if possible, stored in the onboard computer of the inertial unit.

Before each project or after repairs affecting the offset measurement device or the inertial unit, the relation between the center of the inertial unit and the zero point of the offset measurement device should be established.

Field Procedures

When surveying in a helicopter, the helicopter must come to rest on the ground for all ZUPT's and all measurements.

Order Class	Second I	Second II	Third I	Third II
Minimum number of complete runs per line	2	1	1	1
Maximum deviation from a uniform rate of travel (including ZUPT)	15%	20%	25%	30%
Maximum ZUPT interval (ZUPT to ZUPT) (sec)	200	240	300	300

A complete ISS measurement consists of measurement of the line while traveling in one direction, followed by measurement of the same line while traveling in the reverse direction (double-run). A coordinate update should not be performed at the far point or at midpoints of a line, even though those coordinates may be known.

The mark offset should be measured to the nearest 5 mm.

Office Procedures

Order Class	Second I	Second II	Third I	Third II
Maximum difference of smoothed coordinates between forward and reverse run (cm)	60	60	70	80

A minimally constrained least squares adjustment of the raw or filtered survey data will be checked for blunders by examining the normalized residuals. The observation weights will be checked by inspecting the postadjustment estimate of the variance of unit weight. Distance standard errors computed by error propagation in this 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 the best available model for the particular inertial system. Weighted averages of individually smoothed lines are not considered substitutes for a combined least squares adjustment to achieve geodetic accuracy.

3.5 Geodetic Leveling

Geodetic leveling is a measurement system comprised of elevation differences observed between nearby rods. 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	100	50	50 (double-run) 25 (single-run)	25 10

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 check connections to a minimum of six bench marks, three at each end. All other surveys require a minimum of four check connections, two at each end. "Check connection" means that the observed elevation difference agrees with the 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 control. At least one extra connection should always be made.

Distance, survey to network	Maximum spacing of extra connections (km)
0.5 km or less	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"	0.25"	0.50"	0.50"	1.00"
Leveling rod construction	IDS	IDS	IDS† or ISS	ISS	Wood or Metal
Instrument and rod resolution (combined)					
Least count (mm)	0.1	0.1	0.5-1.0*	1.0	1.0

(IDS—Invar, double scale)
(ISS—Invar, single scale)
† if optional micrometer is used.
* 1.0 mm if 3-wire method, 0.5 mm if optical micrometer.

Only a compensator or tilting leveling instrument with an optical micrometer should be used for first-order leveling. Leveling rods should be one piece. Wooden or metal rods may be employed only for third-order work. 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.

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
Maximum angular difference between two lines of sight, reversible compensator	40"	40"	40"	40"	60"
Leveling rod					
Minimum scale calibration standard	N	N	N	M	M
Time interval between scale calibrations (yr)	1	1	—	—	—
Leveling rod bubble verticality maintained to within	10'	10'	10'	10'	10'

(N—National standard)
(M—Manufacturer's standard)

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.

Field Procedures

Order *Class*	*First* *I*	*First* *II*	*Second* *I*	*Second* *II*	*Third*
Minimal observation method	micro-meter	micro-meter	micro-meter or 3-wire	3-wire	center wire
Section running	SRDS or DR or SP	SRDS or DR or SP	SRDS or DR† or SP	SRDS or DR*	SRDS or DR§

Field Procedures—Continued

Order *Class*	*First* *I*	*First* *II*	*Second* *I*	*Second* *II*	*Third*
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)	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)	$4\sqrt{E}$	$5\sqrt{E}$	$6\sqrt{E}$	$8\sqrt{E}$	$12\sqrt{E}$
Single-run methods					
Reverse direction of single runs every half day	yes	yes	yes	—	—
Nonreversible compensator leveling instruments					
Off-level/relevel instrument between observing the high and low rod scales	yes	yes	yes	—	—
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
Double scale rods					
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

(SRDS—Single-Run, Double Simultaneous procedure)
(DR—Double-Run)
(SP—SPur, less than 25 km, double-run)
D—shortest length of section (one-way) in km
E—perimeter of loop in km
† Must double-run when using 3-wire method.
* May single-run if line length between network control points is less than 25 km.
§ May single-run if line length between network control points is less than 10 km.

Double-run leveling may always be used, but single-run leveling done with the double simultaneous procedure may be used only where it can be evaluated by loop closures. Rods should 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. 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.

With double scale rods, the following observing sequence should be used:

backsight, low-scale
backsight, stadia
foresight, low-scale
foresight, stadia
off-level/relevel or reverse compensator
foresight, high-scale
backsight, high-scale

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)	$3\sqrt{D}$	$4\sqrt{D}$	$6\sqrt{D}$	$8\sqrt{D}$	$12\sqrt{D}$
Section misclosure not to exceed (mm)	$3\sqrt{E}$	$4\sqrt{E}$	$6\sqrt{E}$	$8\sqrt{E}$	$12\sqrt{E}$
Loop misclosures					
Algebraic sum of all corrected misclosures not to exceed (mm)	$4\sqrt{F}$	$5\sqrt{F}$	$6\sqrt{F}$	$8\sqrt{F}$	$12\sqrt{F}$
Loop misclosure not to exceed (mm)	$4\sqrt{F}$	$5\sqrt{F}$	$6\sqrt{F}$	$8\sqrt{F}$	$12\sqrt{F}$

(D—shortest length of leveling line (one-way) in km)
(E—shortest one-way length of section in km)
(F—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 postadjustment 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 to 6" or vertical temperature difference observations between 0.5 and 2.5 m above the ground
earth tides and magnetic field
collimation error
crustal motion

3.6 Photogrammetry

Photogrammetry is a measurement system comprised of photographs taken by a precise metric camera and measured by a comparator. Photogrammetry is used for densification of horizontal control. The following specifications apply only to analytic methods.

Network Geometry

Order *Class*	*Second* *I*	*Second* *II*	*Third* *I*	*Third* *II*
Forward overlap not less than	66%	66%	60%	60%
Side overlap not less than	66%	66%	20%	20%
Intersecting rays per point not less than (design criteria)	9	8	3	3

The photogrammetric survey should be areal: single strips of photography are not acceptable. The survey should encompass, ideally, a minimum of eight horizontal control points and four vertical points spaced about the perimeter of the survey. In addition, the horizontal control points should be spaced no farther apart than seven air bases. The horizontal control points should have an order (and class) better than the intended order (and class) of the survey. The vertical points need not meet geodetic control standards. If the required control points are not available, then they must be established by some other measurement system.

Instrumentation

Order *Class*	*Second* *I*	*Second* *II*	*Third* *I*	*Third* *II*
Metric Camera				
Maximum warp of platen not more than (μm)	10	10	10	10
Dimensional control not less than	reseau with maximum spacing of 2 cm	8 fiducials	8 fiducials	8 fiducials
Comparator				
Least count (μm)	1	1	1	1

The camera should be of at least the quality of those employed for large-scale mapping. A platen should be included onto which the film must be satisfactorily flattened during exposure. Note that a reseau should be used for second-order, class I surveys.

Calibration Procedures

Order *Class*	*Second* *I*	*Second* *II*	*Third* *I*	*Third* *II*
Metric camera				
Root mean square of calibrated radial distortion not more than (μm)	1	3	3	5

Calibration Procedures—Continued

Order *Class*	*Second* *I*	*Second* *II*	*Third* *I*	*Third* *II*
Root mean square of calibrated decentering distortion not more than (μm)	1	5†	5†	5†
Root mean square of reseau coordinates not more than (μm)	1	1	3	3
Root mean square of fiducial coordinates not more than (μm)	—	1	3	3

† not usually treated separately in camera calibration facilities; manufacturer's certification is satisfactory.

The metric camera should be calibrated every 2 years, and the comparator should be calibrated every 6 months. These instruments should also be calibrated after repair or modifications.

Characteristics of the camera's internal geometry (radial symmetric distortion, decentered lens distortion, principal point and point of symmetry coordinates, and reseau coordinates) should be determined using recognized calibration techniques, like those described in the current edition of the *Manual of Photogrammetry*. These characteristics will be applied as corrections to the measured image coordinates.

Field Procedures

Photogrammetry involves hybrid measurements: a metric camera photographs targets and features in the field, and a comparator measures these photographs in an office environment. Although this section is entitled "Field Procedures," it deals with the actual measurement process and thus includes comparator specifications.

Order *Class*	*Second* *I*	*Second* *II*	*Third* *I*	*Third* *II*
Targets				
Control points targeted	yes	yes	yes	yes
Pass points targeted	yes	yes	optional	optional
Comparator				
Pointings per target not less than	4	3	2	2
Pointings per reseau (or fiducial) not less than	4	3	2	2
Number of different reseau intersections per target not less than	4	—	—	—
Rejection limit from mean of pointings per target (μm)	3	3	3	3

Office Procedures

Order *Class*	*Second* *I*	*Second* *II*	*Third* *I*	*Third* *II*
Root mean square of adjusted photocoordinates not more than (μm)	4	6	8	12

A least squares adjustment of the photocoordinates, constrained by the coordinates of the horizontal and vertical control points, will be checked for blunders by examining the normalized residuals. The observation weights will be checked by inspecting the postadjustment estimate of the variance of unit weight. Distance standard errors computed by error propagation in this 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 incorporate the quantities determined by calibration.

3.7 Satellite Doppler Positioning

Satellite Doppler positioning is a three-dimensional measurement system based on the radio signals of the U.S. Navy Navigational Satellite System (NNSS), commonly referred to as the TRANSIT system. Satellite Doppler positioning is used primarily to establish horizontal control.

The Doppler observations are processed to determine station positions in Cartesian coordinates, which can be transformed to geodetic coordinates (geodetic latitude and longitude and height above reference ellipsoid). There are two methods by which station positions can be derived: point positioning and relative positioning.

Point positioning, for geodetic applications, requires that the processing of the Doppler data be performed with the precise ephemerides that are supplied by the Defense Mapping Agency. In this method, data from a single station is processed to yield the station coordinates.

Relative positioning is possible when two or more receivers are operated together in the survey area. The processing of the Doppler data can be performed in four modes: simultaneous point positioning, translocation, semishort arc, and short arc. The specifications for relative positioning are valid only for data reduced by the semishort or short arc methods. The semishort arc mode allows up to 5 degrees of freedom in the ephemerides; the short arc mode allows 6 or more degrees of freedom. These modes allow the use of the broadcast ephemerides in place of the precise ephemerides.

The specifications quoted in the following sections are based on the experience gained from the analysis of Doppler surveys performed by agencies of the Federal government. Since the data are primarily from surveys performed within the continental United States, the precisions and related specifications may not be appropriate for other areas of the world.

Network Geometry

The order of a Doppler survey is determined by: the spacing between primary Doppler stations, the order of the base network stations from which the primaries are established, and the method of data reduction that is used. The order and class of a survey cannot exceed the lowest order (and class) of the base stations used to establish the survey.

The primary stations should be spaced at regular intervals which meet or exceed the spacing required for the desired accuracy of the survey. The primary stations will carry the same order as the survey.

Supplemental stations may be established in the same survey as the primary stations. The lowest order (and class) of a supplemental station is determined either by its spacing with, or by the order of, the nearest Doppler or other horizontal control station. The processing mode determines the allowable station spacing.

In carrying out a Doppler survey, one should occupy, using the same Doppler equipment and procedures, at least two existing horizontal network (base) stations of order (and class) equivalent to, or better than, the intended order (and class) of the Doppler survey. If the Doppler survey is to be first-order, at least three base stations must be occupied. If relative positioning is to be used, all base station base lines must be directly observed during the survey. Base stations should be selected near the perimeter of the survey, so as to encompass the entire survey.

Stations which have a precise elevation referenced by geodetic leveling to the National Geodetic Vertical Datum (NGVD) are preferred. This will allow geoidal heights to be determined. As many base stations as possible should be tied to the NGVD. If a selection is to be made, those stations should be chosen which span the largest portion of the survey.

If none of the selected base stations is tied to the NGVD, at least two, preferably more, bench marks of the NGVD should be occupied. An attempt should be made to span the entire survey area.

Datum shifts for transformation of point position solutions should be derived from the observations made on the base stations.

The minimum spacing, D, of the Doppler stations may be computed by a formula determined by the processing mode to be employed. This spacing is also used in conjunction with established control, and other Doppler control, to determine the order and class of the supplemental stations.

By using the appropriate formula, tables can be constructed showing station spacing as a function of point or relative one-sigma position precision (s_p or s_r) and desired survey (or station) order.

Point Positioning

$$D = 2\sqrt{2}\, s_p a$$

where

a = denominator of distance accuracy classification standard (e.g., a = 100,000 for first-order standard).

Order	*First*	*Second*	*Second*	*Third*	*Third*
Class		*I*	*II*	*I*	*II*
s_p (cm)			D (km)		
200	566	242	114	56	28
100	283	141	57	28	14
70	200	100	40	20	10
50	141	71	26	14	7

Relative Positioning

$$D = 2\, s_r a$$

where

a = denominator of distance accuracy classification standard (e.g., a = 100,000 for first-order standard).

Order	*First*	*Second*	*Second*	*Third*	*Third*
Class		*I*	*II*	*I*	*II*
s_r (cm)			D (km)		
50	100	50	20	10	5
35	70	35	14	7	4
20	40	20	8	4	2

However, the spacing for relative positioning should not exceed 500 km.

Instrumentation

The receivers should receive the two carrier frequencies transmitted by the NNSS. The receivers should record the Doppler count of the satellite, the receiver clock times, and the signal strength. The integration interval should be approximately 4.6 sec. Typically six or seven of these intervals are accumulated to form a 30-second Doppler count observation. The reference frequency should be stable to within $5.0(10^{-11})$ per 100 sec. The maximum difference from the average receiver delay should not exceed 50 μsec. The best estimate of the mean electrical center of the antenna should be marked. This mark will be the reference point for all height-of-antenna measurements.

Calibration Procedures

Receivers should be calibrated at least once a year, or whenever a modification to the equipment is made. It is desirable to perform a calibration before every project to verify that the equipment is operational. The two-receiver method explained next is preferred and should be used whenever possible.

Two-Receiver Method

The observations are made on a vector base line, of internal accuracy sufficient to serve as a comparison standard, 10 to 50 m in length. The base line should be located in an area free of radio interference in the 150 and 400 MHz frequencies. The procedures found in the table on relative positioning in "Field Procedures" under the 20 cm column heading will be used. The data are reduced by either shortarc or semishort arc methods. The receivers will be considered operational if the differences between the Doppler and the terrestrial base line components do not exceed 40 cm (along any coordinate axis).

Single-Receiver Method

Observations are made on a first-order station using the procedures found in the table on relative positioning in "Field Procedures" under the 50 cm column heading. The data are reduced with the precise ephemerides. The resultant position must agree within 1 m of the network position.

Field Procedures

The following tables of field procedures are valid only for measurements made with the Navy Navigational Satellite System (TRANSIT).

Point Positioning

s_p (precise ephemerides)	50 cm	70 cm	100 cm	200 cm
Max. standard deviation of mean of counts/pass (cm), broadcast ephemerides	25	25	25	25
Period of observation not less than (hr)	48	36	24	12
Number of observed passes not less than†	40	30	15	8
Number of acceptable passes (evaluated by on-site point processing) not less than	30	20	9	4
Minimum number of acceptable passes within each quadrant*	6	4	2	1
Frequency standard warm-up time (hr)				
crystal	48	48	24	24
atomic	1.5	1.5	1.0	1.0
Maximum interval between meteorological observations (hr)	6	§	§	§

† Number of passes refers to those for which the precise ephemerides are available for reduction.

* There should be a nearly equal number of northward and southward passes.

§ each setup, visit and takedown.

Relative positioning

s_r	20 cm	35 cm	50 cm
Maximum standard deviation of mean of counts/pass (cm), broadcast ephemerides	25	25	25
Period of observation not less than (hr)	48	36	24
Number of observed passes not less than†	40	30	15
Number of acceptable passes (evaluated by on-site point position processing) not less than	30	20	9
Minimum number of acceptable passes within each quadrant*	6	4	2
Frequency standard warm-up time (hr)			
crystal	48	48	48
atomic	1.5	1.5	1.5
Maximum interval between meteorological observations (hr)	6	6	§

† Number of observed passes refers to all satellites available for tracking and reduction with the broadcast or precise ephemerides.

* Number of northward and southward passes should be nearly equal.

§ Each setup, visit and takedown.

The antenna should be located where radio interference is minimal for the 150 and 400 MHz frequencies. Medium frequency radar, high voltage power lines, transformers, excessive noise from automotive ignition systems, and high power radio and television transmission antennas should be avoided. The horizon should not be obstructed above 7.5°.

The antenna should not be located near metal structures, or, when on the roof of a building, less than 2 m from the edge. The antenna must be stably located within 1 mm over the station mark for the duration of the observations. The height difference between the mark and the reference point for the antenna phase center should be measured to the nearest millimeter. If an antenna is moved while a pass is in progress, that pass is not acceptable. If moved, the antenna should be relocated within 5 mm of the original antenna height; otherwise the data may have to be processed as if two separate stations were established. In the case of a reoccupation of an existing Doppler station, the antenna should be relocated within 5 mm of the original observing height.

Long-term reference frequency drift should be monitored to ensure it does not exceed the manufacturer's specifications.

Observations of temperature and relative humidity should be collected, if possible, at or near the height of the phase center of the antenna. Observations of wet-bulb and dry-bulb temperature readings should be recorded to the nearest 0.5°C. Barometric readings at the station site should be recorded to the nearest millibar and corrected for difference in height between the antenna and barometer.

Office Procedures

The processing constants and criteria for determining the quality of point and relative positioning results are as follows:

1. For all passes for a given station occupation, the average number of Doppler counts per pass should be at least 20 (before processing).
2. The cutoff angle for both data points and passes should be 7.5°.
3. For a given pass, the maximum allowable rejection of counts, 3 sigma postprocessing, will be 10.
4. Counts rejected (excluding cutoff angle) for a solution should be less than 10 percent.
5. Depending on number of passes and quality of data, the standard deviation of the range residuals for all passes of a solution should range between:
   Point positioning—10 to 20 cm
   Relative positioning—5 to 20 cm

A minimally constrained least squares adjustment will be checked for blunders by examining the normalized residuals. The observation weights will be checked by inspecting the postadjustment estimate of the variance of unit weight. Distance standard errors computed by error propagation between points in this correctly weighted least squares adjustment will indicate the maximum achievable accuracy classification. The formula presented in "Standards" will be used to arrive at the actual classification. The least squares adjustment will use models which account for:

tropospheric scale bias, 10 percent uncertainty
receiver time delay
satellite/receiver frequency offset
precise ephemeris
tropospheric refraction
ionospheric refraction
long-term ephemeris variations
crustal motion

3.8 Absolute Gravimetry

Absolute gravimetry is a measurement system which determines the magnitude of gravity at a station at a specific time. Absolute gravity measurements are used to establish and extend gravity control. Within the context of a geodetic gravity network, as discussed in "Standards," a series of absolute measurements at a control point is in itself sufficient to establish an absolute gravity value for that location.

The value of gravity at a point is time dependent, being subject to dynamic effects in the Earth. The extent of gravimetric stability can be determined only by repeated observations over many years.

Network Geometry

Network geometry cannot by systematized since absolute observations at a specific location are discrete and uncorrelated with other points. In absolute gravimetry, a network may consist of a single point.

A first-order, class I station must possess gravimetric stability, which only repeated measurements can determine. This gravimetric stability should not be confused with the accuracy determined at a specific time. It is possible for a value to be determined very precisely at two different dates and for the values at each of these respective dates to differ. Although the ultimate stability of a point cannot be determined by a single observation session, an attempt should be made to select sites which are believed to be tectonically stable, and sufficiently distant from large bodies of water to minimize ocean tide coastal loading.

The classification of first-order, class I is reserved for network points which have demonstrated long-term stability. To ensure this stability, the point should be reobserved at least twice during the year of establishment and thereafter at sufficient intervals to ensure the continuing stability of the point. The long-term drift should indicate that the value will not change by more than 20 μGal for at least 5 years. A point intended as first-order, class I will initially be classified as first-order, class II until stability during the first year is demonstrated.

Instrumentation

The system currently being used is a ballistic-laser device and is the only one at the current state of technology considered sufficiently accurate for absolute gravity measurements. An absolute instrument measures gravity at a specific elevation above the surface, usually about 1 m. For this reason, the gravity value is referenced to that level. A measurement of the vertical gravity gradient, using a relative gravity meter and a tripod, must be made to transfer the gravity value to ground level. The accuracy of the relative gravimeter must satisfy the gravity gradient specifications found in "Field Procedures."

Calibration Procedures

Ballistic-laser instruments are extremely delicate and each one represents a unique entity with its own characteristics. It is impossible to identify common systematic errors for all instruments. Therefore, the manufacturer's recommendations for individual instrument calibration should be followed rigorously.

To identify any possible bias associated with a particular instrument, comparisons with other absolute devices are strongly recommended whenever possible. Comparisons with previously established first-order, class I network points, as well as first-order, class II network points tied to the class I points, are also useful.

Field Procedures

The following specifications were determined from results of a prototype device built by J. Faller and M. Zumberge (Zumberge, M., "A Portable Apparatus for Absolute Measurements of the Earth's Gravity," Department of Physics, University of Colorado, 1981) and are given merely as a guideline. It is possible that some of these values may be inappropriate for other instruments or models. Therefore, exceptions to these specifications are allowed on a case-by-case basis upon the recommendation of the manufacturer. Deviations from the specifications should be noted upon submission of data for classification.

Order *Class*	*First* *I*	*First* *II*	*Second*	*Third*
Absolute measurement				
Standard deviation of each accepted measurement set not to exceed (μGal)	20	20	50	100
Minimum number of sets/observation	5	5	5	5
Maximum difference of a measurement set from mean of all measurements (μGal)	12	12	37	48
Barometric pressure standard error (mbar)	4	4	—	—
Gradient measurement				
Standard deviation of measurement of vertical gravity gradient at time of observation (μGal/m)	5	5	5	5
Standard deviation of height of instrument above point (mm)	1	1	5	10

Office Procedures

The manufacturer of an absolute gravity instrument usually provides a reduction process which identifies and accounts for error sources and identifiable parameters. This procedure may be sufficient, making further office adjustments unnecessary.

A least squares adjustment will be checked for blunders by examining the normalized residuals. The observation weights will be checked by inspecting the postadjustment estimate of the variance of unit weight. Gravity value standard deviations computed by error propagation in a correctly weighted, least squares adjustment will indicate the provisional accuracy classification. The least squares adjustment, as well as digital filtering techniques and/or sampling, should use models which account for:

atmospheric mass attraction
microseismic activity
instrumental characteristics
lunisolar attraction
elastic and plastic response of the Earth (tidal loading)

3.9 Relative Gravimetry

Relative gravimetry is a measurement system which determines the difference in magnitude of gravity between two stations. Relative gravity measurements are used to extend and densify gravity control.

Network Geometry

A first-order, class I station must possess gravimetric stability, which only repeated measurements can determine. This gravimetric stability should not be confused with the accuracy determined at a specific time. It is possible for a value to be determined very precisely at two different dates, and for the values at each of these respective dates to differ. Although the ultimate stability of a point cannot be determined by a single observation session, an attempt should be made to select sites which are believed to be tectonically stable.

The classification of first-order, class I is reserved for network points that have demonstrated long-term stability. To ensure this stability, the point should be reobserved at least twice during the year of establishment and thereafter at sufficient intervals. The long-term drift should indicate that the value will not change by more than the 20 μGal for at least 5 years. A point intended as first-order, class I will initially be classified as first-order, class II until stability during the first year is demonstrated.

The new survey is required to tie at least two network points, which should have an order (and class) equivalent to or better than the intended order (and class) of the new survey. This is required to check the validity of existing network points as well as to ensure instrument calibration. Users are encouraged to exceed this minimal requirement. However, if one of the network stations is a first-order, class I mark, then that station alone can satisfy the minimum connecting requirement if the intended order of the new survey is less than first-order.

Instrumentation

Regardless of the type of a relative gravimeter, the internal error is of primary concern.

Order *Class*	*First* *I*	*First* *II*	*Second*	*Third*
Minimum instrument internal error (one-sigma), (μGal)	10	10	20	30

The instrument's internal accuracy may be determined by performing a relative survey over a calibration line (see below) and examining the standard deviation of a single reading. This determination should be performed after the instrument is calibrated using the latest calibration information. Thus the internal error is the measure of instrument uncertainty after all possible systematic error sources have been eliminated by calibration.

Calibration Procedures

An instrument should be properly calibrated before a geodetic survey is performed. The most important calibration item is the determination of the mathematical model that relates dial units, voltage, or some other observable to milligals. This may consist only of a scale factor. In other cases the model may demonstrate nonlinearity or periodicity. Most manufacturers provide tables or scale factors with each instrument. Care must be taken to ensure the validity of these data over time.

When performing first-order work, this calibration model should be determined by a combination of bench tests and field measurements. The bench tests are specified by the manufacturer. A field calibration should be performed over existing control points of first-order, class I or II. The entire usable gravimeter range interval should be sampled to ensure an uncertainty of less than 5 μGal. FGCC member agencies have established calibration lines for this specific purpose.

The response of an instrument to air pressure and temperature should be determined. The meter should be adjusted or calibrated for various pressures and temperatures so that the allowable uncertainty from these sources does not exceed the values in the table below.

The manufacturer's recommendations should be followed to ensure that all internal criteria, such as galvanometer sensitivity, long and cross level or tilt sensitivity, and reading line, are within the manufacturer's allowable tolerances.

The response of an instrument due to local orientation should also be determined. Systematic differences may be due to an instrument's sensitivity to local magnetic variations. Manufacturers attempt to limit or negate such a response. However, if a meter displays a variation with respect to orientation, then one must either have the instrument repaired by the manufacturer, or minimize the effect by fixing the orientation of the instrument throughout a survey.

Order Class	First I	First II	Second	Third
Necessary for user to determine calibration model	Yes	Yes	Yes	No
Allowable uncertainty of calibration model (μGal)	5	5	10	15
Allowable uncertainty due to external air temperature changes (μGal)	1	1	3	—
Maximum uncertainty due to external air pressure changes (μGal)	1	1	2	—
Allowable uncertainty due to other factors (μGal)	3	3	5	—

Field Procedures

A relative gravity survey is performed using a sequence of measurements known as a loop sequence. There are three common types: ladder, modified ladder, and line.

The ladder sequence begins and ends at the same network point, with the survey points being observed twice during the sequence: once in forward running and once in backward running. Of course, more than one network point may be present in a ladder sequence.

Order Class	First I	First II	Second	Third
Minimum number of instruments used in survey	2	2	2	1
Recommended number of instruments used in survey	3	3	2	1
Allowable loop sequence	a	a	a,b	a,b,c
Minimum number of readings at each observation/instrument	5	5	2†	1
Standard deviation of consecutive readings (unclamped) from mean* not to exceed (μGal)	2	2	5	—
Monitor external temperature and air pressure	Yes	Yes	No	No
Standard deviation of temperature measurements (°C)	0.1	0.1	—	—
Standard deviation of air pressure measurement (mbar)	1	1	—	—
Standard deviation of height of instrument above point (mm)	1	1	5	10

(a—ladder) (b—modified ladder) (c—line)

† Although two readings are required, only one reading need be recorded.

* corrected for lunisolar attraction.

The modified ladder sequence also begins and ends at the same network point. However, not all the survey points are observed twice during the sequence. Again, more than one network point may be observed in the sequence.

The line sequence begins at a network point and ends at a different network point. A survey point in a line sequence is usually observed only once.

One should always monitor the internal temperature of the instrument to ensure it does not fluctuate beyond the manufacturer's recommended limits. The time of each reading should be recorded to the nearest minute.

Office Procedures

Order	First I	First II	Second	Third
Rejection Limits				
Maximum standard error of a gravity value (μGal)	20	20	50	100
Total allowable instrument uncertainty (μGal)	10	10	20	30
Model Uncertainties				
Uncertainty of atmospheric mass model (μGal)	0.5	0.5	—	—
Uncertainty of lunisolar attraction (μGal)	1	1	5	5
Uncertainty of Earth elastic and plastic response to tidal loading (μGal)	2	2	5	—

A least squares adjustment, constrained by the network configuration and precision of established gravity control, will be checked for blunders by examining the normalized residuals. The observation weights will be checked by inspecting the postadjustment estimate of the variance of unit weight. Gravity 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 which account for:

instrument calibrations
1) conversion factors (linear and higher order)
2) thermal response (if necessary)
3) atmospheric pressure response (if necessary)

instrument drift
1) static
2) dynamic

atmospheric mass attraction (if necessary)

Earth tides
1) lunisolar attraction
2) Earth elastic and plastic response (if necessary)

4. Information

Geodetic control data and cartographic information that pertain to the National Geodetic Control Networks are widely distributed by a component of the National Geodetic Survey, the National Geodetic Information Branch (NGIB). Users of this information include Federal, State, and local agencies, universities, private companies, and individuals. Data are furnished in response to individual orders, or by an automatic mailing service (the mechanism whereby users who maintain active geodetic files automatically receive newly published data for specified areas). Electronic retrieval of data can be carried out directly from the NGS data base by a user.

Geodetic control data for the national networks are primarily published as standard quadrangles of 30′ in latitude by 30′ in longitude. However, in congested areas, the standard quadrangles are 15′ in latitude by 15′ in longitude. In most areas of Alaska, because of the sparseness of control, quadrangle units are 1° in latitude by 1° in longitude. Data are now available in these formats for all horizontal control and approximately 65 percent of the vertical control. The remaining 35 percent are presented in the old formats; i.e., State leveling lines and description booklets. Until the old format data have been converted to the standard quadrangle formats, the vertical control data in the unconverted areas will be available only by complete county coverage. Field data and recently adjusted projects with data in manuscript form are available from NGS upon special request. The National Geodetic Control Networks are cartographically depicted on approximately 850 different control diagrams. NGS provides other related geodetic information: e.g., geoid heights, deflections of the vertical, calibration base lines, gravity values, astronomic positions, horizontal and vertical data for crustal movement studies, satellite-derived positions, UTM coordinates, computer programs, geodetic calculator programs, and reference materials from the NGS data bases.

The NGIB receives data from all NOAA geodetic field operations and mark-recovery programs. In addition, other Federal, State, and local governments, and private organizations contribute survey data from their field operations. These are incorporated into the NGS data base. NOAA has entered into formal agreements with several Federal and State Government agencies whereby NGIB publishes, maintains, and distributes geodetic data received from these organizations. Guidelines and formats have been established to standardize the data for processing and inclusion into the NGS data base. These formats are available to organizations interested in participating in the transfer of their files to NOAA (appendix C).

Upon completion of the geodetic data base management system, information generated from the data base will be automatically revised. A new data output format is being designed for both horizontal and vertical published control information. These formats, which were necessitated by the requirements of the new adjustments of the horizontal and vertical geodetic networks, will be more comprehensive than the present versions.

New micropublishing techniques are being introduced in the form of computer-generated microforms. Some geodetic data are available on magnetic tape, microfilm, and microfiche. These services will be expanded as the automation system is fully implemented. Charges for digital data are determined on the basis of the individual requests, and reflect processing time, materials, and postage. The booklets *Publications of the National Geodetic Survey* and *Products and Services of the National Geodetic Survey* are available from NGIB.

For additional information, write:

Chief, National Geodetic Information
Branch, N/CG17
National Oceanic and Atmospheric Administration
Rockville, MD 20852

To order by telephone:

data: 301-443-8631
publications: 301-443-8316
computer programs or digital data: 301-443-8623

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(Special reference lists also follow appendixes A and B)

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APPENDIX A
Governmental Authority

A.1 Authority

The U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) is responsible for establishing and maintaining the basic national horizontal, vertical, and gravity geodetic control networks to meet the needs of the Nation. Within NOAA this task is assigned to the National Geodetic Survey, a Division of the Office of Charting and Geodetic Services within the National Ocean Service. This responsibility has evolved from legislation dating back to the Act of February 10, 1807 (2 Stat. 413, which created the first scientific Federal agency, known as the "Survey of the Coast." Current authority is contained in United States Code, Title 33, USC 883a, as amended, and specifically defined by Executive Directive, Bureau of the Budget (now the Office of Management and Budget) Circular No. A-16, Revised (Bureau of the Budget 1967).

To coordinate national mapping, charting, and surveying activities, the Board of Surveys and Maps of the Federal Government was formed December 30, 1919, by Executive Order No. 3206. "Specifications for Horizontal and Vertical Control" were agreed upon by Federal surveying and mapping agencies and approved by the Board on May 9, 1933. When the Board was abolished March 10, 1942, its functions were transferred to the Bureau of the Budget, now the Office of Management and Budget, by Executive Order No. 9094. The basic survey specifications continued in effect. Bureau of the Budget Circular No. A-16, published January 16, 1953, and revised May 6, 1967 (Bureau of the Budget 1967), provides for the coordination of Federal surveying and mapping activities. "Classification and Standards of Accuracy of Geodetic Control Surveys," published March 1, 1957, replaced the 1933 specifications. Exhibit C to Circular A-16, dated October 10, 1958 (Bureau of the Budget 1958), established procedures for the required coordination of Federal geodetic and control surveys performed in accordance with the Bureau of the Budget classifications and standards.

The Federal Geodetic Control Committee (FGCC) was chartered December 11, 1968, and a Federal Coordinator for Geodetic Control and Related Surveys was appointed April 4, 1969. The FGCC Circular No. 1, "Exchange of Information," dated October 16, 1972, prescribes reporting procedures for the committee (vice Exhibit C of Circular A-16) (Federal Geodetic Control Committee 1972).

The Federal Coordinator for Geodetic Control and Related Surveys, Department of Commerce, is responsible for coordinating, planning, and executing national geodetic control surveys and related survey activities of Federal agencies, financed in whole or in part by Federal funds. The Executive Directive (Bureau of the Budget 1967: p. 2) states:

(1) The geodetic control needs of Government agencies and the public at large are met in the most expeditious and economical manner possible with available resources; and
(2) all surveying activities financed in whole or in part by Federal funds contribute to the National Networks of Geodetic Control when it is practicable and economical to do so.

The Federal Geodetic Control Committee assists and advises the Federal Coordinator for Geodetic Control and Related Surveys.

A.2 References

Bureau of the Budget, 1967: Coordination of surveying and mapping activities. *Circular* No. A-16, Revised, May 6, 3 pp. Executive Office of the President, Bureau of the Budget (now Office of Management and Budget), Washington, D.C. 20503.

Bureau of the Budget, 1958: Programing and coordination of geodetic control surveys. *Transmittal Memorandum* No. 2, 1 p., and Exhibit C of *Circular* No. A-16, 4 pp. Executive Office of the President, Bureau of the Budget (now Office of Management and Budget), Washington, D.C. 20503.

Federal Geodetic Control Committee, 1972: Exchange of Information. *Circular* No. 1, Federal Geodetic Control Committee, October 16, 6 pp.

APPENDIX B
Variance Factor Estimation

B.1 Introduction

The classification accuracies for the National Geodetic Control Networks measure how well a survey can provide position, elevation, and gravity. (More specifically, a distance accuracy is used for horizontal networks, and an elevation difference accuracy is used for vertical networks.) The interpretation of what is meant by "how well" contains two parts. A survey must be precise, i.e., fairly free of random error; it must also be accurate, i.e., relatively free of systematic error. This leads to a natural question of how to test for random and systematic error.

Testing for random error is an extremely broad subject, and is not examined here. It is assumed that the standard deviation of distance, elevation difference, or gravity provides an adequate basis to describe the amount of random error in a survey. Further, it is assumed that the selection of the worst instance of the classification accuracy computed at all points (or between all pairs of points) provides a satisfactory means of classifying a new survey. This procedure may seem harsh, but it allows the user of geodetic control to rely better upon a minimum quality of survey work. The nominal quality of a survey could be much higher.

Consider the method of observation equations (see Mikhail (1976) for a general discussion):

$$L_a = F(X_a)$$

where
L_a is a vector of computed values for the observations of dimension n,
X_a is a vector of coordinate and model parameters of dimension u, and
F is a vector of functions that describes the observations in terms of the parameters.

The design matrix, A, is defined as

$$A = \left.\frac{\partial F}{\partial X_a}\right|_{X_a = X_o}$$

where A is a matrix of differential changes in the observation model F with respect to the parameters, X_a, evaluated at a particular set of parameter values, X_o. A vector of observation misclosures is

$$L = L_b - L_a$$

where L_b is the vector of actual observations and L_a is the vector described above.

Associated with the observation vector L_b is a symmetric variance-covariance matrix Σ_{L_b}, which contains information on observation precision and correlation.

The observation equation may now be written in linearized form

$$AX = L + V$$

where V is a vector of residual errors and X is a vector of corrections to the parameter vector X_a. The least squares estimate of X is

$$X = (A^t(\Sigma_{L_b})^{-1}A)^{-1} A^t(\Sigma_{L_b})^{-1}L$$

where the superscripts ^{t} and $^{-1}$ denote transpose and inverse (of a matrix) respectively.

The estimate provides a new set of values for the parameters by

$$X_a + X \rightarrow X_a$$

If the observation model $F(X_a)$ is nonlinear (that is, A is not constant for any set of X_a), then the entire process, starting with the first equation, must be iterated until the vector X reaches a stationary point.

Once convergence is achieved, L_a, computed from the first equation, is the vector of adjusted observations. The vector of observation residual errors, V, is

$$V = L_a - L_b$$

Estimates of parameter precision and correlations are given by the adjusted parameter variance-covariance matrix, Σ_{X_a} computed by

$$\Sigma_{X_a} = (A^t(\Sigma_{L_b})^{-1}A)^{-1}.$$

The precision of any other quantity that can be derived from the parameters may also be computed. Suppose one wishes to compute a vector of quantities, S,

$$S = S(X_a)$$

from the adjusted parameters, X_a. A geometry matrix, G, is defined as

$$G = \left.\frac{\partial S}{\partial X_a}\right|_{X_a = X_o}$$

where G is a matrix of differential changes in the functions, S, with respect to the parameters, X_a, evaluated at a particular set of parameter values, X_o. By the principle of linear error propagation,

$$\Sigma_S = G\,\Sigma_{X_a} G^t$$

or

$$\Sigma_S = G(A^t(\Sigma_{L_b})^{-1}A)^{-1}\,G^t$$

where Σ_S is the variance-covariance matrix of the computed quantities.

This last equation is important since its terms are variances and covariances such as those for distance or height difference. Use of this equation assumes that the model is not too nonlinear, that the parameter vector X_a has been adequately estimated by the method of least squares, that the design matrix A, the geometry matrix G, and the variance-covariance matrix of the observations Σ_{L_b} are known. This last assumption is the focal point for the remainder of this appendix.

We must somehow estimate the n (n + 1)/2 elements of Σ_L. Usually, we know Σ_L subject to some global variance factor, f. We would then assume that

$$\Sigma_L = f\,\Sigma_L^0$$

where

Σ_L = the "true" variance-covariance matrix of the observations

Σ_L^0 = initial estimate of variance-covariance matrix of the observations

Our assumption about the the structure of Σ_L^0 relative to a single factor usually suffices. But this assumption can be improved if we generalize the idea. Consider a partition of the observations into k homogeneous groups. We now estimate k different local variance factors

$$\Sigma_L = \begin{pmatrix} f_1\Sigma_{L_1}^0 & & & 0 \\ & f_2\Sigma_{L_2}^0 & & \\ & & \ddots & \\ 0 & & & f_k\Sigma_{L_k}^0 \end{pmatrix}$$

As will be discussed later, we may also detect systematic error if one of the variance components is based on certified network observations.

B.2 Global Variance Factor Estimation (k = 1)

The global variance factor, f, is simply the a posteriori variance of unit weight, $\hat{\sigma}_0^2$, when given an a priori variance of unit weight, σ_0^2, equal to 1.

It can be shown that

$$E(V^t(\Sigma_L)^{-1}V) = n - u. \qquad \text{(Mikhail 1976: p. 287)}$$

For a single variance factor

$$\Sigma_L = f\,\Sigma_L^0$$

so that

$$\frac{1}{f}\,\Sigma(V^t(\Sigma_L^0)^{-1}V) = n - u$$

or for f to be unbiased (Hamilton 1964, p. 130)

$$f = \frac{E(V^t(\Sigma_L^0)^{-1}V)}{n - u} = \frac{V^t(\Sigma_L^0)^{-1}V}{n - u}.$$

This is identical to the form $\hat{\sigma}_0^2 = \dfrac{V^tPV}{n-u}$, where P is defined as $\sigma_0^2(\Sigma_L^0)^{-1}$

Since we are given that $\sigma_0^2 = 1$, then $P = (\Sigma_L^0)^{-1}$. Then $f = \hat{\sigma}_0^2$, as we wished to prove.

The derivation assumes that there is no bias in the residuals (Mikhail 1976), i.e.,

$$E(V) = 0.$$

However, outliers, as well as systematic errors, can produce a biased global variance factor. We must be satisfied that the observations contain no blunders, and that our mathematical model is satisfactory in order to use the global variance factor.

Particular types of systematic errors—global scale or orientation errors—are not detectable in a survey adjustment. They will not bias the residuals and will not influence the global variance factor. For example, to detect a global scale error, it must be transformed into a local scale error by addition of more data or measurements that can discriminate between global and local.

B.3 Local Variance Factor Estimation (k = 2,3,...)

Let us separate our observations into k homogeneous groups, and assume that we know the variance-covariance matrices of all k groups, $\Sigma_{L_i}^0$, subject to k local variance factors, f_i. Then

$$\Sigma_l = \begin{pmatrix} f_1\Sigma_{L_1}^0 & & & 0 \\ & f_2\Sigma_{L_2}^0 & & \\ & & \ddots & \\ 0 & & & f_k\Sigma_{L_k}^0 \end{pmatrix}$$

A variety of methods has been proposed that can be used to estimate local variance factors. Among them are MInimum Norm Quadratic Unbiased Estimation (MINQUE) (Rao 1971), Iterated MInimum Norm Quadratic Estimation (IMINQE) (Rao 1972), Almost Unbiased Estimation (AUE) (Horn et al. 1975), and Iterated Almost Unbiased Estimation (IAUE) (Lucas 1984). Underlying these methods is the assumption that there is no bias in any group of residuals; that is

$$E(V_k) = 0.$$

This assumption can be turned to our advantage in the detection of local systematic error.

Consider the partition of observations into a network group, subscript N, and a survey group, subscript S ($k = 2$). Then

$$\Sigma_L = \begin{pmatrix} f_N\Sigma_N^0 & 0 \\ 0 & f_S\Sigma_S^0 \end{pmatrix}$$

For an adjustment of the network only, we may estimate

$$\Sigma_N' = f_N'\Sigma_N^0$$

and for an adjustment of the survey only, we may estimate

$$\Sigma_S' = f_S'\Sigma_S^0$$

where f'_S is the global variance factor of the survey observations computed by a least squares adjustment free of outliers and known systematic errors.

With perfect information and an unbiased model we compute $f_N = f'_N$ and $f_S = f'_S$. On the other hand, if our model is biased, this may not be the case. In other words, we have a linkage between systematic error and consistent estimation of local variance factors.

Now assume that our network observations are certified as having no systematic error, and that we have perfect knowledge of their weights. Then $f'_N = 1$ and $\Sigma_N = \Sigma_N^0$. In the absence of residual bias in the survey, we should compute $f_N = 1$ and $f_S = f'_S$. In fact, we could impose a constraint on the computation, $f_N = 1$, to ensure this result. A survey systematic error could then manifest itself as an increase in f_S over f'_S.

There is no guarantee that systematic error in a survey will increase f_S over f'_S. For example, a survey may be connected to the network at only one control point. A scale error local to the survey would remain undetectable with combined variance factor estimation. With a second connection to the network, the survey scale error will begin to be detectable. As the survey is more closely connected to the network, the capability to detect a survey scale error becomes much better. We see that systematic error in a survey that is well-connected to a certified geodetic network can be discovered by local variance factor estimation. Of course a systematic error, such as a scale factor influencing both the network and the survey, would continue to remain hidden.

B.4 Iterated Almost Unbiased Estimation (IAUE)

The IAUE method (Lucas 1984) can be used to estimate covariance elements as well as the variance elements of Σ_L. However, in testing for systematic error we are concerned only with the survey and the network variance factors ($k = 2$).

As suggested by the title, the method is iterative. We start with the initial values

$$f_S^0 \text{ and } \Sigma_S^0, \text{ with } f_N^0 \text{ set to } 1 \ .$$

Let

$$\Sigma_L^0 = \begin{pmatrix} f_N^0\Sigma_N^0 & 0 \\ 0 & f_S^0\Sigma_S^0 \end{pmatrix}$$

$$P_L^0 = (\Sigma_L^0)^{-1} = \begin{pmatrix} P_N^0 & 0 \\ 0 & P_S^0 \end{pmatrix}$$

We now iterate from $i = 0$ to convergence

1) Perform least squares adjustment for

$$\hat{X} = (A^tP_L^iA)^{-1}A^tP_L^iL \ .$$

2) $\Sigma_{V_S}^i = (P_S^i)^{-1} - A_S(A^tP_L^iA)^{-1}A_S^t \ .$

3) $f_S^{i+1} = \dfrac{(V_S^i)^tP_S^iV_S^i}{tr(\Sigma_{V_S}^iP_S^i)}$

where tr is the trace function.

4) $\Sigma_S^{i+1} = f_S^{i+1}\Sigma_S^i \ .$

We test for convergence by

$$\frac{f_S^{i+1} - f_S^i}{f_S^i} < \epsilon$$

where ϵ is a preset quantity > 0. The local survey variance factor is

$$f_S = \prod_{i=0}^{m} f_S^i$$

where m is the number of iterations to convergence. We can then compute a survey variance factor ratio,

$$f_S/f'_S$$

Computer simulations have shown that when the survey variance factor ratio exceeds 1.5, then the survey contains systematic error. This rule becomes less reliable when a survey is minimally connected to a network.

We note that for k = 1, the third step of the method yields

$$f^{i+1} = \frac{(V'PV)^i}{n - u} .$$

It is immediately recognized as the a posteriori estimate of the variance of unit weight. In this special case, IAUE convergence is correct, immediate, and unbiased.

The IAUE method is particularly attractive from a computational point of view. If Σ_L is diagonal, or nearly so, then the requisite elements of Σ_L may be computed from elements of Σ_X that lie completely within the profile of the normal equations. Thus, the usual apparatus of sparse least squares adjustments can be retained.

B.5 References

Hamilton, Walter Clark, 1964: *Statistics in Physical Science*, The Ronald Press Company, New York.

Horn, S.D., Horn, R.A., and Duncan, D.B., 1975: Estimating heteroscedastic variances in linear models, *Journal of the American Statistical Association*, 70, 380-385.

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Rao, C.R., 1972: Estimation of variance and covariance components in linear models, *Journal of the American Statistical Association*, 67, 112-115.

Rao, C.R., 1971: Estimation of variance and covariance components—MINQUE theory, *Journal of Multivariate Analysis*, 1, 257-275.

APPENDIX C

Procedures for Submitting Data to the National Geodetic Survey

The National Geodetic Survey (NGS) has determined that the value to the national network of geodetic observations performed by other Federal, State, and local organizations compensates for the costs of analyzing, adjusting, and publishing the associated data. Consequently, a procedure has been established for data from horizontal, vertical, and gravity control surveys to be submitted to NGS. Persons submitting data must adhere to the requirements stated herein, but in any event, the final decision of acceptance on data will be the responsibility of the Chief, NGS.

The survey data must be submitted in the format specified in the Federal Geodetic Control Committee (FGCC) publication, *Input Formats and Specifications of the National Geodetic Survey Data Base,* which describes the procedures for submission of data for adjustment and assimilation into the National Geodetic Survey data base. Volume I (Horizontal control data), volume II (Vertical control data) or volume III (Gravity control data) may be purchased from:

National Geodetic Information Branch (N/CG17x2)
National Oceanic and Atmospheric Administration
Rockville, MD 20852

Horizontal control surveys must be accomplished to at least third-order, class I standards and tied to the National Geodetic Horizontal Network. Vertical control surveys must be accomplished in accordance with third-order or higher standards and tied to the National Geodetic Vertical Network. Gravity control surveys must be accomplished to at least second-order standards and tied to the National Geodetic Gravity Network. Third-order gravity surveys ("detail" surveys) will be accepted by NGS for inclusion into the NGS Gravity Working Files only in accordance with the above mentioned FGCC publication. A clear and accurate station description should be provided for all control points.

The original field records (or acceptable copies), including sketches, record books, and project reports, are required. NGS will retain these records in the National Archives. This is necessary if questions arise concerning the surveys on which the adjusted data are based. In lieu of the original notes, high quality photo copies and microfilm are acceptable. The material in the original field books or sheets are needed, not the abstracts or intermediate computations.

Reconnaissance reports should be submitted before beginning the field measurements, describing proposed connections to the national network, the instrumentation, and the field procedures to be used. This will enable NGS to comment on the proposed survey, drawing on the information available in the NGS data base concerning the accuracy and condition of these points, and to determine if the proposed survey can meet its anticipated accuracy. This project review saves the submitting agency the expense of placing data that would fail to meet accuracy criteria into computer-readable form.

2/12/91

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA 22092

In Reply Refer To:
WGS-Mail Stop 510

FEB 05 1991

Dr. D. David Moyer
NGS Geodetic Advisor
610 Walnut Street
1050 WARF Building
Madison, Wisconsin 53705

Dear Dr. Moyer:

Enclosed are 20 copies of the National Map Accuracy Standards that were requested by Nancy von Meyer in our telephone conversation of January 28.

Also enclosed is a copy of the new accuracy standards that are currently under development by the U.S. Geological Survey. The changes and improvements are:

- Applies to both graphic and digital cartographic products.
- Establishes three levels of accuracy, class 1, class 2, and class 3.
- Limits are given in RMS error in each component.
- No relaxation in horizontal accuracy standards for larger scale products.
- Allows sample testing for a product series that were made using similar instruments, procedures, and materials.

The limits for class 1 cartographic products, although stated in different terms, are nearly the same as for the current National Map Accuracy Standards. The new standards probably won't be formally adopted for several years since the approval process involves all Federal agencies that make or utilize cartographic products.

If you have any questions regarding these standards, please contact Bill Chapman (703) 648-4658.

Sincerely yours,

Glenn Osick

for: Joel L. Morrison
Assistant Division Chief for Research
National Mapping Division

Enclosures

United States National Map Accuracy Standards

With a view to the utmost economy and expedition in producing maps which fulfill not only the broad needs for standard or principal maps, but also the reasonable particular needs of individual agencies, standards of accuracy for published maps are defined as follows:

1. **Horizontal accuracy**. For maps on publication scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error by more than 1/30 inch, measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, 1/50 inch. These limits of accuracy shall apply in all cases to positions of well-defined points only. Well-defined points are those that are easily visible or recoverable on the ground, such as the following: monuments or markers, such as bench marks, property boundary monuments; intersections of roads, railroads, etc.; corners of large buildings or structures (or center points of small buildings); etc. In general what is well defined will also be determined by what is plottable on the scale of the map within 1/100 inch. Thus while the intersection of two road or property lines meeting at right angles would come within a sensible interpretation, identification of the intersection of such lines meeting at an acute angle would obviously not be practicable within 1/100 inch. Similarly, features not identifiable upon the ground within close limits are not to be considered as test points within the limits quoted, even though their positions may be scaled closely upon the map. In this class would come timber lines, soil boundaries, etc.
2. **Vertical accuracy**, as applied to contour maps on all publication scales, shall be such that not more than 10 percent of the elevations tested shall be in error more than one-half the contour interval. In checking elevations taken from the map, the apparent vertical error may be decreased by assuming a horizontal displacement within the permissible horizontal error for a map of that scale.
3. **The accuracy of any map may be tested** by comparing the positions of points whose locations or elevations are shown upon it with corresponding positions as determined by surveys of a higher accuracy. Tests shall be made by the producing agency, which shall also determine which of its maps are to be tested, and the extent of such testing.
4. **Published maps meeting these accuracy requirements** shall note this fact on their legends, as follows: "This map complies with National Map Accuracy Standards."
5. **Published maps whose errors exceed those aforestated** shall omit from their legends all mention of standard accuracy.
6. **When a published map is a considerable enlargement** of a map drawing (manuscript) or of a published map, that fact shall be stated in the legend. For example, "This map is an enlargement of a 1:20,000-scale map drawing," or "This map is an enlargement of a 1:24,000-scale published map."
7. **To facilitate ready interchange and use of basic information for map construction** among all Federal mapmaking agencies, manuscript maps and published maps, wherever economically feasible and consistent with the uses to which the map is to be put, shall conform to latitude and longitude boundaries, being 15 minutes of latitude and longitude, or 7.5 minutes, or 3–3/4 minutes in size.

Issued June 10, 1941
Revised April 26, 1943
Revised June 17, 1947

U.S. BUREAU OF THE BUDGET

chapman
usnmac.dft
draft 12/6/90

UNITED STATES NATIONAL CARTOGRAPHIC STANDARDS FOR SPATIAL ACCURACY

(Formerly National Map Accuracy Standards)

These standards concern the definitions of spatial accuracy as they pertain to cartographic data, both digital and graphic, prepared or utilized by Federal agencies.

1. **Horizontal Accuracy.** For cartographic data intended for publication at 1:250,000 scale and larger, the root mean square (rms) error* in either the x or y coordinates will not exceed 0.25 millimeter, measured on the intended publication scale. These limits of accuracy shall apply in all cases to positions of well-defined points.

2. **Vertical Accuracy.** For elevation data, the rms error will not exceed one-third of the intended (planned) contour interval. For purposes of checking elevations, the apparent vertical error at each test point may be reduced by shifting the position in any direction by 0.50 millimeter. Spot elevations shall be given within a limiting rms error of one-sixth of the intended (planned) contour interval.

3. **Accuracy Test.** The accuracy of any cartographic product may be tested by comparing the positions or elevation of points with corresponding positions or elevations as determined by surveys of a higher accuracy. The rms error will be calculated separately for the horizontal (x and y) and/or vertical (z) coordinate tested using all of the test point discrepancies. Tests for compliance of a product are optional. Products may be tested for either horizontal or vertical accuracy or both.

4. **Cartographic Products.** Those products meeting both horizontal and vertical accuracy requirements shall carry the note, "Complies with National Cartographic Standards for Spatial Accuracy". Products failing either the horizontal or vertical accuracy requirements, or both, will display "Complies with National Cartographic Standards for Spatial Accuracy - Class ___ ". The rms errors

for Class 2 products will not exceed 0.50 millimeters in the x or y coordinates and two-thirds of the contour interval in the vertical. All products that exceed those limits will be Class 3.

5. **Product Series.** Sample testing is permitted for determining the class level of a series of one hundred or more cartographic products that were made using similar instruments, procedures, and materials. At least three percent (but not less than 30) products of a series will be tested and the class of the whole series will be based on the results. If 90 percent or more of the sample products meet class 1 standards, then the whole production group can be certified as class 1.

6. **Nonstandard Products.** Those products produced in areas where it is impractical to meet or test for compliance with these standards (e.g. due to dense timber or foliage) will not carry an accuracy statement.

*rms error (x) $= \sqrt{(x_1^2 + x_2^2 + x_3^2 + \ldots x_N^2)/N}$

Where:

x_1 = discrepancy in the x component, test point # 1.

x_N = discrepancy in the x component, test point # N.

N = Total number of test points for the x component.

Public Land Survey Monument Record

Form

The following Administrative Rule is from the Architect, Engineer, Designer and Surveyor Section 7.08 (2) of the Wisconsin Administrative Code and relates to the required form for a public land survey monument record:

A-E 7.08 (2) **Form Required**. A U.S. public land survey monument record shall be prepared on the board-approved form or on a form substantially the same as the board-approved form which includes all the elements required by this section. A form used for this purpose shall be entitled, "U.S. Public Land Survey Monument Record".

In addition to the form following this page, a board-approved from is available from:

Department of Regulation and Licensing
Bureau of Business and Design Professions
1400 East Washington Avenue,
P.O. Box 8935
Madison, Wisconsin 53708

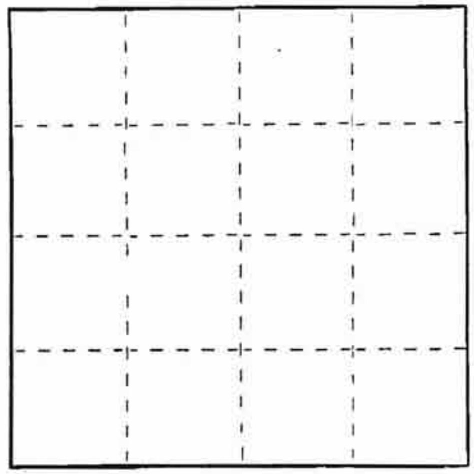
(7\i\adrule)

U. S. PUBLIC LAND SURVEY MONUMENT RECORD

INSTRUCTIONS: This record shall show the location of the corner and shall include all of the following nine elements (a through i).

(a) Identify the corner by reference to the U.S. public land survey system.

○ = Corner monument restored.



(b) Describe any record evidence, monument evidence, occupational evidence, testimonial evidence or any other material evidence you considered, and whether the monument was found or placed.

(c) In the plan view drawing below, provide reference ties to at least 4 witness monuments, or, if the location is within a municipality, to at least 2 witness monuments. (Witness monuments shall be made of concrete, natural stone, iron or other equally durable material.) Describe witness monuments.

(d) Show a plan view drawing depicting the relevant monuments and reference ties which is sufficient in detail to enable accurate relocation of the corner monument if the corner monument is disturbed. Indicate north.

(e) Describe any material discrepancy between the location of the corner as restored or reestablished and the location of that corner as previously restored or reestablished by distance and direction. Show the discrepancy on the plan view drawing under (d), above. Show the distances between the corner as previously restored or reestablished and (1) the corner as restored or reestablished, and (2) to at least 2 of the witness monuments shown on the drawing in (d), above.

(f) Was the corner restored through acceptance of (1) an obliterated evidence location, or, (2) a found perpetuated location?

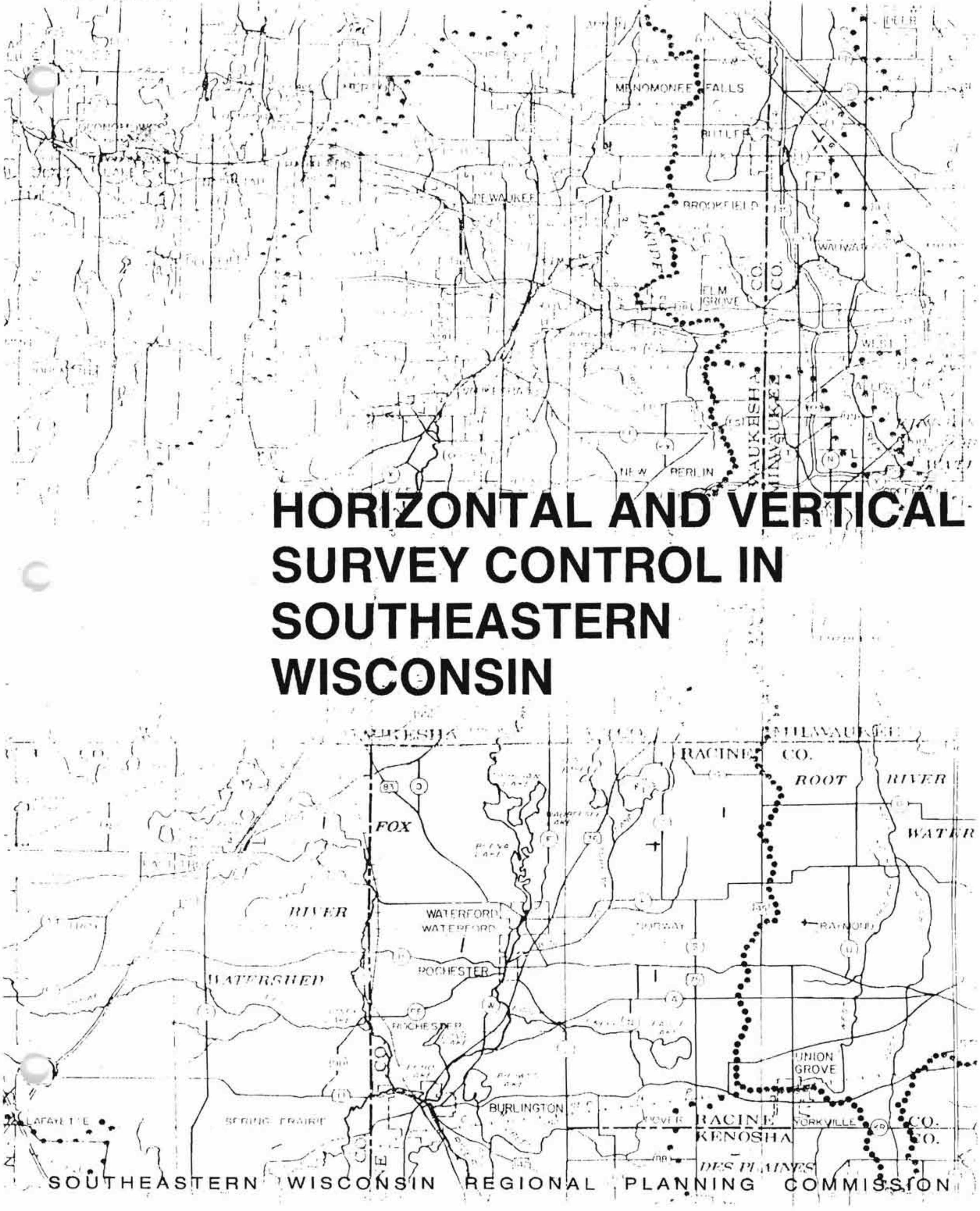
(g&h) Was the corner reestablished through lost corner proportionate methods? If so, show the method, including the directions and distances to other public land survey corners used as evidence or used for proportioning in determining the corner location?

Affix Land Surveyor Seal

(i) I, ______________________________ (type or print name) certify that the corner location shown on this record was determined by me or under my direction and control and that this U.S. Public Land Survey Monument Record is correct and complete to the best of my knowledge and belief.

______________________________ ______________________________
Signature Date

TECHNICAL REPORT NUMBER 7
(2nd Edition)



HORIZONTAL AND VERTICAL SURVEY CONTROL IN SOUTHEASTERN WISCONSIN

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

TECHNICAL REPORT NUMBER 7
SECOND EDITION

HORIZONTAL AND VERTICAL SURVEY CONTROL IN SOUTHEASTERN WISCONSIN

Prepared by the

Southeastern Wisconsin Regional Planning Commission
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Waukesha, Wisconsin 53187-1607

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Appendix A

DETAILED SPECIFICATIONS FOR AERIAL PHOTOGRAPHY, CONTROL SURVEYS, AND TOPOGRAPHIC MAPPING

Appendix A-1

DETAILED SPECIFICATIONS FOR AERIAL PHOTOGRAPHY, CONTROL SURVEYS, AND ONE INCH EQUALS 100 FEET SCALE TRADITIONAL TOPOGRAPHIC MAPPING

I. GENERAL

These specifications set forth the requirements of the __________ for photogrammetric mapping services, including aerial photography, topographic mapping, and accompanying control surveys and control survey monumentation. The Engineer shall furnish all labor, materials, and equipment necessary to complete properly the work specified herein.

II. PHOTOGRAPHY

A. General
The Engineer shall perform the necessary flying and photography to provide photographic coverage of an area approximately _____ square miles in extent shown on the sketch map attached hereto as Exhibit "A." The Engineer may sublet this phase of the work to a qualified and experienced firm specializing in aerial photography. The __________, however, retains the right to approve or reject any or all such firms which the Engineer may wish to engage.

B. Scale
The flight height above the average elevation of the ground shall be such that the negatives will have an average scale of one inch equals five hundred feet (1" = 500'). Negatives having a departure from the specified scale by more than 5 percent because of tilt or abrupt changes in flying altitude may be rejected. The photography shall be suitable for compilation of the topographic maps specified herein, and the mapping flight height shall not vary from 3,000 feet above mean terrain by more than 5 percent.

C. Overlap
The overlap shall be sufficient to provide full stereoscopic coverage of the area to be mapped. The endlap shall average 63 percent plus or minus 5 percent. Endlap of less than 56 percent or more than 68 percent in one or more negatives shall be cause for rejection of the negatives in which such deficiency or excess occurs unless, within a stereoscopic pair, endlap exceeding 68 percent is necessary in areas of low ground elevation to attain the minimum 58 percent endlap in adjacent areas of high ground elevation. Wherever there is a change in direction of the flight lines, vertical photography on the beginning of a forward section shall endlap the photography of a back section by 100 percent. Any negatives having sidelap of less than 20 percent or more than 55 percent may be rejected.

D. Tilt
Negatives made with the optical axis of the aerial camera in a vertical position are desired. Tilt of any negative by more than three degrees, an average tilt of more than one degree for the entire project, or tilt between any two successive negatives exceeding four degrees may be cause for rejection.

E. Crab
Crab in excess of three degrees may be cause for rejection of the flight line of negatives or portions thereof in which such crab occurs.

F. Quality

The photographs shall be clear and sharp in detail and of average uniform density. They shall be free from clouds, cloud shadows, light streaks, static marks, or other blemishes which would interfere with their intended use. Except upon prior written authorization to the contrary by the __________, all photography shall be taken when the area to be mapped is free of snow, before foliation, and at such time as to ensure a minimum solar angle of 30 degrees.

G. Camera

For topographic and contour mapping, photography shall be exposed with a distortion-free six-inch focal length precision aerial mapping camera equipped with a between-the-lens element shutter to produce negatives nine inches by nine inches in size. The Engineer shall furnish the __________ with a precision camera calibration report prepared by the National Bureau of Standards for the camera to be used.

H. Contact Prints

The contact prints from the vertical negatives shall be printed on double-weight semi-matte paper of suitable contrast.

I. Photo Index

Photo indices shall be prepared by directly photographing on safety base film at a convenient scale the assembly of contact prints from all indexed and evaluated prints used. One photo index map reproduced on cronopaque or other approved dimensionally stable base material shall be delivered to the __________. The photo index shall carry a suitable title, scale, and north point.

J. Delivery of Photography

One set of contact print photographs on double-weight semi-matte paper at a scale of one inch equals five hundred feet (1" = 500') shall be furnished the __________ upon completion of this contract.

K. Ownership of Negatives

All negatives shall become the property of the __________ and shall be delivered to the __________ upon completion of this contract.

III. CONTROL SURVEYS

A. General

The Engineer shall furnish all labor, materials, and equipment necessary to complete properly the necessary horizontal and vertical control survey monumentation as specified herein.

B. Horizontal Control

1. The horizontal control survey work shall include the recovery or relocation and monumentation of all U. S. Public Land Survey corners, including section and one-quarter-section corners, "centers" of sections, and correction corners, throughout and along the exterior of the approximately _____ square mile area to be mapped. These corners, totaling ___ in all, are indicated on the sketch map attached hereto as Exhibit "A." If the original U. S. Public Land Survey corners are not recoverable, the Engineer shall determine the status thereof under U. S. Public Land Office definitions and shall follow the prescribed procedures of that Office in their relocation. In any case, the original land survey corners and corners as aforementioned shall be monumented and witnessed as provided under Section III E herein.

2. All field work with respect to the location and relocation of all the aforementioned corners shall be based upon, and include the assembly of, all authoritative information, such as title documents, subdivision plats, private and public survey records, and

existing monumentation and occupation, that may be useful in determining the actual position of the U. S. Public Land Survey lines and corners and all other corners, as well as the proper analysis of this information, to arrive at the best determination of the actual location of the said lines and corners. Proper performance in this regard depends largely upon a knowledge of local survey customs, conditions, and laws of boundaries and titles, and for this reason, must be properly supervised by a competent and qualified registered land surveyor. The Engineer shall sublet this phase of the control survey work to a qualified and experienced land survey firm which regularly practices in the area to be mapped. The __________, however, retains the right to approve or reject any or all such local firms which the Engineer may wish to engage.

3. With regard to the location or relocation of the "center" of the section, that point which physical or other evidence indicates to be the "used or recognized center of the section" (occupied center) shall be located or relocated in accordance with paragraph 2 above and monumented as provided under Section III E 5 herein. When all sources of information have been explored and there is no evidence of an "occupied center," the Engineer, after approval by the __________, shall set and monument, in accordance with Section III E 5, the "true center" of the section. Such "true center" shall be that point at the intersection of straight lines joining opposite quarter corners.

4. The double corners along town lines shall be located or relocated and monumented in accordance with paragraphs 1 and 2 above; and the closing corners governing the location of the U. S. Public Land Survey lines in the northerly tier of one-quarter sections in Township ___ North, Range ___ East, shall be set on the straight lines connecting the section and one-quarter-section corners on the town line governing the location of the U. S. Public Land Survey lines in the southerly tier of one-quarter sections in Township ___ North, Range ___ East.

5. Having recovered or relocated and monumented all of the aforementioned corners in the approximately _____ square mile area specified, control survey traverses shall be run which utilize and incorporate all of the monumented corners as stations, to determine the coordinates of the said corners and the lengths and bearings of all the quarter-section lines. All coordinates shall be based upon the Wisconsin Coordinate System, South Zone; and sufficient survey connections shall be made to basic National Geodetic Survey (NGS) control stations of the National Geodetic Survey control net to permit the proper checks and adjustments to be made both in traverse lengths and bearings and in the coordinate values of the monumented U. S. Public Land Survey corners. Such ties shall originate and end at basic control stations for which closures are known and available or shall be run to make a closed and checked circuit. Upon prior approval of the __________ the Engineer may substitute other survey methods, such as triangulation or trilateration, for the above-specified traverses in order to determine the coordinates of the monumented corners and the lengths and bearings of all the quarter-section lines. Approval by the __________ of such substitute survey methods shall be based upon a review of detailed net layouts and procedures proposed to be followed by the Engineer.

The accuracy of the horizontal control surveys shall conform to the specifications for NGS third-order class I accuracy for traverse as set forth in "Standards and Specifications for Geodetic Control Networks" prepared by the Federal Geodetic Control Committee. This publication is incorporated in these specifications by reference as though fully herein set forth. All field measurements shall be accurately adjusted by NGS methods to provide closed traverses before traverse station coordinates are computed, the coordinates of the U. S. Public Land Survey corners are computed, and attendant lengths and bearings of the quarter-section lines are computed so as to form closed geometric figures for the quarter sections, and before the topographic mapping is undertaken.

Whenever the Engineer recovers and uses an NGS control survey station in the conduct of the control survey work he shall prepare a "Report on Condition of Survey Mark and Witness Marks" utilizing the standard form provided for this purpose by the NGS, and forward the completed copy of the form to the NGS Washington Office, with a copy to the __________.

All supplemental control for photo mapping purposes shall be based upon the control net just described.

C. Vertical Control
The vertical control survey shall be based upon National Geodetic Vertical Datum, 1929 Adjustment, as established by the NGS and hereinafter referred to as "NGVD." Closed spirit-level circuits shall be run to establish permanent bench marks in the project area. All spirit-level circuits shall be of second-order class II accuracy as set forth in "Standards and Specifications for Geodetic Control Networks" prepared by the Federal Geodetic Control Committee. This publication is incorporated in these specifications by reference as though fully herein set forth. All level circuits shall be accurately adjusted for closure by NGS methods. Elevations shall be obtained for ___ monuments marking the section and quarter-section corners throughout the area to be mapped, and these monuments shall serve as permanent bench marks. In addition, permanent reference bench marks shall be set wherever possible and as may be directed by the __________ along the spirit-level lines on such objects as bridge abutments and wing walls, headwalls of large culverts, water tables of large buildings, outcroppings of ledge rock, or any other stable objects which are unlikely to be displaced vertically. It is the intent of these specifications that one additional bench mark shall be established for each U. S. Public Land Survey corner monumented and shall be set so that the elevation of the corner monument may be readily verified from the additional permanent bench mark by a single spirit-level position. Supplementary vertical control for topographic mapping shall provide a minimum of four vertical control points in each stereoscopic model. The supplementary control points shall be established by field survey and shall be located at or near the four corners of the stereoscopic models used in topographic map preparation.

D. Control Survey Computation Data and Plats
The Engineer shall keep all field notes and office computations in a neat and orderly manner, clearly indexed, and open for inspection and checking during the course of the work. Upon completion and acceptance, the originals of all field notes and computations shall be furnished the __________ and shall become their property. The Engineer shall at all times before final acceptance of the work furnish instruments and assistance to a duly authorized agent of the __________ for such checking of field work and computations as may be deemed necessary by the __________.

1. The Engineer shall deliver to the __________ for final acceptance a diagram summarizing the control survey data. Exhibit "B" attached hereto illustrates the required form and content of this diagram. This diagram shall be prepared in ink on dimensionally stable polyester base material having a minimum thickness of 0.007 inch and a working surface suitable for inking to a scale of one inch equals one thousand feet (1" = 1,000'), and shall show correctly on its face:

   a. The exact grid length and bearing on the exterior boundaries of all the quarter sections. In addition, the ground level lengths of the exterior boundaries of all quarter sections, converted from National Geodetic Vertical Datum, shall be shown in distinctive lettering.

   b. All corners established and monuments erected in the field in their proper positions and orientations. The material of which the monuments and bench marks are made shall be noted at the representation thereof or by legend.

c. The number of degrees, minutes, and seconds in the interior angles of all quarter sections.

d. The coordinates of all section, quarter-section, and center of section corners surveyed.

e. The section number, indicated at the center of each section.

f. All basic NGS control stations within, and adjacent to, the project area and to which the horizontal control surveys are tied, together with the coordinates of the NGS stations.

g. A north point based upon grid bearings. The angle between geodetic and grid bearing (theta angle) shall be shown and shall represent the average value for the project area.

2. The Engineer shall provide for each secondary control station established (each corner within the project area), for each azimuth mark established, for each traverse station established, and for each reference bench mark established which is not also a secondary control station, a dossier on 8 1/2-inch by 11-inch tracing paper. Exhibit "C" attached hereto illustrates the required form and content for these dossiers. The following information shall be given for each station on the dossiers:

   a. Title giving the legal description by section, township, and range for the corners, permanent reference bench marks which are not also secondary control stations, traverse stations, and azimuth marks. Bench marks, traverse stations, and azimuth marks shall also be identified by assigned numbers. The center of a section shall be identified as the "true" or "occupied" center as the case may be.

   b. A sketch, showing the control station and the monument erected, to reach the station in relation to the salient features of the immediate vicinity. Witness monuments set shall be shown together with their ties. A north point shall be properly located thereon. The names of adjoining streets, state trunk highways, or public land shall be indicated. The bearing to the azimuth mark for the station shall be shown, together with a brief description of the azimuth mark.

   c. The coordinates of the corner and bench mark elevation of the monument referred to NGVD. For reference bench marks which are not also a secondary control station, only the bench mark elevation referred to NGVD need be given.

   d. The angle between geodetic and grid bearing at the station (theta angle).

   e. If necessary to supplement the sketch, a clear and concise description of each station so as to permit its ready recovery.

   f. An affidavit by the land surveyor setting forth the classification assigned to the corner (existing, obliterated, or lost) during its recovery or relocation and the salient factors determining the location or relocation, with particular emphasis upon old monumentation and accessories thereto found and used in the relocation process.

E. Monumenting

The Engineer shall mark or monument each section and quarter-section corner surveyed as follows:

1. Where the corner falls within an existing surfaced traveled way (concrete, bituminous surface, gravel), by drilling or cutting a neat hole in the pavement or street surface and setting a precast concrete monument in accordance with Exhibit "D." Where the corner falls within a concrete or bituminous surfaced traveled way, the Engineer may erect a

concrete monument similar to the one shown in Exhibit "D" by excavating a hole 9 inches in diameter by 36 inches deep and pouring the monument in place using "AA" portland cement and placing the required reinforcing steel and brass cap substantially in accordance with Exhibit "D." In all cases, the elevation and setting must be approved by the __________.

2. Where the corner falls on an earth surface, by setting a precast concrete monument as shown in Exhibit "D." In all cases, the elevation and setting must be approved by the __________.

3. Where the corner falls in a lake, stream, or inaccessible area, by setting a witness corner on the section or quarter-section line at a distance approved by the __________ away from the ordinary high water of the lake, the bank of the stream, or from an inaccessible area. Such witness corners shall be monumented by setting a precast concrete monument, and the elevation and setting shall be approved by the __________.

4. In all cases, the monuments erected shall be witnessed. Witness marks shall be selected for permanence and shall preferably consist of crosses cut in concrete curbs, walks, pavements, or culvert headwalls. Railroad spikes set in trees and telephone or power poles may be acceptable, but where used in poles shall be set flush with the surface of the telephone or power poles. In open fields, 1-inch-diameter by 36-inch-long iron pipe may be used. At least four such witness marks shall be established for each corner and tied to the section or quarter-section corner.

5. The brass caps shall conform to the details shown in Exhibit "E" attached hereto and be stamped with the corner notation at the time of setting. The concrete monument shall conform to the details shown in Exhibit "D" attached hereto. The dies used to cast the brass caps shall become the property of the __________.

6. In addition to the foregoing, the Engineer shall set one azimuth mark for each section or quarter-section corner surveyed using wherever possible a well-defined, permanent, distant object of the landscape that can be clearly identified and described. Where it is not possible or practical to use such an object, a commercial survey monument of a design approved by the __________ may be substituted.

IV. TOPOGRAPHIC MAPS

A. General

The Engineer shall prepare topographic maps to National Map Accuracy Standards in the form of ink tracings of the original manuscripts on dimensionally stable polyester base material having a minimum thickness of 0.007 inch. The area to be mapped, totaling _____ square miles, is shown on the sketch map attached hereto as Exhibit "A."

Base sheets suitable for the preparation of cadastral maps shall be provided. These sheets consist of reproducible tracings of the topographic map sheets showing all information required under Section IV B 1, 2, 3, 4, 5, 6, and 7 hereof, except hypsography, pavements, trails, fences, wooded areas, and other identifiable features.

B. Data to be Shown

The finished maps shall be drawn to a scale of one inch equals one hundred feet (1" = 100') and shall show correctly on each map face the following information:

1. Hypsography by contour lines having a vertical interval of two feet. All contours shall be drawn clear and sharp as continuous solid lines except through structures. Every fifth contour shall be accentuated and numbered. Elevations of saddles, kettles, summits, high points of all crests and low points of all sags in existing roadways, all existing road intersections, and all bridge decks at both ends of the bridge shall be shown as

determined photogrammetrically, except where field elevations are available, to the nearest one-quarter contour interval. All contour lines and elevations shall be referred to National Geodetic Vertical Datum as established by the NGS.

2. All planimetric details, such as pavements, curbs, walks, trails, railways, power lines, telephone lines, buildings, fences, wooded areas, and other identifiable features on the photography, shall be shown in their correct positions and orientation within the tolerances of these specifications.

3. All hydrographic features, such as marshes, lakes, streams, watercourses, and drainage ditches, shall be shown in their correct positions and orientation within the tolerances of these specifications.

4. All section and quarter-section lines and U. S. Public Land Survey corners established in the field surveys shall be shown in their correct positions and orientation, together with their exact grid lengths and bearings. The material of which the monuments marking said corners are made shall be indicated by symbol and legend, together with the state plane coordinates and bench mark elevations of the corners.

5. A north point based upon grid bearing. The angle between geodetic and grid bearing (theta angle) shall be shown on each map and shall represent an average value for the area covered by the map sheet.

6. A combination factor, sea level and scale, shall be given on each sheet for the reduction of measured ground lengths to corresponding grid lengths on the Wisconsin State Plane Coordinate System. The factor shall represent an average value for the area covered by the map sheet.

7. Grid lines shall be indicated at five-inch intervals and shall conform to the Wisconsin State Plane Coordinate System. Only the intersections of grid lines shall be shown on the completed maps, together with corresponding state plane coordinate values.

8. Such lettering as may be secured from available maps of the area or as may be furnished by the __________ relative to the names of salient geographic features. The names of all state and county trunk highways, public streets, and major streams and lakes shall be shown on the maps.

C. Drafting

All drafting shall be to a high standard of workmanship. The map sheets shall be 36 inches by 36 inches in size, and each sheet shall cover an entire U. S. Public Land Survey quarter section. The title shall contain a graphic scale and the following information: scale, date, type of map, location by county and state, name of the __________, name of the Engineer, and appropriate project and sheet numbers. The topographic maps shall overlap the adjacent one-quarter sections by 50 feet beyond the section or one-quarter-section lines.

D. Precision and Accuracy Standards

1. The maps shall be prepared to National Map Accuracy Standards, and a certificate to this effect shall appear on the face of each map sheet.

2. Each grid line or tick shall be plotted on the finished map sheets within 1/100 of an inch of the true grid values.

3. Each horizontal control station, section corner, and quarter-section corner shall be plotted on the finished map sheets within 1/100 of an inch of the true position as expressed by the adjusted coordinates computed for the point.

4. Ninety percent of all well-defined planimetric features shall be plotted so that their position on the finished maps shall be accurate to within 1/30 of an inch of their true coordinate position, and no point shall be more than 1/20 of an inch from its true position.

5. The contours shall faithfully express the relief detail and topographic forms. Ninety percent of the elevations determined from the solid-line contours of the map shall have an accuracy with respect to true elevation of one-half contour interval, based on a two-foot contour interval, and no such elevations shall be in error by more than one contour interval.

6. All spot elevations shown on the maps, other than elevations of vertical control stations, shall be shown to the nearest 0.5 foot.

7. The completed topographic maps shall be field checked by the __________. The field measurements shall be compared against the map data, and any map sheets that do not conform to National Map Accuracy Standards and the requirements of these specifications shall be corrected by the Engineer to fully meet the specified accuracy.

V. ITEMS TO BE DELIVERED

Upon completion the Engineer shall deliver to the __________ the following items:

A. One set of reproducible original tracings on dimensionally stable polyester base material of the completed topographic maps of the project area as designated herein.

B. One set of reproducible tracings on dimensionally stable polyester base material of the cadastral base sheets specified under Section IV A herein.

C. One reproducible tracing of the control summary diagram specified under Section III D 1 herein.

D. One set of reproducible tracings of the control station dossier sheets specified under Section III D 2 herein.

E. One set of contact print aerial photographs specified under Section II J herein.

F. One set of contact print aerial photographs with vertical and horizontal control identified thereon. These photos shall be printed as specified under Section II H herein.

G. The original field notes and computations as specified under Section III D herein.

H. One photo index as specified under Section II herein.

I. The original aerial photograph negatives specified under Section II K herein.

J. The patterns used to cast the brass caps for the survey monuments.

VI. DELIVERY DATES

A. Photography
All photography shall be completed in the spring of ____. The contact prints and photo indices shall be delivered within 30 days after the completion of photography.

B. Topographic Maps
All topographic maps and cadastral base sheets shall be delivered on or before __________.

C. Control Survey Data
All control survey data shall be delivered on or before __________.

VII. BASIS OF PAYMENT

The contract price of the work, the lump sum of $ ____________, shall include all photogrammetric and control survey engineering services necessary for the delivery of the complete, finished photography, control surveys and monumentation, and maps and all other materials and items specified herein. This total contract price shall consist of the lump sum prices listed below for integral portions of the work:

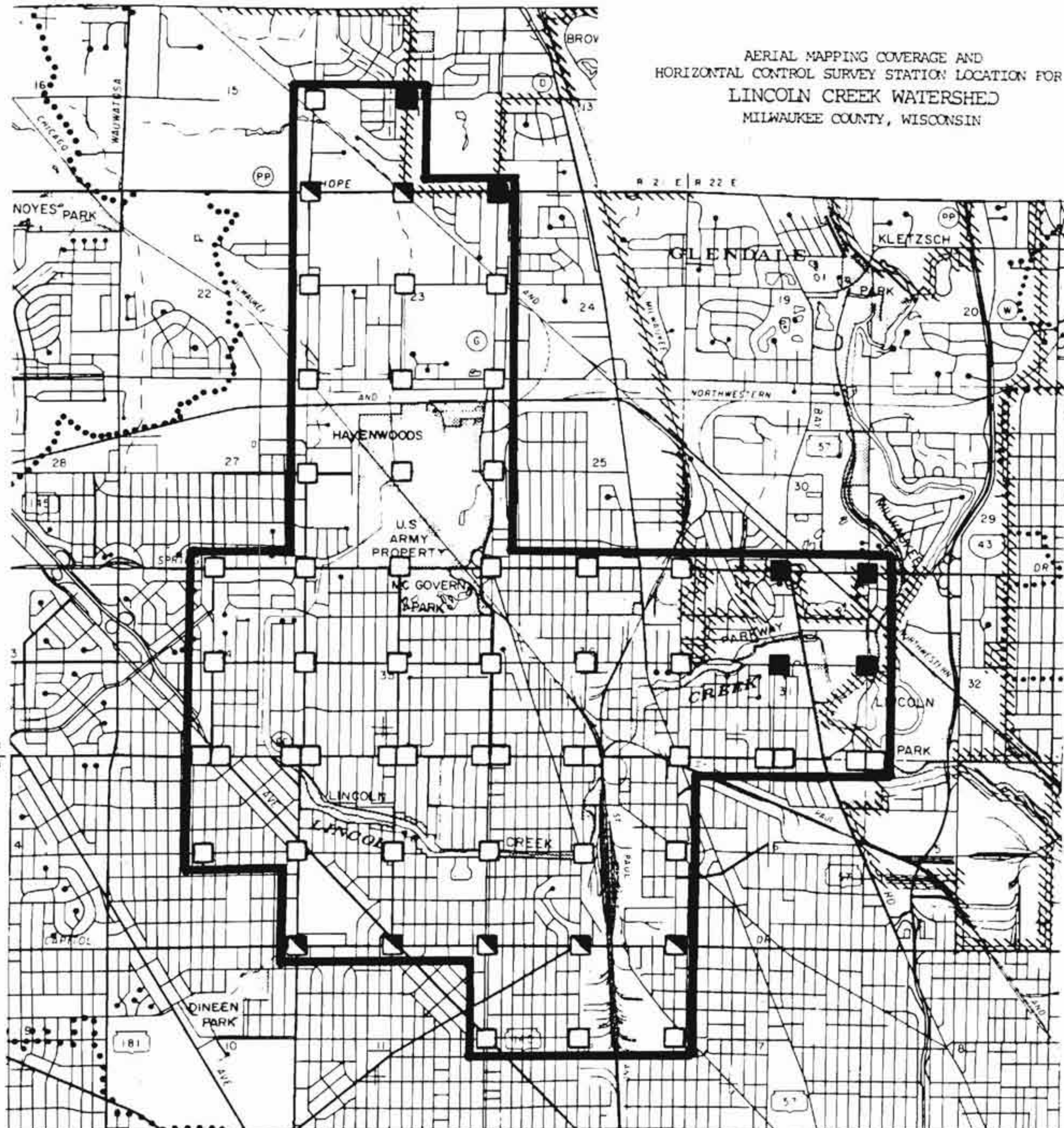
A.	Aerial photography of _____ square miles as specified @ $ _____ per square mile:	$ ___________
B.	Location, relocation, and monumentation of ____ U. S. Public Land Survey corners as specified @ $ _____ per corner:	$ ___________
C.	Vertical control surveys over ____ U. S. Public Land Survey corners as specified @ $ _____ per corner:	$ ___________
D.	Horizontal control surveys over ____ U. S. Public Land Survey corners as specified @ $ _____ per corner:	$ ___________
E.	Topographic mapping and cadastral base sheets of _____ square miles as specified @ $ _____ per square mile:	$ ___________
	Total	$ ___________

The foregoing unit prices are provided solely as a basis for computing any adjustment in the total cost of the contract that may have to be made due to any changes in the scope of the work ordered in writing by the __________ during the conduct of the project, and as a basis for computing work progress payments to the Engineer under the project.

It is expressly understood and agreed that in no event will the total compensation and reimbursement to be paid exceed the amounts stipulated above for all the service required as specified herein. The Engineer must submit invoices to the __________ during the progress of the work for partial payment on account for work completed and accepted to date. Such invoices shall not be submitted more often than every 30 days. The amount shown on such invoices shall be estimated on the basis of contract prices and the quantity of work completed and accepted by the __________. Such invoices will be checked by the __________ and payment made in an amount not to exceed 90 percent of such amount thereof as has been found by the __________ to reasonably represent the value of partially completed work, less any amounts previously paid on account. Payment of the 10 percent withheld during progress of the work shall be made upon final approval of the work by the __________.

Exhibit A

SAMPLE MAP SHOWING AERIAL MAPPING COVERAGE AND HORIZONTAL CONTROL SURVEY STATION LOCATION



LEGEND

- ■ U.S. Public Land Survey corners which have been previously relocated, monumented, and tied into both horizontal and vertical survey control networks.
- □ U.S. Public Land Survey corners which are to be relocated, monumented, and tied into both horizontal and vertical survey control networks.
- ▬ Area for which aerial photography coverage is to be provided and throughout which new 1" = 100' scale, 2' contour interval, topographic maps are to be prepared.
- ◪ U.S. Public Land Survey corners which have been previously relocated and monumented but which are to be referenced and tied into both horizontal and vertical survey control networks.

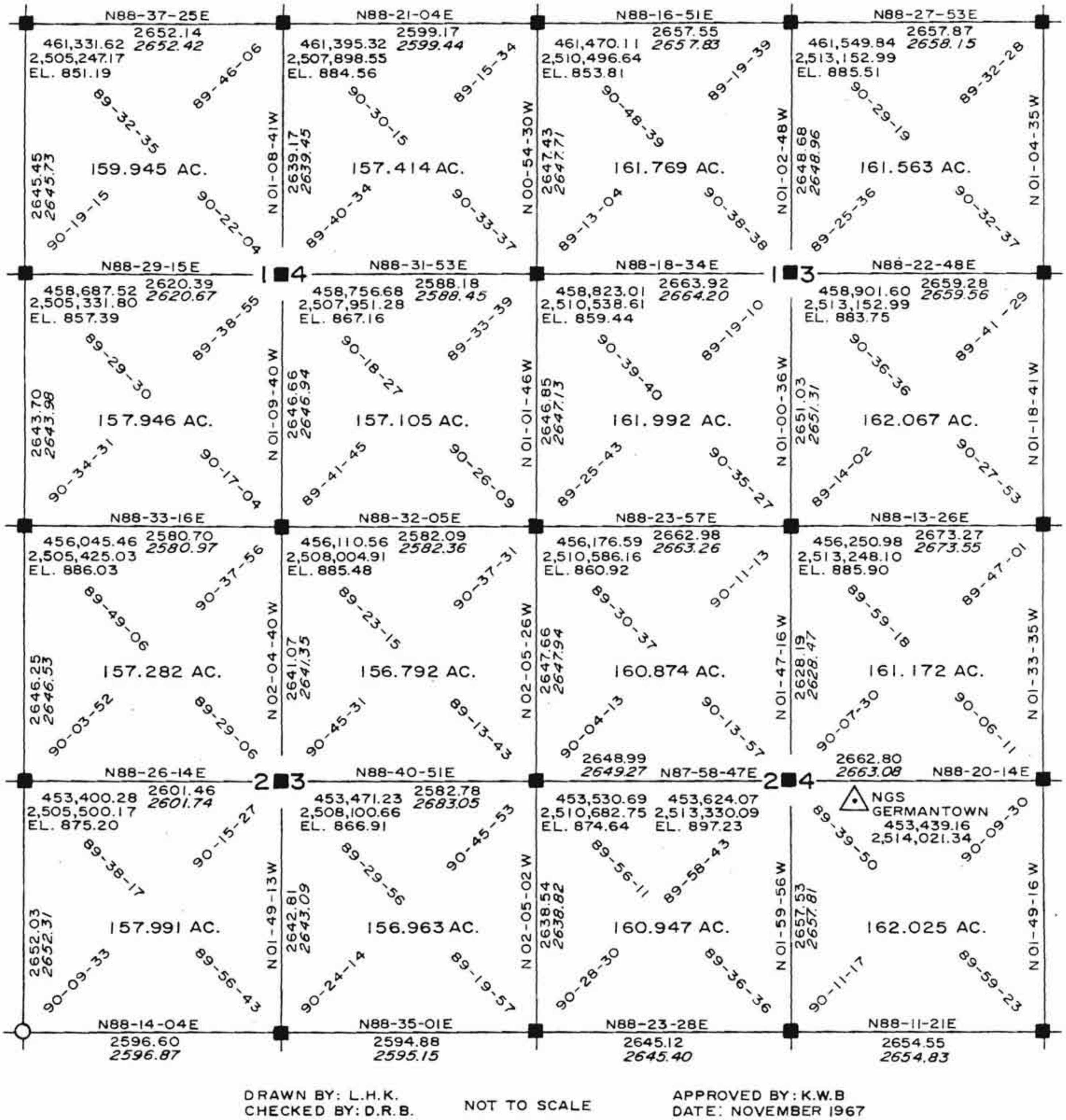
1" = 4000'

Drawn by: L.H.K.
Approved by: K.W.B.
Date: October 15, 1985

Source: SEWRPC.

Exhibit B

SAMPLE SHEET SHOWING PORTION OF REQUIRED HORIZONTAL AND VERTICAL CONTROL SURVEY DATA SUMMARY SHEET



Source: SEWRPC.

Exhibit C

RECORD OF CONTROL SURVEY STATION FORM

RECORD OF U.S. PUBLIC LAND SURVEY CONTROL STATION

U.S. PUBLIC LAND SURVEY CORNER ┼ T___N, R___E, ________________ COUNTY, WIS.

GEODETIC SURVEY BY: ________________________ YEAR: ________

STATE PLANE COORDINATES OF: ________________ ________________

NORTH ________________ ________________

EAST ________________ ________________

ELEVATION OF STATION: ________________ ________________

HORIZONTAL DATUM: WISCONSIN STATE PLANE COORDINATE SYSTEM, SOUTH ZONE

VERTICAL DATUM: NATIONAL GEODETIC VERTICAL DATUM OF 1929

CONTROL ACCURACY: THETA ANGLE: ____________

HORIZONTAL: ____________________ VERTICAL: ____________________

LOCATION SKETCH:

SURVEYOR'S AFFIDAVIT:

STATE OF WISCONSIN) SS
__________ COUNTY)

I HEREBY CERTIFY THAT ________________________

DATE OF SURVEY: __________ ____________________ S - __________

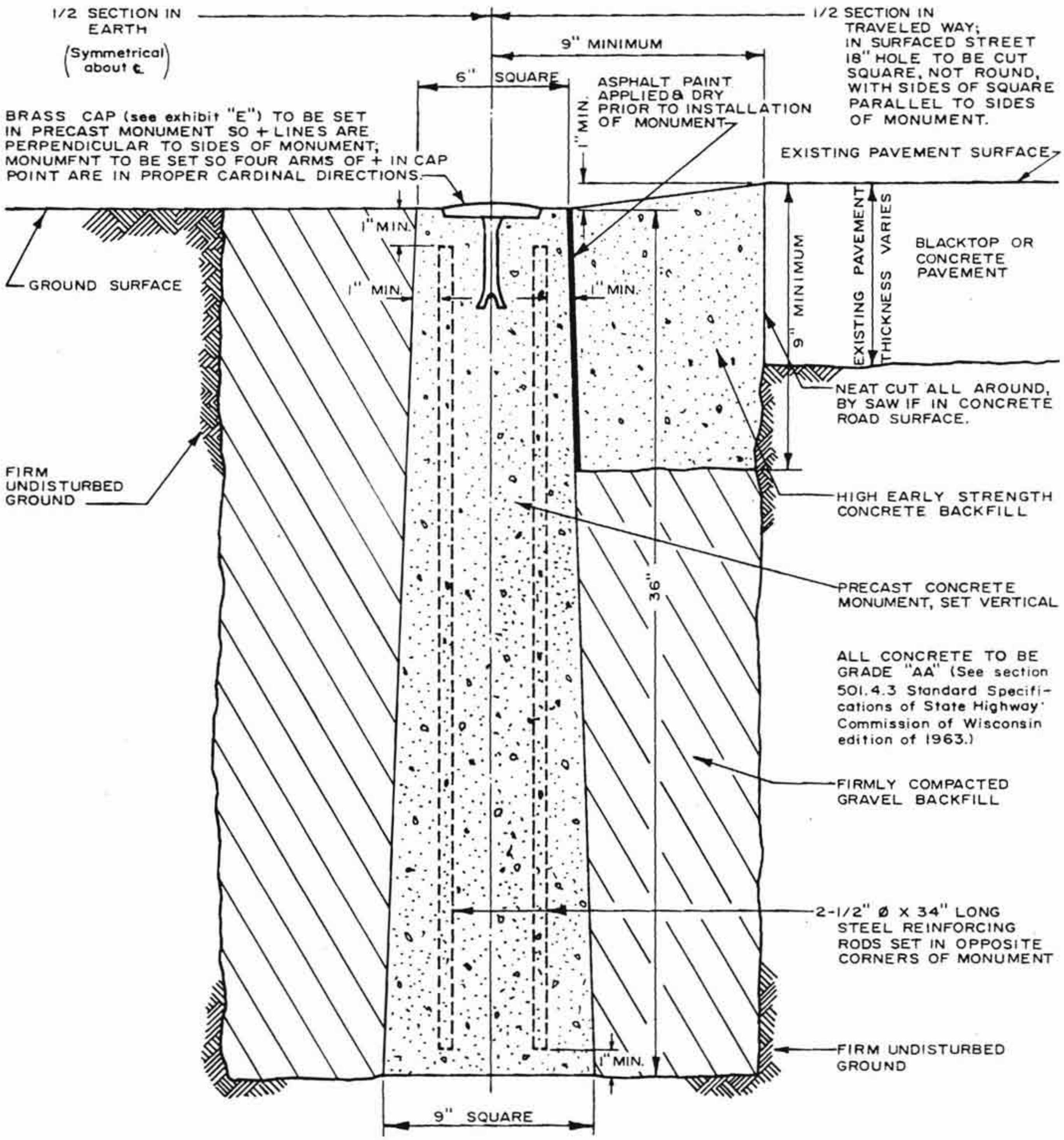
REGISTERED LAND SURVEYOR

FORM PREPARED BY SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

Source: SEWRPC.

Exhibit D

DETAIL OF MONUMENT AND MONUMENT INSTALLATION FOR SURVEY CONTROL STATIONS



DRAWN BY: L.H.K.
CHECKED BY: D.R.B.

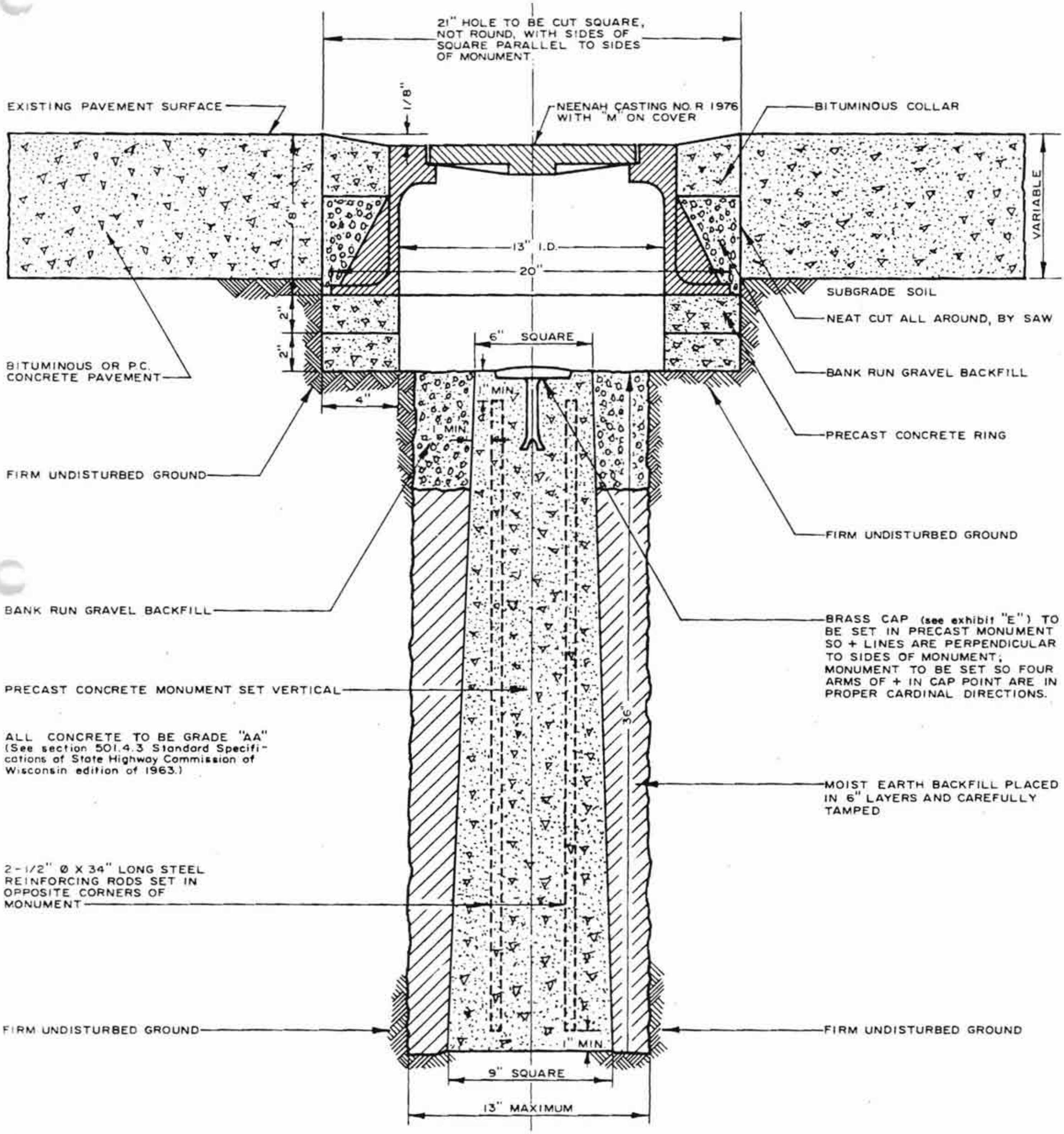
NOT TO SCALE

APPROVED BY: K.W.B.
DATE: NOVEMBER 1967

Source: SEWRPC.

Exhibit D (Optional)

TYPICAL ALTERNATIVE CONTROL SURVEY MONUMENT INSTALLATION IN SURFACED TRAVELED WAY OF STREETS AND HIGHWAYS



DRAWN BY: L.H.K.
CHECKED BY: D.R.B.

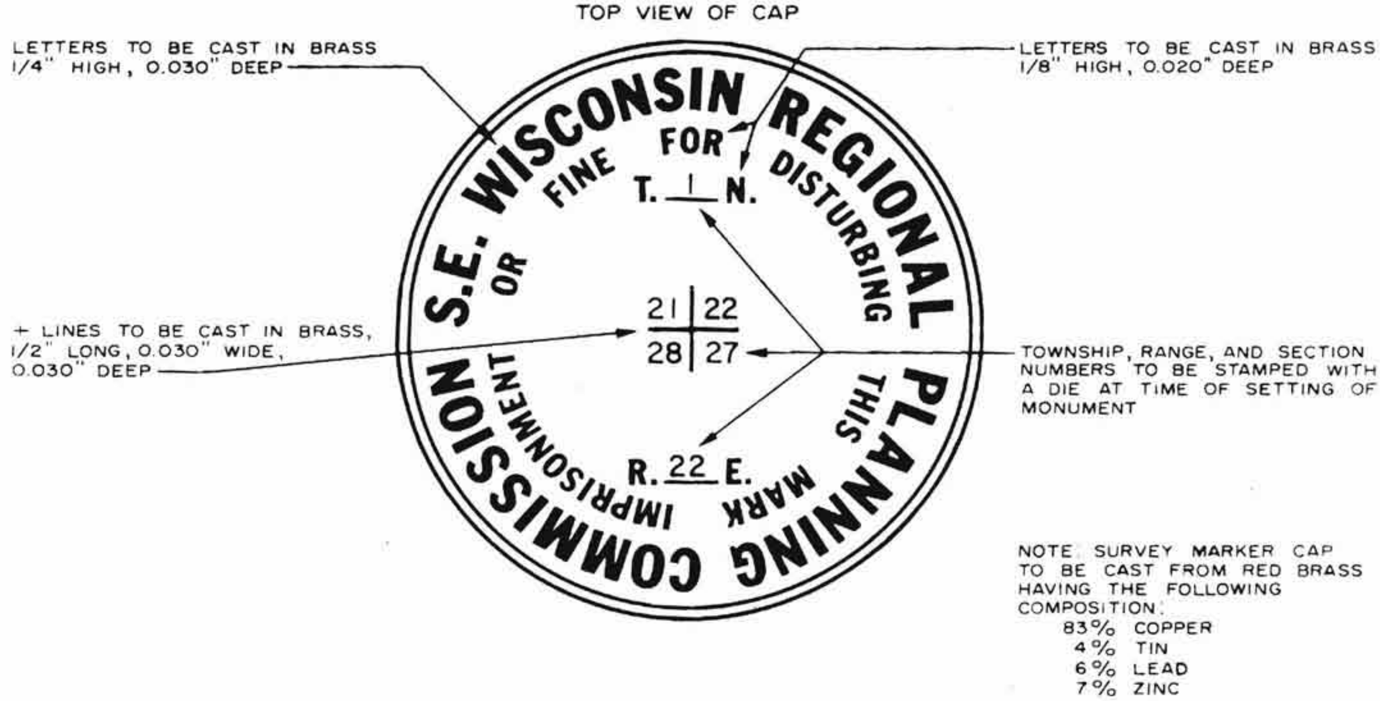
NOT TO SCALE

APPROVED BY: K.W.B
DATE: DECEMBER 1967

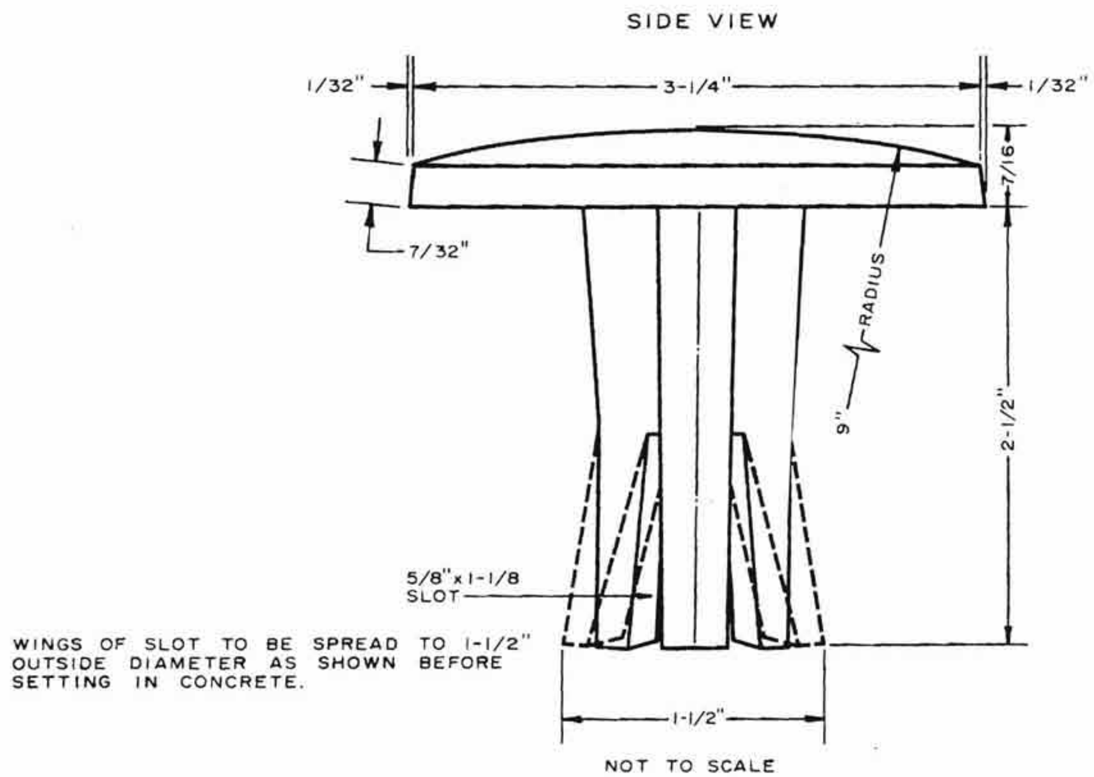
Source: SEWRPC.

Exhibit E

DETAIL OF BRASS SURVEY MARKER FOR SURVEY CONTROL STATION MONUMENTS



DRAWN BY: D. P. S.
CHECKED BY: L. H. K.
APPROVED BY: K. W. B.
DATE: FEB. 22, 1986



Source: SEWRPC.

Appendix A-2

DETAILED SPECIFICATIONS FOR AERIAL PHOTOGRAPHY, CONTROL SURVEYS, AND ONE INCH EQUALS 200 FEET SCALE TRADITIONAL TOPOGRAPHIC MAPPING

I. GENERAL

These specifications set forth the requirements of the __________ for photogrammetric mapping services, including aerial photography, topographic mapping, and accompanying control surveys and control survey monumentation. The Engineer shall furnish all labor, materials, and equipment necessary to complete properly the work specified herein.

II. PHOTOGRAPHY

A. General
The Engineer shall perform the necessary flying and photography to provide photographic coverage of an area approximately _____ square miles in extent shown on the sketch map attached hereto as Exhibit "A." The Engineer may sublet this phase of the work to a qualified and experienced firm specializing in aerial photography. The __________, however, retains the right to approve or reject any or all such firms which the Engineer may wish to engage.

B. Scale
The flight height above the average elevation of the ground shall be such that the negatives will have an average scale of one inch equals eight hundred feet (1" = 800'). Negatives having a departure from the specified scale by more than 5 percent because of tilt or abrupt changes in flying altitude may be rejected. The photography shall be suitable for compilation of the topographic maps specified herein, and the mapping flight height shall not vary from 4,800 feet above mean terrain by more than 5 percent.

C. Overlap
The overlap shall be sufficient to provide full stereoscopic coverage of the area to be mapped. The endlap shall average 63 percent plus or minus 5 percent. Endlap of less than 56 percent or more than 68 percent in one or more negatives shall be cause for rejection of the negatives in which such deficiency or excess occurs unless, within a stereoscopic pair, endlap exceeding 68 percent is necessary in areas of low ground elevation to attain the minimum 58 percent endlap in adjacent areas of high ground elevation. Wherever there is a change in direction of the flight lines, vertical photography on the beginning of a forward section shall endlap the photography of a back section by 100 percent. Any negatives having sidelap of less than 20 percent or more than 55 percent may be rejected.

D. Tilt
Negatives made with the optical axis of the aerial camera in a vertical position are desired. Tilt of any negative by more than three degrees, an average tilt of more than one degree for the entire project, or tilt between any two successive negatives exceeding four degrees may be cause for rejection.

E. Crab
Crab in excess of three degrees may be cause for rejection of the flight line of negatives or portions thereof in which such crab occurs.

F. Quality
The photographs shall be clear and sharp in detail and of average uniform density. They shall be free from clouds, cloud shadows, light streaks, static marks, or other blemishes which would interfere with their intended use. Except upon prior written authorization to the contrary by

the __________, all photography shall be taken when the area to be mapped is free of snow, before foliation, and at such time as to ensure a minimum solar angle of 30 degrees.

G. Camera

For topographic and contour mapping, photography shall be exposed with a distortion-free six-inch focal length precision aerial mapping camera equipped with a between-the-lens element shutter to produce negatives nine inches by nine inches in size. The Engineer shall furnish the __________ with a precision camera calibration report prepared by the National Bureau of Standards for the camera to be used.

H. Contact Prints

The contact prints from the vertical negatives shall be printed on double-weight semi-matte paper of suitable contrast.

I. Photo Index

Photo indices shall be prepared by directly photographing on safety base film at a convenient scale the assembly of contact prints from all indexed and evaluated prints used. One photo index map reproduced on cronopaque or other approved dimensionally stable base material shall be delivered to the __________. The photo index shall carry a suitable title, scale, and north point.

J. Delivery of Photography

One set of contact print photographs on double-weight semi-matte paper at a scale of one inch equals eight hundred feet (1" = 800') shall be furnished the __________ upon completion of this contract.

K. Ownership of Negatives

All negatives shall become the property of the __________ and shall be delivered to the __________ upon completion of this contract.

III. CONTROL SURVEYS

A. General

The Engineer shall furnish all labor, materials, and equipment necessary to complete properly the necessary horizontal and vertical control survey monumentation as specified herein.

B. Horizontal Control

1. The horizontal control survey work shall include the recovery or relocation and monumentation of all U. S. Public Land Survey corners, including section and one-quarter-section corners, "centers" of sections, and correction corners, throughout and along the exterior of the approximately _____ square mile area to be mapped. These corners, totaling ____ in all, are indicated on the sketch map attached hereto as Exhibit "A." If the original U. S. Public Land Survey corners are not recoverable, the Engineer shall determine the status thereof under U. S. Public Land Office definitions and shall follow the prescribed procedures of that Office in their relocation. In any case, the original land survey corners and corners as aforementioned shall be monumented and witnessed as provided under Section III E herein.

2. All field work with respect to the location and relocation of all the aforementioned corners shall be based upon, and include the assembly of, all authoritative information, such as title documents, subdivision plats, private and public survey records, and existing monumentation and occupation, that may be useful in determining the actual position of the U. S. Public Land Survey lines and corners and all other corners, as well as the proper analysis of this information, to arrive at the best determination of the actual location of the said lines and corners. Proper performance in this regard depends largely upon a knowledge of local survey customs, conditions, and laws of boundaries

and titles, and for this reason, must be properly supervised by a competent and qualified registered land surveyor. The Engineer shall sublet this phase of the control survey work to a qualified and experienced land survey firm which regularly practices in the area to be mapped. The __________, however, retains the right to approve or reject any or all such local firms which the Engineer may wish to engage.

3. With regard to the location or relocation of the "center" of the section, that point which physical or other evidence indicates to be the "used or recognized center of the section" (occupied center) shall be located or relocated in accordance with paragraph 2 above and monumented as provided under Section III E 5 herein. When all sources of information have been explored and there is no evidence of an "occupied center," the Engineer, after approval by the __________, shall set and monument, in accordance with Section III E 5, the "true center" of the section. Such "true center" shall be that point at the intersection of straight lines joining opposite quarter corners.

4. The double corners along town lines shall be located or relocated and monumented in accordance with paragraphs 1 and 2 above; and the closing corners governing the location of the U. S. Public Land Survey lines in the northerly tier of one-quarter sections in Township ___ North, Range ___ East, shall be set on the straight lines connecting the section and one-quarter-section corners on the town line governing the location of the U. S. Public Land Survey lines in the southerly tier of one-quarter sections in Township ___ North, Range ___ East.

5. Having recovered or relocated and monumented all of the aforementioned corners in the approximately _____ square mile area specified, control survey traverses shall be run which utilize and incorporate all of the monumented corners as stations, to determine the coordinates of the said corners and the lengths and bearings of all the quarter-section lines. All coordinates shall be based upon the Wisconsin Coordinate System, South Zone; and sufficient survey connections shall be made to basic National Geodetic Survey (NGS) control stations of the National Geodetic Survey control net to permit the proper checks and adjustments to be made in both traverse lengths and bearings and in the coordinate values of the monumented U. S. Public Land Survey corners. Such ties shall originate and end at basic control stations for which closures are known and available, or shall be run to make a closed and checked circuit. Upon prior approval of the __________, the Engineer may substitute other survey methods, such as triangulation or trilateration, for the above-specified traverses in order to determine the coordinates of the monumented corners and the lengths and bearings of all the quarter-section lines. Approval by the __________ of such substitute survey methods shall be based upon a review of detailed net layouts and procedures proposed to be followed by the Engineer.

   The accuracy of the horizontal control surveys shall conform to the specifications for NGS third-order class I accuracy for traverse as set forth in "Standards and Specifications for Geodetic Control Networks" prepared by the Federal Geodetic Control Committee. This publication is incorporated in these specifications by reference as though fully herein set forth. All field measurements shall be accurately adjusted by NGS methods to provide closed traverses before traverse station coordinates are computed, the coordinates of the U. S. Public Land Survey corners are computed, and attendant lengths and bearings of the quarter-section lines are computed so as to form closed geometric figures for the quarter sections, and before the topographic mapping is undertaken.

   Whenever the Engineer recovers and uses an NGS control survey station in the conduct of the control survey work, he shall prepare a "Report on Condition of Survey Mark and Witness Marks," utilizing the standard form provided for this purpose by the NGS, and forward the completed copy of the form to the NGS Washington Office, with a copy to the __________.

All supplemental control for photo mapping purposes shall be based upon the control net just described.

C. Vertical Control

The vertical control survey shall be based upon National Geodetic Vertical Datum, 1929 Adjustment, as established by the NGS and hereinafter referred to as "NGVD." Closed spirit-level circuits shall be run to establish permanent bench marks in the project area. All spirit-level circuits shall be of second-order class II accuracy as set forth in "Standards and Specifications for Geodetic Control Networks" prepared by the Federal Geodetic Control Committee. This publication is incorporated in these specifications by reference as though fully herein set forth. All level circuits shall be accurately adjusted for closure by NGS methods. Elevations shall be obtained for ____ monuments marking the section and quarter-section corners throughout the area to be mapped, and these monuments shall serve as permanent bench marks. In addition, permanent reference bench marks shall be set wherever possible and as may be directed by the __________ along the spirit-level lines on such objects as bridge abutments and wing walls, headwalls of large culverts, water tables of large buildings, outcroppings of ledge rock, or any other stable objects which are unlikely to be displaced vertically. It is the intent of these specifications that one additional bench mark shall be established for each U. S. Public Land Survey corner monumented and shall be set so that the elevation of the corner monument may be readily verified from the additional permanent bench mark by a single spirit-level position. Supplementary vertical control for topographic mapping shall provide a minimum of four vertical control points in each stereoscopic model. The supplementary control points shall be established by field survey and shall be located at or near the four corners of the stereoscopic models used in topographic map preparation.

D. Control Survey Computation Data and Plats

The Engineer shall keep all field notes and office computations in a neat and orderly manner, clearly indexed, and open for inspection and checking during the course of the work. Upon completion and acceptance, the originals of all field notes and computations shall be furnished the __________ and shall become their property. The Engineer shall at all times before final acceptance of the work furnish instruments and assistance to a duly authorized agent of the __________ for such checking of field work and computations as may be deemed necessary by the __________.

1. The Engineer shall deliver to the __________ for final acceptance a diagram summarizing the control survey data. Exhibit "B" attached hereto illustrates the required form and content of this diagram. This diagram shall be prepared in ink on dimensionally stable polyester base material having a minimum thickness of 0.007 inch and a working surface suitable for inking to a scale of one inch equals one thousand feet (1" = 1,000'), and shall show correctly on its face:

   a. The exact grid length and bearing on the exterior boundaries of all the quarter sections. In addition, the ground level lengths of the exterior boundaries of all quarter sections, converted from National Geodetic Vertical Datum, shall be shown in distinctive lettering.

   b. All corners established and monuments erected in the field in their proper positions and orientations. The material of which the monuments and bench marks are made shall be noted at the representation thereof or by legend.

   c. The number of degrees, minutes, and seconds in the interior angles of all quarter sections.

   d. The coordinates of all section, quarter-section, and center of section corners surveyed.

e. The section number, indicated at the center of each section.

f. All basic NGS control stations within, and adjacent to, the project area and to which the horizontal control surveys are tied, together with the coordinates of the NGS stations.

g. A north point based upon grid bearings. The angle between geodetic and grid bearing (theta angle) shall be shown and shall represent the average value for the project area.

2. The Engineer shall provide for each secondary control station established (each corner within the project area), for each azimuth mark established, for each traverse station established, and for each reference bench mark established which is not also a secondary control station, a dossier on 8 1/2-inch by 11-inch tracing paper. Exhibit "C" attached hereto illustrates the required form and content for these dossiers. The following information shall be given for each station on the dossiers:

   a. Title giving the legal description by section, township, and range for the corners, permanent reference bench marks which are not also secondary control stations, traverse stations, and azimuth marks. Bench marks, traverse stations, and azimuth marks shall also be identified by assigned numbers. The center of a section shall be identified as the "true" or "occupied" center as the case may be.

   b. A sketch, showing the control station and the monument erected, to reach the station in relation to the salient features of the immediate vicinity. Witness monuments set shall be shown together with their ties. A north point shall be properly located thereon. The names of adjoining streets, state trunk highways, or public land shall be indicated. The bearing to the azimuth mark for the station shall be shown, together with a brief description of the azimuth mark.

   c. The coordinates of the corner and bench mark elevation of the monument referred to NGVD. For reference bench marks which are not also a secondary control station, only the bench mark elevation referred to NGVD need be given.

   d. The angle between geodetic and grid bearing at the station (theta angle).

   e. If necessary to supplement the sketch, a clear and concise description of each station so as to permit its ready recovery.

   f. An affidavit by the land surveyor setting forth the classification assigned to the corner (existing, obliterated, or lost) during its recovery or relocation and the salient factors determining the location or relocation, with particular emphasis upon old monumentation and accessories thereto found and used in the relocation process.

E. Monumenting

The Engineer shall mark or monument each section and quarter-section corner surveyed as follows:

1. Where the corner falls within an existing surfaced traveled way (concrete, bituminous surface, gravel), by drilling or cutting a neat hole in the pavement or street surface and setting a precast concrete monument in accordance with Exhibit "D." Where the corner falls within a concrete or bituminous surfaced traveled way, the Engineer may erect a concrete monument similar to the one shown in Exhibit "D" by excavating a hole 9 inches in diameter by 36 inches deep and pouring the monument in place using "AA" portland cement and placing the required reinforcing steel and brass cap substantially in accordance with Exhibit "D." In all cases, the elevation and setting must be approved by the ___________.

2. Where the corner falls on an earth surface, by setting a precast concrete monument as shown in Exhibit "D." In all cases, the elevation and setting must be approved by the __________.

3. Where the corner falls in a lake, stream, or inaccessible area, by setting a witness corner on the section or quarter-section line at a distance approved by the __________ away from the ordinary high water of the lake, the bank of the stream, or from an inaccessible area. Such witness corners shall be monumented by setting a precast concrete monument, and the elevation and setting shall be approved by the __________.

4. In all cases, the monuments erected shall be witnessed. Witness marks shall be selected for permanence and shall preferably consist of crosses cut in concrete curbs, walks, pavements, or culvert headwalls. Railroad spikes set in trees and telephone or power poles may be acceptable, but where used in poles shall be set flush with the surface of the telephone or power poles. In open fields, 1-inch-diameter by 36-inch-long iron pipe may be used. At least four such witness marks shall be established for each corner and tied to the section or quarter-section corner.

5. The brass caps shall conform to the details shown in Exhibit "E" attached hereto and be stamped with the corner notation at the time of setting. The concrete monument shall conform to the details shown in Exhibit "D" attached hereto. The dies used to cast the brass caps shall become the property of the __________.

6. In addition to the foregoing, the Engineer shall set one azimuth mark for each section or quarter-section corner surveyed using wherever possible a well-defined, permanent, distant object of the landscape that can be clearly identified and described. Where it is not possible or practical to use such an object, a commercial survey monument of a design approved by the __________ may be substituted.

IV. TOPOGRAPHIC MAPS

A. General

The Engineer shall prepare topographic maps to National Map Accuracy Standards in the form of ink tracings of the original manuscripts on dimensionally stable polyester base material having a minimum thickness of 0.007 inch. The area to be mapped, totaling _____ square miles, is shown on the sketch map attached hereto as Exhibit "A."

Base sheets suitable for the preparation of cadastral maps shall be provided. These sheets consist of reproducible tracings of the topographic map sheets showing all information required under Section IV B 1, 2, 3, 4, 5, 6, and 7 hereof, except hypsography, pavements, trails, fences, wooded areas, and other identifiable features.

B. Data to be Shown

The finished maps shall be drawn to a scale of one inch equals two hundred feet (1" = 200') and shall show correctly on each map face the following information:

1. Hypsography by contour lines having a vertical interval of two feet. All contours shall be drawn clear and sharp as continuous solid lines except through structures. Every fifth contour shall be accentuated and numbered. Elevations of saddles, kettles, summits, high points of all crests and low points of all sags in existing roadways, all existing road intersections, and all bridge decks at both ends of the bridge shall be shown as determined photogrammetrically, except where field elevations are available, to the nearest one-quarter contour interval. All contour lines and elevations shall be referred to National Geodetic Vertical Datum as established by the NGS.

2. All planimetric detail, such as pavements, curbs, trails, railways, power line towers, buildings, fences, wooded areas, and other identifiable features on the photography, shall

be shown in their correct positions and orientation within the tolerances of these specifications.

3. All hydrographic features, such as marshes, lakes, streams, watercourses, and drainage ditches, shall be shown in their correct positions and orientation within the tolerances of these specifications.

4. All section and quarter-section lines and U. S. Public Land Survey corners established in the field surveys shall be shown in their correct positions and orientation, together with their exact grid lengths and bearings. The material of which the monuments marking said corners are made shall be indicated by symbol and legend, together with the state plane coordinates and bench mark elevations of the corners.

5. A north point based upon grid bearing. The angle between geodetic and grid bearing (theta angle) shall be shown on each map and shall represent an average value for the area covered by the map sheet.

6. A combination factor, sea level and scale, shall be given on each sheet for the reduction of measured ground lengths to corresponding grid lengths on the Wisconsin State Plane Coordinate System. The factor shall represent an average value for the area covered by the map sheet.

7. Grid lines shall be indicated at five-inch intervals and shall conform to the Wisconsin State Plane Coordinate System. Only the intersections of grid lines shall be shown on the completed maps, together with corresponding state plane coordinate values.

8. Such lettering as may be secured from available maps of the area or as may be furnished by the __________ relative to the names of salient geographic features. The names of all state and county trunk highways, public streets, and major streams and lakes shall be shown on the maps.

C. Drafting
All drafting shall be to a high standard of workmanship. The map sheets shall be 36 inches by 36 inches in size, and each sheet shall cover an entire U. S. Public Land Survey section. The title shall contain a graphic scale and the following information: scale, date, type of map, location by county and state, name of the __________, name of the Engineer, and appropriate project and sheet numbers. The topographic maps shall overlap the adjacent one-quarter sections by 100 feet beyond the section or one-quarter-section lines.

D. Precision and Accuracy Standards

1. The maps shall be prepared to National Map Accuracy Standards, and a certificate to this effect shall appear on the face of each map sheet.

2. Each grid line or tick shall be plotted on the finished map sheets within 1/100 of an inch of the true grid values.

3. Each horizontal control station, section corner, and quarter-section corner shall be plotted on the finished map sheets within 1/100 of an inch of the true position as expressed by the adjusted coordinates computed for the point.

4. Ninety percent of all well-defined planimetric features shall be plotted so that their position on the finished maps shall be accurate to within 1/30 of an inch of their true coordinate position, and no point shall be more than 1/20 of an inch from its true position.

5. The contours shall faithfully express the relief detail and topographic forms. Ninety percent of the elevations determined from the solid-line contours of the map shall have an accuracy

with respect to true elevation of one-half contour interval, based on a two-foot contour interval, and no such elevations shall be in error by more than one contour interval.

6. All spot elevations shown on the maps, other than elevations of vertical control stations, shall be shown to the nearest 0.5 foot.

7. The completed topographic maps shall be field checked by the __________. The field measurements shall be compared against the map data, and any map sheets that do not conform to National Map Accuracy Standards and the requirements of these specifications shall be corrected by the Engineer to fully meet the specified accuracy.

V. ITEMS TO BE DELIVERED

Upon completion the Engineer shall deliver to the __________ the following items:

A. One set of reproducible original tracings on dimensionally stable polyester base material of the completed topographic maps of the project area as designated herein.

B. One set of reproducible tracings on dimensionally stable polyester base material of the cadastral base sheets specified under Section IV A herein.

C. One reproducible tracing of the control summary diagram specified under Section III D 1 herein.

D. One set of reproducible tracings of the control station dossier sheets specified under Section III D 2 herein.

E. One set of contact print aerial photographs specified under Section II J herein.

F. One set of contact print aerial photographs with vertical and horizontal control identified thereon. These photos shall be printed as specified under Section II H herein.

G. The original field notes and computations as specified under Section III D herein.

H. One photo index as specified under Section II herein.

I. The original aerial photograph negatives specified under Section II K herein.

J. The patterns used to cast the brass caps for the survey monuments.

VI. DELIVERY DATES

A. Photography
All photography shall be completed in the spring of ____. The contact prints and photo indices shall be delivered within 30 days after the completion of photography.

B. Topographic Maps
All topographic maps and cadastral base sheets shall be delivered on or before __________.

C. Control Survey Data
All control survey data shall be delivered on or before __________.

VII. BASIS OF PAYMENT

The contract price of the work, the lump sum of $ ____________, shall include all photogrammetric and control survey engineering services necessary for the delivery of the complete, finished photography, control surveys and monumentation, and maps and all other materials and items specified herein. This total contract price shall consist of the lump sum prices listed below for integral portions of the work:

A. Aerial photography of _____ square miles as specified @ $ _____ per square mile:	$ ___________
B. Location, relocation, and monumentation of ____ U. S. Public Land Survey corners as specified @ $ ____ per corner:	$ ___________
C. Vertical control surveys over U. S. Public Land Survey corners as specified @ $_____ per corner:	$ ___________
D. Horizontal control surveys over ___U. S. Public Land Survey corners as specified @ $ _____ per corner:	$ ___________
E. Topographic mapping and cadastral base sheets of _____ square miles as specified @ $ _____ per square mile:	$ ___________
Total	$ ___________

The foregoing unit prices are provided solely as a basis for computing any adjustment in the total cost of the contract that may have to be made due to any changes in the scope of the work ordered in writing by the __________ during the conduct of the project, and as a basis for computing work progress payments to the Engineer under the project.

It is expressly understood and agreed that in no event will the total compensation and reimbursement to be paid exceed the amounts stipulated above for all the service required as specified herein. The Engineer must submit invoices to the __________ during the progress of the work for partial payment on account for work completed and accepted to date. Such invoices shall not be submitted more often than every 30 days. The amount shown on such invoices shall be estimated on the basis of contract prices and the quantity of work completed and accepted by the __________. Such invoices will be checked by the __________ and payment made in an amount not to exceed 90 percent of such amount thereof as has been found by the __________ to reasonably represent the value of partially completed work, less any amounts previously paid on account. Payment of the 10 percent withheld during progress of the work shall be made upon final approval of the work by the __________.

Appendix A-3

DETAILED SPECIFICATIONS FOR AERIAL PHOTOGRAPHY, CONTROL SURVEYS, AND ONE INCH EQUALS 100 FEET SCALE DIGITAL TOPOGRAPHIC MAPPING

I. GENERAL

These specifications set forth the requirements of __________, for photogrammetric mapping services and digital map preparation, including aerial photography, topographic mapping, and accompanying control surveys and control survey monumentation. The Engineer shall furnish all labor, materials, and equipment necessary to complete properly the work specified herein.

II. PHOTOGRAPHY

A. General
The Engineer shall perform the necessary flying and photography to provide photographic coverage of an area approximately _____ square miles in extent shown on the sketch map attached hereto as Exhibit "A." The Engineer may sublet this phase of the work to a qualified and experienced firm specializing in aerial photography. The __________, however, retains the right to approve or reject any or all such firms which the Engineer may wish to engage.

B. Scale
The flight height above the average elevation of the ground shall be such that the negatives will have an average scale of one inch equals five hundred feet (1" = 500'). Negatives having a departure from the specified scale by more than 5 percent because of tilt or abrupt changes in flying altitude may be rejected. The photography shall be suitable for compilation of the topographic maps specified herein, and the mapping flight height shall not vary from 3,000 feet above mean terrain by more than 5 percent.

C. Overlap
The overlap shall be sufficient to provide full stereoscopic coverage of the area to be mapped. The endlap shall average 63 percent plus or minus 5 percent. Endlap of less than 56 percent or more than 68 percent in one or more negatives shall be cause for rejection of the negatives in which such deficiency or excess occurs unless, within a stereoscopic pair, endlap exceeding 68 percent is necessary in areas of low ground elevation to attain the minimum 58 percent endlap in adjacent areas of high ground elevation. Wherever there is a change in direction of the flight lines, vertical photography on the beginning of a forward section shall endlap the photography of a back section by 100 percent. Any negatives having sidelap of less than 20 percent or more than 55 percent may be rejected.

D. Tilt
Negatives made with the optical axis of the aerial camera in a vertical position are desired. Tilt of any negative by more than three degrees, an average tilt of more than one degree for the entire project, or tilt between any two successive negatives exceeding four degrees may be cause for rejection.

E. Crab
Crab in excess of three degrees may be cause for rejection of the flight line of negatives or portions thereof in which such crab occurs.

F. Quality
The photographs shall be clear and sharp in detail and of average uniform density. They shall be free from clouds, cloud shadows, light streaks, static marks, or other blemishes which would interfere with their intended use. Except upon prior written authorization to the contrary by

the __________, all photography shall be taken when the area to be mapped is free of snow, before foliation, and at such time as to ensure a minimum solar angle of 30 degrees.

G. Camera
For topographic and contour mapping, photography shall be exposed with a distortion-free six-inch focal length precision aerial mapping camera equipped with a between-the-lens element shutter to produce negatives nine inches by nine inches in size. The Engineer shall furnish the __________ with a precision camera calibration report prepared by the National Bureau of Standards for the camera to be used.

H. Contact Prints
The contact prints from the vertical negatives shall be printed on double-weight semi-matte paper of suitable contrast.

I. Photo Index
Photo indices shall be prepared by directly photographing on safety base film at a convenient scale the assembly of contact prints from all indexed and evaluated prints used. One photo index map reproduced on cronopaque or other approved dimensionally stable base material shall be delivered to the __________. The photo index shall carry a suitable title, scale, and north point.

J. Delivery of Photography
One set of contact print photographs on double-weight semi-matte paper at a scale of one inch equals five hundred feet (1" = 500') shall be furnished the __________ upon completion of this contract.

K. Ownership of Negatives
All negatives shall become the property of the __________ and shall be delivered to the __________ upon completion of this contract.

III. CONTROL SURVEYS

A. General
The Engineer shall furnish all labor, materials, and equipment necessary to complete properly the necessary horizontal and vertical control survey monumentation as specified herein.

B. Horizontal Control

1. The horizontal control survey work shall include the recovery or relocation and monumentation of all U. S. Public Land Survey corners, including section and one-quarter-section corners, "centers" of sections, and correction corners, throughout and along the exterior of the approximately _____ square mile area to be mapped. These corners, totaling ____ in all, are indicated on the sketch map attached hereto as Exhibit "A." If the original U. S. Public Land Survey corners are not recoverable, the Engineer shall determine the status thereof under U. S. Public Land Office definitions and shall follow the prescribed procedures of that Office in their relocation. In any case, the original land survey corners and corners as aforementioned shall be monumented and witnessed as provided under Section III E herein.

2. All field work with respect to the location and relocation of all the aforementioned corners shall be based upon, and include the assembly of, all authoritative information, such as title documents, subdivision plats, private and public survey records, and existing monumentation and occupation, that may be useful in determining the actual position of the U. S. Public Land Survey lines and corners and all other corners, as well as the proper analysis of this information, to arrive at the best determination of the actual location of the said lines and corners. Proper performance in this regard depends

largely upon a knowledge of local survey customs, conditions, and laws of boundaries and titles, and for this reason, must be properly supervised by a competent and qualified registered land surveyor. The Engineer shall sublet this phase of the control survey work to a qualified and experienced land survey firm which regularly practices in the area to be mapped. The __________, however, retains the right to approve or reject any or all such local firms which the Engineer may wish to engage.

3. With regard to the location or relocation of the "center" of the section, that point which physical or other evidence indicates to be the "used or recognized center of the section" (occupied center) shall be located or relocated in accordance with paragraph 2 above and monumented as provided under Section III E 5 herein. When all sources of information have been explored and there is no evidence of an "occupied center," the Engineer, after approval by the __________, shall set and monument, in accordance with Section III E 5, the "true center" of the section. Such "true center" shall be that point at the intersection of straight lines joining opposite quarter corners.

4. The double corners along town lines shall be located or relocated and monumented in accordance with paragraphs 1 and 2 above; and the closing corners governing the location of the U. S. Public Land Survey lines in the northerly tier of one-quarter sections in Township ___ North, Range ___ East, shall be set on the straight lines connecting the section and one-quarter-section corners on the town line governing the location of the U. S. Public Land Survey lines in the southerly tier of one-quarter sections in Township ___ North, Range ___ East.

5. Having recovered or relocated and monumented all of the aforementioned corners in the approximately _____ square mile area specified, control survey traverses shall be run which utilize and incorporate all of the monumented corners as stations, to determine the coordinates of the said corners and the lengths and bearings of all the quarter-section lines. All coordinates shall be based upon the Wisconsin Coordinate System, South Zone; and sufficient survey connections shall be made to basic National Geodetic Survey (NGS) control stations of the National Geodetic Survey control net to permit the proper checks and adjustments to be made both in traverse lengths and bearings and in the coordinate values of the monumented U. S. Public Land Survey corners. Such ties shall originate and end at basic control stations for which closures are known and available or shall be run to make a closed and checked circuit. Upon prior approval of the __________, the Engineer may substitute other survey methods, such as triangulation or trilateration, for the above-specified traverses in order to determine the coordinates of the monumented corners and the lengths and bearings of all the quarter-section lines. Approval by the __________ of such substitute survey methods shall be based upon a review of detailed net layouts and procedures proposed to be followed by the Engineer.

   The accuracy of the horizontal control surveys shall conform to the specifications for NGS third-order class I accuracy for traverse as set forth in "Standards and Specifications for Geodetic Control Networks" prepared by the Federal Geodetic Control Committee. This publication is incorporated in these specifications by reference as though fully herein set forth. All field measurements shall be accurately adjusted by NGS methods to provide closed traverses before traverse station coordinates are computed, the coordinates of the U. S. Public Land Survey corners are computed, and attendant lengths and bearings of the quarter-section lines are computed so as to form closed geometric figures for the quarter sections, and before the topographic mapping is undertaken.

   Whenever the Engineer recovers and uses an NGS control survey station in the conduct of the control survey work, he shall prepare a "Report on Condition of Survey Mark and Witness Marks" utilizing the standard form provided for this purpose by the NGS, and forward the completed copy of the form to the NGS Washington Office, with a copy to the __________.

All supplemental control for photo mapping purposes shall be based upon the control net just described.

C. Vertical Control

The vertical control survey shall be based upon National Geodetic Vertical Datum, 1929 Adjustment, as established by the NGS and hereinafter referred to as "NGVD." Closed spirit-level circuits shall be run to establish permanent bench marks in the project area. All spirit-level circuits shall be of second-order class II accuracy as set forth in "Standards and Specifications for Geodetic Control Networks" prepared by the Federal Geodetic Control Committee. This publication is incorporated in these specifications by reference as though fully herein set forth. All level circuits shall be accurately adjusted for closure by NGS methods. Elevations shall be obtained for ___ monuments marking the section and quarter-section corners throughout the area to be mapped, and these monuments shall serve as permanent bench marks. In addition, permanent reference bench marks shall be set wherever possible and as may be directed by the __________ along the spirit-level lines on such objects as bridge abutments and wing walls, headwalls of large culverts, water tables of large buildings, outcroppings of ledge rock, or any other stable objects which are unlikely to be displaced vertically. It is the intent of these specifications that one additional bench mark shall be established for each U. S. Public Land Survey corner monumented and shall be set so that the elevation of the corner monument may be readily verified from the additional permanent bench mark by a single spirit-level position. Supplementary vertical control for topographic mapping shall provide a minimum of four vertical control points in each stereoscopic model. The supplementary control points shall be established by field survey and shall be located at or near the four corners of the stereoscopic models used in topographic map preparation.

D. Control Survey Computation Data and Plats

The Engineer shall keep all field notes and office computations in a neat and orderly manner, clearly indexed, and open for inspection and checking during the course of the work. Upon completion and acceptance, the originals of all field notes and computations shall be furnished the __________ and shall become their property. The Engineer shall at all times before final acceptance of the work furnish instruments and assistance to a duly authorized agent of the __________ for such checking of field work and computations as may be deemed necessary by the __________.

1. The Engineer shall deliver to the __________ for final acceptance a diagram summarizing the control survey data. Exhibit "B" attached hereto illustrates the required form and content of this diagram. This diagram shall be prepared in ink on dimensionally stable polyester base material having a minimum thickness of 0.007 inch and a working surface suitable for inking to a scale of one inch equals one thousand feet (1" = 1,000'), and shall show correctly on its face:

   a. The exact grid length and bearing on the exterior boundaries of all the quarter sections. In addition, the ground level lengths of the exterior boundaries of all quarter sections, converted from National Geodetic Vertical Datum, shall be shown in distinctive lettering.

   b. All corners established and monuments erected in the field in their proper positions and orientations. The material of which the monuments and bench marks are made shall be noted at the representation thereof or by legend.

   c. The number of degrees, minutes, and seconds in the interior angles of all quarter sections.

   d. The coordinates of all section, quarter-section, and center of section corners surveyed.

e. The section number, indicated at the center of each section.

f. All basic NGS control stations within, and adjacent to, the project area and to which the horizontal control surveys are tied, together with the coordinates of the NGS stations.

g. A north point based upon grid bearings. The angle between geodetic and grid bearing (theta angle) shall be shown and shall represent the average value for the project area.

2. The Engineer shall provide for each secondary control station established (each corner within the project area), for each azimuth mark established, for each traverse station established, and for each reference bench mark established which is not also a secondary control station, a dossier on 8 1/2-inch by 11-inch tracing paper. Exhibit "C" attached hereto illustrates the required form and content for these dossiers. The following information shall be given for each station on the dossiers:

   a. Title giving the legal description by section, township, and range for the corners, permanent reference bench marks which are not also secondary control stations, traverse stations, and azimuth marks. Bench marks, traverse stations, and azimuth marks shall also be identified by assigned numbers. The center of a section shall be identified as the "true" or "occupied" center as the case may be.

   b. A sketch, showing the control station and the monument erected, to reach the station in relation to the salient features of the immediate vicinity. Witness monuments set shall be shown together with their ties. A north point shall be properly located thereon. The names of adjoining streets, state trunk highways, or public land shall be indicated. The bearing to the azimuth mark for the station shall be shown, together with a brief description of the azimuth mark.

   c. The coordinates of the corner and bench mark elevation of the monument referred to NGVD. For reference bench marks which are not also a secondary control station, only the bench mark elevation referred to NGVD need be given.

   d. The angle between geodetic and grid bearing at the station (theta angle).

   e. If necessary to supplement the sketch, a clear and concise description of each station so as to permit its ready recovery.

   f. An affidavit by the land surveyor setting forth the classification assigned to the corner (existing, obliterated, or lost) during its recovery or relocation and the salient factors determining the location or relocation, with particular emphasis upon old monumentation and accessories thereto found and used in the relocation process.

E. Monumenting

The Engineer shall mark or monument each section and quarter-section corner surveyed as follows:

1. Where the corner falls within an existing surfaced traveled way (concrete, bituminous surface, gravel), by drilling or cutting a neat hole in the pavement or street surface and setting a precast concrete monument in accordance with Exhibit "D." Where the corner falls within a concrete or bituminous surfaced traveled way, the Engineer may erect a concrete monument similar to the one shown in Exhibit "D" by excavating a hole 9 inches in diameter by 36 inches deep and pouring the monument in place using "AA" portland cement and placing the required reinforcing steel and brass cap substantially in accordance with Exhibit "D." In all cases, the elevation and setting must be approved by the ___________.

2. Where the corner falls on an earth surface, by setting a precast concrete monument as shown in Exhibit "D." In all cases, the elevation and setting must be approved by the __________.

3. Where the corner falls in a lake, stream, or inaccessible area, by setting a witness corner on the section or quarter-section line at a distance approved by the __________ away from the ordinary high water of the lake, the bank of the stream, or from an inaccessible area. Such witness corners shall be monumented by setting a precast concrete monument, and the elevation and setting shall be approved by the __________.

4. In all cases, the monuments erected shall be witnessed. Witness marks shall be selected for permanence and shall preferably consist of crosses cut in concrete curbs, walks, pavements, or culvert headwalls. Railroad spikes set in trees and telephone or power poles may be acceptable, but where used in poles shall be set flush with the surface of the telephone or power poles. In open fields, 1-inch-diameter by 36-inch-long iron pipe may be used. At least four such witness marks shall be established for each corner and tied to the section or quarter-section corner.

5. The brass caps shall conform to the details shown in Exhibit "E" attached hereto and be stamped with the corner notation at the time of setting. The concrete monument shall conform to the details shown in Exhibit "D" attached hereto. The dies used to cast the brass caps shall become the property of the __________.

6. In addition to the foregoing, the Engineer shall set one azimuth mark for each section or quarter-section corner surveyed using wherever possible a well-defined, permanent, distant object of the landscape that can be clearly identified and described. Where it is not possible or practical to use such an object, a commercial survey monument of a design approved by the __________ may be substituted.

IV. TOPOGRAPHIC MAPS

A. General

The Engineer shall prepare topographic maps to National Map Accuracy Standards in the form of digital map files. For the purpose of interpreting these standards within the context of the digital map files, the "publication scale" of these digital maps shall be one inch equals one hundred feet (1" = 100'). The Engineer shall also provide finished topographic maps drawn to a scale of one inch equals one hundred feet (1"= 100'). These finished maps shall be prepared in the form of ink tracings of the digital map files on dimensionally stable polyester base material having a minimum thickness of 0.004 inch. The area to be mapped, totaling _____ square miles, is shown on the sketch map attached hereto as Exhibit "A."

Base sheets suitable for the preparation of cadastral maps shall be provided. These sheets consist of reproducible tracings of the topographic map sheets showing all information required under Section IV B 1, 2, 3, 4, 5, 6, and 7 hereof, except hypsography, pavements, trails, fences, wooded areas, and other identifiable features.

B. Data to be Shown

Both the digital map files and the finished maps shall show correctly on each map face the following information:

1. Hypsography by contour lines having a vertical interval of two feet. All contours shall be drawn clear and sharp as continuous solid lines except through structures. Every fifth contour shall be accentuated and numbered. Elevations of saddles, kettles, summits, high points of all crests and low points of all sags in existing roadways, all existing road intersections, and all bridge decks at both ends of the bridge shall be shown as determined photogrammetrically, except where field elevations are available, to the

nearest one-quarter contour interval. All contour lines and elevations shall be referred to National Geodetic Vertical Datum as established by the NGS.

2. All planimetric details, such as pavements, curbs, walks, trails, railways, power lines, telephone lines, buildings, fences, wooded areas, and other identifiable features on the photography, shall be shown in their correct positions and orientation within the tolerances of these specifications.

3. All hydrographic features, such as marshes, lakes, streams, watercourses, and drainage ditches, shall be shown in their correct positions and orientation within the tolerances of these specifications.

4. All section and quarter-section lines and U. S. Public Land Survey corners established in the field surveys shall be shown in their correct positions and orientation, together with their exact grid lengths and bearings. The material of which the monuments marking said corners are made shall be indicated by symbol and legend, together with the state plane coordinates and bench mark elevations of the corners.

5. A north point based upon grid bearing. The angle between geodetic and grid bearing (theta angle) shall be shown on each map and shall represent an average value for the area covered by the map sheet.

6. A combination factor, sea level and scale, shall be given on each sheet for the reduction of measured ground lengths to corresponding grid lengths on the Wisconsin State Plane Coordinate System. The factor shall represent an average value for the area covered by the map sheet.

7. Grid lines shall be indicated at five-inch intervals and shall conform to the Wisconsin State Plane Coordinate System. Only the intersections of grid lines shall be shown on the completed maps, together with corresponding state plane coordinate values.

8. Such lettering as may be secured from available maps of the area or as may be furnished by the __________ relative to the names of salient geographic features. The names of all state and county trunk highways, public streets, and major streams and lakes shall be shown on the maps.

C. Digital Map File Organization and Specifications
The Engineer shall organize the digital map files in such a manner as to provide for plotted digital topographic maps similar in overall appearance to the topographic maps historically prepared for the __________. Among other things, this will require the preparation in digital form of a standard "map sheet" format, including appropriate title and legend information.

1. The digital map sheets shall be 36 inches by 36 inches in size when plotted at a scale of one inch equals one hundred feet (1" = 100'), and each sheet shall cover an entire U. S. Public Land Survey quarter section. The title shall contain a graphic scale and the following information: scale, date, type of map, location by county and state, name of the __________, name of the Engineer, and appropriate project and sheet numbers. The topographic maps shall overlap the adjacent one-quarter sections by 50 feet beyond the section or one-quarter-section lines.

2. The digital files shall be organized in such a manner that data elements can be selectively retrieved, manipulated, and displayed, either singly or in combination with other data elements. The categories of data elements within the file structure shall be as listed in the following table. All items identified in the individual data element column shall be individually retrievable within the digital map file structure.

Major Data Element Group	Individual Data Element Group
Map Sheet Elements	—Map border, map title and legend boxes, and map title lettering —Graphic scale, north point, and their associated lettering —Map legend symbols and map legend lettering —NGS triangulation station symbol locations, traverse station symbol locations, photo center symbol locations, bench mark symbol locations, and their associated lettering where they occur interior to the U. S. Public Land Survey section and quarter-section lines of the area being mapped —Wisconsin State Plane Coordinate System grid intersections and their corresponding state plane coordinate values where they occur exterior to the U. S. Public Land Survey section and quarter-section lines of the area being mapped and interior to the map sheet border
Geodetic and Geographic Reference Elements	—Wisconsin State Plane Coordinate System grid intersections where they occur interior to the U. S. Public Land Survey section and quarter-section lines of the area being mapped —U. S. Public Land Survey corners and monument symbols and their state plane coordinates —U. S. Public Land Survey section and quarter-section lines and their grid lengths and grid bearings
Hydrographic Elements	—Lakes, ponds, streams, watercourses, and drainage ditches symbolized as open water and their associated lettering —Streams, watercourses, and drainage ditches not symbolized as open water and their associated lettering —Marshes and their associated lettering

Major Data Element Group	Individual Data Element Group
Planimetric Elements	—Pavements and curbs and their associated lettering —Unimproved roads and their associated lettering —Driveways and their associated lettering —Trails and their associated lettering —Walks, power lines, telephone lines, and fences and their associated lettering —Railways and their associated lettering —Buildings, building foundations, and ruins and their associated lettering —Wooded areas and their associated lettering —Dams, piers, dock walls, and similar water-related structures and their associated lettering —Culverts and culvert headwalls and their associated lettering —Bridges and their associated lettering —Bridge wing walls, retaining walls, and similar transportation-related structures and their associated lettering —Runways, taxiways, and similar aviation-related features and their associated lettering —All other identifiable planimetric features not separately enumerated above and their associated lettering
Hyposometric Elements	—Accentuated contour lines and their numbers —Other contour lines —Spot elevations and their associated lettering —Water surface elevations and their associated lettering —U. S. Public Land Survey corner elevations

3. Point, line, and area data symbolization and lettering styles and sizes shall be established by the Engineer in such a manner that maps plotted from the digital files will approach in appearance, insofar as is possible, maps historically prepared for the __________. Samples of map feature symbolization and lettering styles and types proposed to be used by the Engineer shall be provided to the __________ for review and approval prior to the production of any maps. Upon completion of the project, the Engineer shall provide, in digital format, a copy of all symbolization conventions developed for the project.

4. Contour lines, land/water contact lines, and similar types of mapped lines shall be digitally encoded in such a manner that their plotted appearance approaches that of

traditional, drafted maps when plotted at the scale of one inch equals one hundred feet (1" = 100').

5. All continuous lines crossing map file boundaries shall have connectable points on the appropriate U. S. Public Land Survey section and quarter-section lines in the adjoining files. These points shall have identical x and y values.

6. All digital map data files shall be provided to the __________ in Intergraph Standard Interchange Format (ISIF). The ISIF file must be in ASCII format and supplied as a 1600-bpi, nine-track tape with a logical record length of 80 and a block length of 4000. There can be only one ISIF command per logical record, and carriage control commands or line feed commands cannot occur in the record. When creating an ISIF file, the Engineer shall provide the following operands for the Intergraph Set Environment File:

   AR = ORIGIN
   DP = Y
   ED = N
   FT = N
   LR = 80
   MA = N
   MO = 2D
   NE = NO
   PT = Y
   TD = 1600

   The Engineer shall provide a paper copy of the Set Environment File when the ISIF files are delivered. The paper copy shall show the operand settings for all variables listed above, as well as the operand settings of all other variables used to generate the ISIF files.

7. The Engineer shall also provide to the __________ a complete set of the Intergraph design files used to generate the ISIF files and prepare the finished topographic maps. Prior to the creation of the Intergraph design files, the Engineer shall submit the proposed file layout—that is, the level assignment of all map features and, as may be applicable, the text size, line code, color, weight, cell name, and pattern name associated with each map feature—to the __________ for review and approval.

   The Engineer shall observe the following conventions in creating the Intergraph design files:

   a. Only the following types of Intergraph graphics element generation will be permitted: line strings, circles, circular arcs, curves, complex strings (legal types only), symbols, and B-spline curves (type O-general B-spline curves with no knots).

   b. Only the Intergraph "TXT" command for graphics text generation will be permitted. However, either origin-based or box-referenced text can be utilized.

   c. The use of Intergraph miscellaneous command structures will not be permitted.

   The Engineer shall provide a paper copy of the final Intergraph design file layout when the files are delivered. The paper copy shall show the level assignments of all map features and, as may be applicable, the text size, line code, color, weight, cell name, and pattern name associated with each map feature.

8. All computer software used by the Engineer in the preparation and transfer of the digital map files shall be capable of maintaining the full mathematical precision of the horizontal and vertical control survey information developed under Section III of this contract. This may require the use of computer software written in double precision.

9. The Wisconsin State Plane Coordinate System, South Zone, shall be utilized as the coordinate system for the encoding of all digital map data elements.

D. Preparation of Finished Topographic Maps
The Engineer shall utilize digital plotting equipment having a minimum resolution of 400 DPI and capable of preparing finished topographic maps that approach in their overall appearance finished topographic maps prepared for the __________ by traditional hand drafting techniques. All plotting of the finished topographic maps shall be to a high standard of workmanship. The plotted map sheets shall be 36 inches by 36 inches in size, and each sheet shall cover an entire U. S. Public Land Survey quarter section. The title shall contain a graphic scale and the following information: scale, date, type of map, location by county and state, name of the __________, name of the Engineer, and appropriate project and sheet numbers. The finished topographic maps shall overlap the adjacent one-quarter sections by 50 feet beyond the section or one-quarter-section lines.

E. Precision and Accuracy Standards

1. Both the digital map files and the finished topographic maps shall be prepared to meet National Map Accuracy Standards at the scale of one inch equals one hundred feet (1" = 100'), and a certificate to this effect shall appear on the face of each map sheet.

2. The map projection grid for the digital map files shall be constructed inside the computer memory through key entry procedures. Digital plotting equipment utilized by the Engineer shall be capable of plotting each grid line or tick on the finished map sheets within 1/100 of an inch of the true grid values.

3. Each horizontal control station, section corner, and quarter-section corner contained in the digital map files shall be plotted on the map projection grid through key entry of the adjusted coordinates computed for the point. Digital plotting equipment utilized by the Engineer shall be capable of plotting each horizontal control station, section corner, and quarter-section corner on the finished map sheets within 1/100 of an inch of the true position as expressed by the adjusted coordinates computed for the point.

4. Ninety percent of all well-defined planimetric features shall be plotted so that their position in the digital map files and on the finished maps shall be accurate to within 1/30 of an inch of their true coordinate position, and no point shall be more than 1/20 of an inch from its true position.

5. The contours shall faithfully express the relief detail and topographic forms. Ninety percent of the elevations determined from the solid-line contours of the map shall have an accuracy with respect to true elevation of one-half contour interval, based on a two-foot contour interval, and no such elevations shall be in error by more than one contour interval.

6. All spot elevations shown on the maps, other than elevations of vertical control stations, shall be shown to the nearest 0.5 foot.

7. The completed topographic maps shall be field checked by the __________. The field measurements shall be compared against the map data, and any map sheets that do not conform to National Map Accuracy Standards and the requirements of these specifications shall be corrected by the Engineer to fully meet the specified accuracy.

V. ITEMS TO BE DELIVERED

Upon completion the Engineer shall deliver to the __________ the following items:

A. Two sets of digital map files specified under Section IV C herein containing topographic maps of the project area as designated herein. One set of files shall be ISIF files which shall be accompanied by a paper copy of the Set Environment File used in their preparation. The second set of files shall be in Intergraph design file format. The Intergraph design files shall be accompanied by a digital file of all point, line, and area symbology used in their preparation, as well as a paper copy of the Intergraph design file layout.

B. One set of reproducible original tracings on dimensionally stable polyester base material of the completed topographic maps of the project area as designated herein.

C. One set of reproducible tracings on dimensionally stable polyester base material of the cadastral base sheets specified under Section IV A herein.

D. One reproducible tracing of the control summary diagram specified under Section III D 1 herein.

E. One set of reproducible tracings of the control station dossier sheets specified under Section III D 2 herein.

F. One set of contact print aerial photographs specified under Section II J herein.

G. One set of contact print aerial photographs with vertical and horizontal control identified thereon. These photos shall be printed as specified under Section II H herein.

H. The original field notes and computations as specified under Section III D herein.

I. One photo index as specified under Section II herein.

J. The original aerial photograph negatives specified under Section II K herein.

K. The patterns used to cast the brass caps for the survey monuments.

VI. DELIVERY DATES

A. Photography
All photography shall be completed in the spring of ____. The contact prints and photo indices shall be delivered within 30 days after the completion of photography.

B. Topographic Maps and Digital Map Files
All topographic maps, digital map files, and cadastral base sheets shall be delivered on or before ___________.

C. Control Survey Data
All control survey data shall be delivered on or before ___________.

VII. BASIS OF PAYMENT

The contract price of the work, the lump sum of $ ____________, shall include all photogrammetric and control survey engineering services and all computer programming and computer operation services necessary for the delivery of the complete, finished photography, control surveys and monumentation, and maps and all other materials and items specified herein. This total contract price shall consist of the lump sum prices listed below for integral portions of the work:

A. Aerial photography of _____ square miles as specified @ $ _____ per square mile: $ ___________

B. Location, relocation, and monumentation of
____ U. S. Public Land Survey corners as
specified @ $ _____ per corner: $ ___________

C. Vertical control surveys over ____ U. S. Public Land
Survey corners as specified @ $ _____ per corner: $ ___________

D. Horizontal control surveys over ____ U. S. Public Land
Survey corners as specified @ $ _____ per corner: $ ___________

E. Digital map file creation, topographic mapping,
and cadastral base sheets of _____ square miles
as specified @ $ _____ per square mile: $ ___________

Total $ ___________

The foregoing unit prices are provided as a basis for computing any adjustment in the total cost of the contract that may have to be made due to any changes in the scope of the work ordered in writing by the __________ during the conduct of the project, and as a basis for computing work progress payments to the Engineer under the project.

It is expressly understood and agreed that in no event will the total compensation and reimbursement to be paid exceed the amounts stipulated above for all the service required as specified herein. The Engineer must submit invoices to the __________ during the progress of the work for partial payment on account for work completed and accepted to date. Such invoices shall not be submitted more often than every 30 days. The amount shown on such invoices shall be estimated on the basis of contract prices and the quantity of work completed and accepted by the __________. Such invoices will be checked by the __________ and payment made in an amount not to exceed 90 percent of such amount thereof as has been found by the __________ to reasonably represent the value of partially completed work, less any amounts previously paid on account. Payment of the 10 percent withheld during progress of the work shall be made upon final approval of the work by the __________.

Appendix A-4

DETAILED SPECIFICATIONS FOR AERIAL PHOTOGRAPHY, CONTROL SURVEYS, AND ONE INCH EQUALS 200 FEET SCALE DIGITAL TOPOGRAPHIC MAPPING

I. GENERAL

These specifications set forth the requirements of __________, for photogrammetric mapping services and digital map preparation, including aerial photography, topographic mapping, and accompanying control surveys and control survey monumentation. The Engineer shall furnish all labor, materials, and equipment necessary to complete properly the work specified herein.

II. PHOTOGRAPHY

A. General

The Engineer shall perform the necessary flying and photography to provide photographic coverage of an area approximately _____ square miles in extent shown on the sketch map attached hereto as Exhibit "A." The Engineer may sublet this phase of the work to a qualified and experienced firm specializing in aerial photography. The __________, however, retains the right to approve or reject any or all such firms which the Engineer may wish to engage.

B. Scale

The flight height above the average elevation of the ground shall be such that the negatives will have an average scale of one inch equals eight hundred feet (1" = 800'). Negatives having a departure from the specified scale by more than 5 percent because of tilt or abrupt changes in flying altitude may be rejected. The photography shall be suitable for compilation of the topographic maps specified herein, and the mapping flight height shall not vary from 4,800 feet above mean terrain by more than 5 percent.

C. Overlap

The overlap shall be sufficient to provide full stereoscopic coverage of the area to be mapped. The endlap shall average 63 percent plus or minus 5 percent. Endlap of less than 56 percent or more than 68 percent in one or more negatives shall be cause for rejection of the negatives in which such deficiency or excess occurs unless, within a stereoscopic pair, endlap exceeding 68 percent is necessary in areas of low ground elevation to attain the minimum 58 percent endlap in adjacent areas of high ground elevation. Wherever there is a change in direction of the flight lines, vertical photography on the beginning of a forward section shall endlap the photography of a back section by 100 percent. Any negatives having sidelap of less than 20 percent or more than 55 percent may be rejected.

D. Tilt

Negatives made with the optical axis of the aerial camera in a vertical position are desired. Tilt of any negative by more than three degrees, an average tilt of more than one degree for the entire project, or tilt between any two successive negatives exceeding four degrees may be cause for rejection.

E. Crab

Crab in excess of three degrees may be cause for rejection of the flight line of negatives or portions thereof in which such crab occurs.

F. Quality

The photographs shall be clear and sharp in detail and of average uniform density. They shall be free from clouds, cloud shadows, light streaks, static marks, or other blemishes which would interfere with their intended use. Except upon prior written authorization to the contrary by the __________, all photography shall be taken when the area to be mapped is free of snow, before foliation, and at such time as to ensure a minimum solar angle of 30 degrees.

G. Camera

For topographic and contour mapping, photography shall be exposed with a distortion-free six-inch focal length precision aerial mapping camera equipped with a between-the-lens element shutter to produce negatives nine inches by nine inches in size. The Engineer shall furnish the __________ with a precision camera calibration report prepared by the National Bureau of Standards for the camera to be used.

H. Contact Prints

The contact prints from the vertical negatives shall be printed on double-weight semi-matte paper of suitable contrast.

I. Photo Index

Photo indices shall be prepared by directly photographing on safety base film at a convenient scale the assembly of contact prints from all indexed and evaluated prints used. One photo index map reproduced on chronopaque or other approved dimensionally stable base material shall be delivered to the __________. The photo index shall carry a suitable title, scale, and north point.

J. Delivery of Photography

One set of contact print photographs on double-weight semi-matte paper at a scale of one inch equals eight hundred feet (1" = 800') shall be furnished the __________ upon completion of this contract.

K. Ownership of Negatives

All negatives shall become the property of the __________ and shall be delivered to the __________ upon completion of this contract.

III. CONTROL SURVEYS

A. General

The Engineer shall furnish all labor, materials, and equipment necessary to complete properly the necessary horizontal and vertical control survey monumentation as specified herein.

B. Horizontal Control

1. The horizontal control survey work shall include the recovery or relocation and monumentation of all U. S. Public Land Survey corners, including section and one-quarter-section corners, "centers" of sections, and correction corners, throughout and along the exterior of the approximately _____ square mile area to be mapped. These corners, totaling ____ in all, are indicated on the sketch map attached hereto as Exhibit "A." If the original U. S. Public Land Survey corners are not recoverable, the Engineer shall determine the status thereof under U. S. Public Land Office definitions and shall follow the prescribed procedures of that Office in their relocation. In any case, the original land survey corners and corners as aforementioned shall be monumented and witnessed as provided under Section III E herein.

2. All field work with respect to the location and relocation of all the aforementioned corners shall be based upon, and include the assembly of, all authoritative information, such as title documents, subdivision plats, private and public survey records, and existing monumentation and occupation, that may be useful in determining the actual position of the U. S. Public Land Survey lines and corners and all other corners, as well as the proper analysis of this information, to arrive at the best determination of the actual location of the said lines and corners. Proper performance in this regard depends largely upon a knowledge of local survey customs, conditions, and laws of boundaries

and titles, and for this reason, must be properly supervised by a competent and qualified registered land surveyor. The Engineer shall sublet this phase of the control survey work to a qualified and experienced land survey firm which regularly practices in the area to be mapped. The __________, however, retains the right to approve or reject any or all such local firms which the Engineer may wish to engage.

3. With regard to the location or relocation of the "center" of the section, that point which physical or other evidence indicates to be the "used or recognized center of the section" (occupied center) shall be located or relocated in accordance with paragraph 2 above and monumented as provided under Section III E 5 herein. When all sources of information have been explored and there is no evidence of an "occupied center," the Engineer, after approval by the __________, shall set and monument, in accordance with Section III E 5, the "true center" of the section. Such "true center" shall be that point at the intersection of straight lines joining opposite quarter corners.

4. The double corners along town lines shall be located or relocated and monumented in accordance with paragraphs 1 and 2 above; and the closing corners governing the location of the U. S. Public Land Survey lines in the northerly tier of one-quarter sections in Township ___ North, Range ___ East, shall be set on the straight lines connecting the section and one-quarter-section corners on the town line governing the location of the U. S. Public Land Survey lines in the southerly tier of one-quarter sections in Township ___ North, Range ___ East.

5. Having recovered or relocated and monumented all of the aforementioned corners in the approximately _____ square mile area specified, control survey traverses shall be run which utilize and incorporate all of the monumented corners as stations, to determine the coordinates of the said corners and the lengths and bearings of all the quarter-section lines. All coordinates shall be based upon the Wisconsin Coordinate System, South Zone; and sufficient survey connections shall be made to basic National Geodetic Survey (NGS) control stations of the National Geodetic Survey control net to permit the proper checks and adjustments to be made both in traverse lengths and bearings and in the coordinate values of the monumented U. S. Public Land Survey corners. Such ties shall originate and end at basic control stations for which closures are known and available or shall be run to make a closed and checked circuit. Upon prior approval of the __________, the Engineer may substitute other survey methods, such as triangulation or trilateration, for the above-specified traverses in order to determine the coordinates of the monumented corners and the lengths and bearings of all the quarter-section lines. Approval by the __________ of such substitute survey methods shall be based upon a review of detailed net layouts and procedures proposed to be followed by the Engineer.

   The accuracy of the horizontal control surveys shall conform to the specifications for NGS third-order class I accuracy for traverse as set forth in "Standards and Specifications for Geodetic Control Networks" prepared by the Federal Geodetic Control Committee. This publication is incorporated in these specifications by reference as though fully herein set forth. All field measurements shall be accurately adjusted by NGS methods to provide closed traverses before traverse station coordinates are computed, the coordinates of the U. S. Public Land Survey corners are computed, and attendant lengths and bearings of the quarter-section lines are computed so as to form closed geometric figures for the quarter sections, and before the topographic mapping is undertaken.

   Whenever the Engineer recovers and uses an NGS control survey station in the conduct of the control survey work, he shall prepare a "Report on Condition of Survey Mark and Witness Marks" utilizing the standard form provided for this purpose by the NGS, and forward the completed copy of the form to the NGS Washington Office, with a copy to the __________.

All supplemental control for photo mapping purposes shall be based upon the control net just described.

C. Vertical Control
The vertical control survey shall be based upon National Geodetic Vertical Datum, 1929 Adjustment, as established by the NGS and hereinafter referred to as "NGVD." Closed spirit-level circuits shall be run to establish permanent bench marks in the project area. All spirit-level circuits shall be of second-order class II accuracy as set forth in "Standards and Specifications for Geodetic Control Networks" prepared by the Federal Geodetic Control Committee. This publication is incorporated in these specifications by reference as though fully herein set forth. All level circuits shall be accurately adjusted for closure by NGS methods. Elevations shall be obtained for ___ monuments marking the section and quarter-section corners throughout the area to be mapped, and these monuments shall serve as permanent bench marks. In addition, permanent reference bench marks shall be set wherever possible and as may be directed by the __________ along the spirit-level lines on such objects as bridge abutments and wing walls, headwalls of large culverts, water tables of large buildings, outcroppings of ledge rock, or any other stable objects which are unlikely to be displaced vertically. It is the intent of these specifications that one additional bench mark shall be established for each U. S. Public Land Survey corner monumented and shall be set so that the elevation of the corner monument may be readily verified from the additional permanent bench mark by a single spirit-level position. Supplementary vertical control for topographic mapping shall provide a minimum of four vertical control points in each stereoscopic model. The supplementary control points shall be established by field survey and shall be located at or near the four corners of the stereoscopic models used in topographic map preparation.

D. Control Survey Computation Data and Plats
The Engineer shall keep all field notes and office computations n a neat and orderly manner, clearly indexed, and open for inspection and checking during the course of the work. Upon completion and acceptance, the originals of all field notes and computations shall be furnished the __________ and shall become their property. The Engineer shall at all times before final acceptance of the work furnish instruments and assistance to a duly authorized agent of the __________ for such checking of field work and computations as may be deemed necessary by the __________.

1. The Engineer shall deliver to the __________ for final acceptance a diagram summarizing the control survey data. Exhibit "B" attached hereto illustrates the required form and content of this diagram. This diagram shall be prepared in ink on dimensionally stable polyester base material having a minimum thickness of 0.007 inch and a working surface suitable for inking to a scale of one inch equals one thousand feet (1" = 1,000'), and shall show correctly on its face:

   a. The exact grid length and bearing on the exterior boundaries of all the quarter sections. In addition, the ground level lengths of the exterior boundaries of all quarter sections, converted from National Geodetic Vertical Datum, shall be shown in distinctive lettering.

   b. All corners established and monuments erected in the field in their proper positions and orientations. The material of which the monuments and bench marks are made shall be noted at the representation thereof or by legend.

   c. The number of degrees, minutes, and seconds in the interior angles of all quarter sections.

   d. The coordinates of all section, quarter-section, and center of section corners surveyed.

e. The section number, indicated at the center of each section.

f. All basic NGS control stations within, and adjacent to, the project area and to which the horizontal control surveys are tied, together with the coordinates of the NGS stations.

g. A north point based upon grid bearings. The angle between geodetic and grid bearing (theta angle) shall be shown and shall represent the average value for the project area.

2. The Engineer shall provide for each secondary control station established (each corner within the project area), for each azimuth mark established, for each traverse station established, and for each reference bench mark established which is not also a secondary control station, a dossier on 8 1/2-inch by 11-inch tracing paper. Exhibit "C" attached hereto illustrates the required form and content for these dossiers. The following information shall be given for each station on the dossiers:

   a. Title giving the legal description by section, township, and range for the corners, permanent reference bench marks which are not also secondary control stations, traverse stations, and azimuth marks. Bench marks, traverse stations, and azimuth marks shall also be identified by assigned numbers. The center of a section shall be identified as the "true" or "occupied" center as the case may be.

   b. A sketch, showing the control station and the monument erected, to reach the station in relation to the salient features of the immediate vicinity. Witness monuments set shall be shown together with their ties. A north point shall be properly located thereon. The names of adjoining streets, state trunk highways, or public land shall be indicated. The bearing to the azimuth mark for the station shall be shown, together with a brief description of the azimuth mark.

   c. The coordinates of the corner and bench mark elevation of the monument referred to NGVD. For reference bench marks which are not also a secondary control station, only the bench mark elevation referred to NGVD need be given.

   d. The angle between geodetic and grid bearing at the station (theta angle).

   e. If necessary to supplement the sketch, a clear and concise description of each station so as to permit its ready recovery.

   f. An affidavit by the land surveyor setting forth the classification assigned to the corner (existing, obliterated, or lost) during its recovery or relocation and the salient factors determining the location or relocation, with particular emphasis upon old monumentation and accessories thereto found and used in the relocation process.

E. Monumenting

The Engineer shall mark or monument each section and quarter-section corner surveyed as follows:

1. Where the corner falls within an existing surfaced traveled way (concrete, bituminous surface, gravel), by drilling or cutting a neat hole in the pavement or street surface and setting a precast concrete monument in accordance with Exhibit "D." Where the corner falls within a concrete or bituminous surfaced traveled way, the Engineer may erect a concrete monument similar to the one shown in Exhibit "D" by excavating a hole 9 inches in diameter by 36 inches deep and pouring the monument in place using "AA" portland cement and placing the required reinforcing steel and brass cap substantially in accordance with Exhibit "D." In all cases, the elevation and setting must be approved by the __________.

2. Where the corner falls on an earth surface, by setting a precast concrete monument as shown in Exhibit "D." In all cases, the elevation and setting must be approved by the __________.

3. Where the corner falls in a lake, stream, or inaccessible area, by setting a witness corner on the section or quarter-section line at a distance approved by the __________ away from the ordinary high water of the lake, the bank of the stream, or from an inaccessible area. Such witness corners shall be monumented by setting a precast concrete monument, and the elevation and setting shall be approved by the __________.

4. In all cases, the monuments erected shall be witnessed. Witness marks shall be selected for permanence and shall preferably consist of crosses cut in concrete curbs, walks, pavements, or culvert headwalls. Railroad spikes set in trees and telephone or power poles may be acceptable, but where used in poles shall be set flush with the surface of the telephone or power poles. In open fields, 1-inch-diameter by 36-inch-long iron pipe may be used. At least four such witness marks shall be established for each corner and tied to the section or quarter-section corner.

5. The brass caps shall conform to the details shown in Exhibit "E" attached hereto and be stamped with the corner notation at the time of setting. The concrete monument shall conform to the details shown in Exhibit "D" attached hereto. The dies used to cast the brass caps shall become the property of the __________.

6. In addition to the foregoing, the Engineer shall set one azimuth mark for each section or quarter-section corner surveyed using wherever possible a well-defined, permanent, distant object of the landscape that can be clearly identified and described. Where it is not possible or practical to use such an object, a commercial survey monument of a design approved by the __________ may be substituted.

IV. TOPOGRAPHIC MAPS

A. General

The Engineer shall prepare topographic maps to National Map Accuracy Standards in the form of digital map files. For the purpose of interpreting these standards within the context of the digital map files, the "publication scale" of these digital maps shall be one inch equals two hundred feet (1" = 200'). The Engineer shall also provide finished topographic maps drawn to a scale of one inch equals two hundred feet (1" = 200'). These finished maps shall be prepared in the form of ink tracings of the digital map files on dimensionally stable polyester base material having a minimum thickness of 0.004 inch. The area to be mapped, totaling _____ square miles, is shown on the sketch map attached hereto as Exhibit "A."

Base sheets suitable for the preparation of cadastral maps shall be provided. These sheets consist of reproducible tracings of the topographic map sheets showing all information required under Section IV B 1, 2, 3, 4, 5, 6, and 7 hereof, except hypsography, pavements, trails, fences, wooded areas, and other identifiable features.

B. Data to be Shown

Both the digital map files and the finished maps shall show correctly on each map face the following information:

1. Hypsography by contour lines having a vertical interval of two feet. All contours shall be drawn clear and sharp as continuous solid lines except through structures. Every fifth contour shall be accentuated and numbered. Elevations of saddles, kettles, summits, high points of all crests and low points of all sags in existing roadways, all existing road intersections, and all bridge decks at both ends of the bridge shall be shown as determined photogrammetrically, except where field elevations are available, to the

nearest one-quarter contour interval. All contour lines and elevations shall be referred to National Geodetic Vertical Datum as established by the NGS.

2. All planimetric detail, such as pavements, curbs, trails, railways, power line towers, buildings, fences, wooded areas, and other identifiable features on the photography, shall be shown in their correct positions and orientation within the tolerances of these specifications.

3. All hydrographic features, such as marshes, lakes, streams, watercourses, and drainage ditches, shall be shown in their correct positions and orientation within the tolerances of these specifications.

4. All section and quarter-section lines and U. S. Public Land Survey corners established in the field surveys shall be shown in their correct positions and orientation, together with their exact grid lengths and bearings. The material of which the monuments marking said corners are made shall be indicated by symbol and legend, together with the state plane coordinates and bench mark elevations of the corners.

5. A north point based upon grid bearing. The angle between geodetic and grid bearing (theta angle) shall be shown on each map and shall represent an average value for the area covered by the map sheet.

6. A combination factor, sea level and scale, shall be given on each sheet for the reduction of measured ground lengths to corresponding grid lengths on the Wisconsin State Plane Coordinate System. The factor shall represent an average value for the area covered by the map sheet.

7. Grid lines shall be indicated at five-inch intervals and shall conform to the Wisconsin State Plane Coordinate System. Only the intersections of grid lines shall be shown on the completed maps, together with corresponding state plane coordinate values.

8. Such lettering as may be secured from available maps of the area or as may be furnished by the ___________ relative to the names of salient geographic features. The names of all state and county trunk highways, public streets, and major streams and lakes shall be shown on the maps.

C. Digital Map File Organization and Specifications
The Engineer shall organize the digital map files in such a manner as to provide for plotted digital topographic maps similar in overall appearance to the topographic maps historically prepared for the ___________. Among other things, this will require the preparation in digital form of a standard "map sheet" format, including appropriate title and legend information.

1. The digital map sheets shall be 36 inches by 36 inches in size when plotted at a scale of one inch equals two hundred feet (1" = 200'), and each sheet shall cover an entire U. S. Public Land Survey section. The title shall contain a graphic scale and the following information: scale, date, type of map, location by county and state, name of the ___________, name of the Engineer, and appropriate project and sheet numbers. The topographic maps shall overlap the adjacent sections by 100 feet beyond the section lines.

2. The digital files shall be organized in such a manner that data elements can be selectively retrieved, manipulated, and displayed, either singly or in combination with other data elements. The categories of data elements within the file structure shall be as listed in the following table. All items identified in the individual data element column shall be individually retrievable within the digital map file structure.

Major Data Element Group	Individual Data Element Group
Map Sheet Elements	—Map border, map title and legend boxes, and map title lettering —Graphic scale, north point, and their associated lettering —Map legend symbols and map legend lettering —NGS triangulation station symbol locations, traverse station symbol locations, photo center symbol locations, bench mark symbol locations, and their associated lettering where they occur interior to the U. S. Public Land Survey section lines of the area being mapped —Wisconsin State Plane Coordinate System grid intersections and their corresponding state plane coordinate values where they occur exterior to the U. S. Public Land Survey section lines of the area being mapped and interior to the map sheet border
Geodetic and Geographic Reference Elements	—Wisconsin State Plane Coordinate System grid intersections where they occur interior to the U. S. Public Land Survey section lines of the area being mapped —U. S. Public Land Survey corners and monument symbols and their state plane coordinates —U. S. Public Land Survey section and quarter-section lines and their grid lengths and grid bearings
Hydrographic Elements	—Lakes, ponds, streams, watercourses, and drainage ditches symbolized as open water and their associated lettering —Streams, watercourses, and drainage ditches not symbolized as open water and their associated lettering —Marshes and their associated lettering

Major Data Element Group	Individual Data Element Group
Planimetric Elements	—Pavements and curbs and their associated lettering —Unimproved roads and their associated lettering —Driveways and their associated lettering —Trails and their associated lettering —Power line towers and fences and their associated lettering —Railways and their associated lettering —Buildings, building foundations, and ruins and their associated lettering —Wooded areas and their associated lettering —Dams, piers, dock walls, and similar water-related structures and their associated lettering —Culverts and culvert headwalls and their associated lettering —Bridges and their associated lettering —Bridge wing walls, retaining walls, and similar transportation-related structures and their associated lettering —Runways, taxiways, and similar aviation-related features and their associated lettering —All other identifiable planimetric features not separately enumerated above and their associated lettering
Hyposometric Elements	—Accentuated contour lines and their numbers —Other contour lines —Spot elevations and their associated lettering —Water surface elevations and their associated lettering —U. S. Public Land Survey corner elevations

3. Point, line, and area data symbolization and lettering styles and sizes shall be established by the Engineer in such a manner that maps plotted from the digital files will approach in appearance, insofar as is possible, maps historically prepared for the __________. Samples of map feature symbolization and lettering styles and types proposed to be used by the Engineer shall be provided to the __________ for review and approval prior to the production of any maps. Upon completion of the project, the Engineer shall provide, in digital format, a copy of all symbolization conventions developed for the project.

4. Contour lines, land/water contact lines, and similar types of mapped lines shall be digitally encoded in such a manner that their plotted appearance approaches that of

traditional, drafted maps when plotted at the scale of one inch equals two hundred feet (1" = 200').

5. All continuous lines crossing map file boundaries shall have connectable points on the appropriate U. S. Public Land Survey section lines in the adjoining files. These points shall have identical x and y values.

6. All digital map data files shall be provided to the __________ in Intergraph Standard Interchange Format (ISIF). The ISIF file must be in ASCII format and supplied as a 1600-bpi, nine-track tape with a logical record length of 80 and a block length of 4000. There can be only one ISIF command per logical record, and carriage control commands or line feed commands cannot occur in the record. When creating an ISIF file, the Engineer shall provide the following operands for the Intergraph Set Environment File:

   AR = ORIGIN
   DP = Y
   ED = N
   FT = N
   LR = 80
   MA = N
   MO = 2D
   NE = NO
   PT = Y
   TD = 1600

   The Engineer shall provide a paper copy of the Set Environment File when the ISIF files are delivered. The paper copy shall show the operand settings for all variables listed above, as well as the operand settings of all other variables used to generate the ISIF files.

7. The Engineer shall also provide to the __________ a complete set of the Intergraph design files used to generate the ISIF files and prepare the finished topographic maps. Prior to the creation of the Intergraph design files, the Engineer shall submit the proposed file layout—that is, the level assignment of all map features and, as may be applicable, the text size, line code, color, weight, cell name, and pattern name associated with each map feature—to the __________ for review and approval.

   The Engineer shall observe the following conventions in creating the Intergraph design files:

   a. Only the following types of Intergraph graphics element generation will be permitted: line strings, circles, circular arcs, curves, complex strings (legal types only), symbols, and B-spline curves (type O-general B-spline curves with no knots).

   b. Only the Intergraph "TXT" command for graphics text generation will be permitted. However, either origin-based or box-referenced text can be utilized.

   c. The use of Intergraph miscellaneous command structures will not be permitted.

   The Engineer shall provide a paper copy of the final Intergraph design file layout when the files are delivered. The paper copy shall show the level assignments of all map features and, as may be applicable, the text size, line code, color, weight, cell name, and pattern name associated with each map feature.

8. All computer software used by the Engineer in the preparation and transfer of the digital map files shall be capable of maintaining the full mathematical precision of the horizontal and vertical control survey information developed under Section III of this contract. This may require the use of computer software written in double precision.

9. The Wisconsin State Plane Coordinate System, South Zone, shall be utilized as the coordinate system for the encoding of all digital map data elements.

D. Preparation of Finished Topographic Maps
The Engineer shall utilize digital plotting equipment having a minimum resolution of 400 DPI and capable of preparing finished topographic maps that approach in their overall appearance finished topographic maps prepared for the __________ by traditional hand drafting techniques. All plotting of the finished topographic maps shall be to a high standard of workmanship. The plotted map sheets shall be 36 inches by 36 inches in size, and each sheet shall cover an entire U. S. Public Land Survey section. The title shall contain a graphic scale and the following information: scale, date, type of map, location by county and state, name of the __________, name of the Engineer, and appropriate project and sheet numbers. The finished topographic maps shall overlap the adjacent sections by 100 feet beyond the section lines.

E. Precision and Accuracy Standards

1. Both the digital map files and the finished topographic maps shall be prepared to meet National Map Accuracy Standards at the scale of one inch equals two hundred feet (1" = 200'), and a certificate to this effect shall appear on the face of each map sheet.

2. The map projection grid for the digital map files shall be constructed inside the computer memory through key entry procedures. Digital plotting equipment utilized by the Engineer shall be capable of plotting each grid line or tick on the finished map sheets within 1/100 of an inch of the true grid values.

3. Each horizontal control station, section corner, and quarter-section corner contained in the digital map files shall be placed on the map projection grid through key entry of the adjusted coordinates computed for the point. Digital plotting equipment utilized by the Engineer shall be capable of plotting each horizontal control station, section corner, and quarter-section corner on the finished map sheets within 1/100 of an inch of the true position as expressed by the adjusted coordinates computed for the point.

4. Ninety percent of all well-defined planimetric features shall be plotted so that their position in the digital map files and on the finished maps shall be accurate to within 1/30 of an inch of their true coordinate position, and no point shall be more than 1/20 of an inch from its true position.

5. The contours shall faithfully express the relief detail and topographic forms. Ninety percent of the elevations determined from the solid-line contours of the map shall have an accuracy with respect to true elevation of one-half contour interval, based on a two-foot contour interval, and no such elevations shall be in error by more than one contour interval.

6. All spot elevations shown on the maps, other than elevations of vertical control stations, shall be shown to the nearest 0.5 foot.

7. The completed topographic maps shall be field checked by the __________. The field measurements shall be compared against the map data, and any map sheets that do not conform to National Map Accuracy Standards and the requirements of these specifications shall be corrected by the Engineer to fully meet the specified accuracy.

V. ITEMS TO BE DELIVERED

Upon completion the Engineer shall deliver to the __________ the following items:

A. Two sets of digital map files specified under Section IV C herein containing topographic maps of the project area as designated herein. One set of files shall be ISIF files which shall be accompanied by a paper copy of the Set Environment File used in their preparation. The second set of files shall be in Intergraph design file format. The Intergraph design files shall be accompanied by a digital file of all point, line, and area symbology used in their preparation, as well as a paper copy of the Intergraph design file layout.

B. One set of reproducible original tracings on dimensionally stable polyester base material of the completed topographic maps of the project area as designated herein.

C. One set of reproducible tracings on dimensionally stable polyester base material of the cadastral base sheets specified under Section IV A herein.

D. One reproducible tracing of the control summary diagram specified under Section III D 1 herein.

E. One set of reproducible tracings of the control station dossier sheets specified under Section III D 2 herein.

F. One set of contact print aerial photographs specified under Section II J herein.

G. One set of contract print aerial photographs with vertical and horizontal control identified thereon. These photos shall be printed as specified under Section II H herein.

H. The original field notes and computations as specified under Section III D herein.

I. One photo index as specified under Section II herein.

J. The original aerial photograph negatives specified under Section II K herein.

K. The patterns used to cast the brass caps for the survey monuments.

VI. DELIVERY DATES

A. Photography
All photography shall be completed in the spring of ____. The contact prints and photo indices shall be delivered within 30 days after the completion of photography.

B. Topographic Maps and Digital Map Files
All topographic maps, digital map files, and cadastral base sheets shall be delivered on or before __________.

C. Control Survey Data
All control survey data shall be delivered on or before __________.

VII. BASIS OF PAYMENT

The contract price of the work, the lump sum of $ ____________, shall include all photogrammetric and control survey engineering services and all computer programming and computer operation services necessary for the delivery of the complete, finished photography, control surveys and monumentation, and maps and all other materials and items specified herein. This total contract price shall consist of the lump sum prices listed below for integral portions of the work:

A. Aerial photography of _____ square miles as specified @ $ _____ per square mile: $ ____________

B. Location, relocation, and monumentation of ____ U. S. Public Land Survey corners as specified @ $ _____ per corner: $ __________

C. Vertical control surveys over ____ U. S. Public Land Survey corners as specified @ $ _____ per corner: $ __________

D. Horizontal control surveys over ____ U. S. Public Land Survey corners as specified @ $ _____ per corner: $ __________

E. Digital map file creation, topographic mapping, and cadastral base sheets of _____ square miles as specified @ $ _____ per square mile: $ __________

Total $ __________

The foregoing unit prices are provided as a basis for computing any adjustment in the total cost of the contract that may have to be made due to any changes in the scope of the work ordered in writing by the __________ during the conduct of the project, and as a basis for computing work progress payments to the Engineer under the project.

It is expressly understood and agreed that in no event will the total compensation and reimbursement to be paid exceed the amounts stipulated above for all the service required as specified herein. The Engineer must submit invoices to the __________ during the progress of the work for partial payment on account for work completed and accepted to date. Such invoices shall not be submitted more often than every 30 days. The amount shown on such invoices shall be estimated on the basis of contract prices and the quantity of work completed and accepted by the __________. Such invoices will be checked by the __________ and payment made in an amount not to exceed 90 percent of such amount thereof as has been found by the __________ to reasonably represent the value of partially completed work, less any amounts previously paid on account. Payment of the 10 percent withheld during progress of the work shall be made upon final approval of the work by the __________.

GEOMETRIC GEODETIC ACCURACY STANDARDS

AND

SPECIFICATIONS FOR USING GPS RELATIVE POSITIONING TECHNIQUES

FEDERAL GEODETIC CONTROL COMMITTEE

Rear Adm. Wesley V. Hull, Chairman

Version 5.0: May 11, 1988
Reprinted with corrections: August 1, 1989

Note: This is a preliminary document. Use only as a guideline for the planning and execution of geodetic surveys using GPS relative positioning techniques.

FOREWORD

This document was first prepared and distributed in draft form as version 1.0 in May 1, 1985. It supersedes all previous versions, including version 4.0, dated September 1, 1986.

The document is subject to frequent revisions as requirements for classification of geodetic control surveys change, as the definitions for accuracy standards are modified, as we gain experience in performing GPS surveys with an enhanced satellite system, as GPS surveying equipment are improved, as the field procedures are streamlined, and as refinements are made to processing software.

Questions and comments may be sent to:

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D I S C L A I M E R

Until this document is officially sanctioned by the Federal Geodetic Control Committee (FGCC), distribution does not constitute, in any way, an endorsement by the National Geodetic Survey, CGS, NOS, NOAA, or the FGCC. The "Geometric Geodetic Survey Standards and Specifications for Geodetic Surveys Using GPS Relative Positioning Techniques" is intended only for the purpose of providing the user, guidelines for planning, execution and classification of geodetic surveys performed by GPS satellite surveying relative positioning methods using carrier phase observations.

GEOMETRIC GEODETIC ACCURACY STANDARDS
AND
SPECIFICATIONS FOR GPS RELATIVE POSITIONING TECHNIQUES

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GEOMETRIC GEODETIC ACCURACY STANDARDS
AND
SPECIFICATIONS FOR USING GPS RELATIVE POSITIONING TECHNIQUES

Federal Geodetic Control Committee
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ABSTRACT. The practical experience gained in performing relative positioning geodetic surveys using Global Positioning System (GPS) satellite surveying techniques, the advancements in software developments, improvements in geodetic survey receiver systems, development of improved planning methods and observing strategies, and the results of tests by the Federal Geodetic Control Committee, provide the basis for development of geometric (three-dimensional) geodetic survey standards and specifications for GPS relative positioning surveys. The geometric standards are designed to meet classification requirements for a wide range of three-dimensional relative positional accuracy requirements. The GPS specifications cover network geometry, instrumentation, calibration procedures, field procedures, and office reduction procedures. Because application of GPS relative positioning techniques are relatively new, definitions for the accuracy standards and specifications for field procedures and data analysis will undergo rapid evolution. This will mean frequent revisions for the next several years or until at least a few years beyond deployment of the Block II satellites of the operational GPS constellation (presently 1991).

INTRODUCTION

The rapidly growing use of the Global Positioning System (GPS) for geodetic surveying applications has resulted in a critical need for development of acceptable accuracy standards and GPS survey specifications. Specifications are essential to promote efficiency in the conduct of field operations and to facilitate classification of surveys.

The extensive GPS survey field experience and numerous reports on the analysis of results for GPS survey projects are the basis for developing specifications for GPS geodetic surveys. These results are documented in unpublished National Geodetic Survey (NGS) GPS project reports, published NGS special reports, the FGCC GPS survey system test reports, papers in the proceedings of the First International Symposium on Precise Positioning with the Global Positioning System held in Rockville, Maryland, April 1985 (Goad 1985), and papers in the proceedings of the Fourth International Geodetic Symposium on Satellite Positioning held in Austin, Texas, April 1986 (Defense Mapping Agency (DMA) and NGS 1986).

The GPS specifications are for control surveys performed by relative positioning techniques where two or more receivers are collecting carrier phase measurement data simultaneously. They are a guide for determining how to meet requirements for horizontal, vertical, and azimuth accuracy standards.

Survey standards are defined as minimum accuracies that are necessary to meet specific objectives. Specifications are defined as field methods required to meet a particular survey standard. This document will complement the FGCC (Federal Geodetic Control Committee) Standards and Specifications for Geodetic Control Networks dated September 1984 (FGCC 1984).

The 1984 standards for horizontal coordinates are based on a "distance accuracy standard" which is the ratio of the relative positional error of a pair of control points to the horizontal separation of those points. As this ratio increases, the classification of the control survey degrades. If a relative positional error is constant, classification degrades as minimum separation between stations decreases. Thus, there is a minimum station spacing for the 1984 standards. The most stringent distance accuracy standard is 1:100,000 (10 ppm) which is classified as an order 1 standard. For example, if the relative positional error was ± 1 cm (2 sigma), the minimum distance between stations in a project would be 1 km.

The 1984 vertical control standards, which are based on elevation difference accuracies, is considerably more stringent. For example, the maximum elevation difference accuracies for a first-order, class I, survey range from 2.0 to 0.05 ppm for bench marks spaced 1 to 100 km apart. This is computed using the equation $b = S/\sqrt{d}$ where b is the maximum elevation difference accuracy, S is propagated elevation difference in mm between stations, and d is distance between stations in km. Thus, for a relative positional error of ± 1 cm (2 sigma), the minimum distance between stations in a project would be 100 km.

Experience has shown that it is possible to successfully measure base lines by GPS relative positioning techniques and obtain precisions routinely at the (1 cm + 1-2 ppm) level in each component or 10 times better than the FGCC 1984 order 1 standard. With careful planning, the use of appropriate observing strategies, and data processing with optimized software and procedures, precisions approaching (0.3 cm + 0.01 ppm) have been achieved. This is 1000 times better than the existing order 1 distance accuracy standard of 1:100,000.

Geometric or ellipsoidal height differences, when combined with geoid height differences, can give very useful orthometric height differences. Typical accuracies for orthometric height differences determined from the results of GPS relative positioning surveys range from a centimeter to several decimeters (depending on location of the survey project and spacing between stations). In most cases, the dominant error in the orthometric height differences is the error in estimating the geoidal slope or geoid undulation differences (Zilkoski and Hothem 1988).

In part 1 of this document, geometric (three-dimensional) accuracy standards for classifying relative positioning surveys by space measurement techniques are presented. These accuracy standards complement the terrestrial distance accuracy standards provided in the September 1984 document. In addition to three low orders, three high order standards are provided: 0.01, 0.1 and 1 ppm.

To classify elevation differences determined indirectly from use of space survey systems such as GPS, accuracy standards consistent with expected user requirements are proposed in Appendix E. These proposed elevation difference standards do not replace the present FGCC accuracy standards for elevation differences determined directly by precise differential or trigonometric leveling measurement techniques. They are to be used only for classifying or specifying the accuracy for elevation (orthometric height) differences determined from systems that measure height differences relative to a reference ellipsoid rather than a mean sea level datum or the National Geodetic Vertical Datum (NGVD) 1929.

The format for GPS relative positioning specifications is based on the current edition of the FGCC document for standards and specifications for geodetic control networks (FGCC 1984). The section on specifications includes network design and geometry, instrumentation, calibration procedures, field procedures, and office processing procedures.

These geometric accuracy standards and GPS relative positioning survey specifications are now under review by the Federal Geodetic Control Committee (FGCC). The FGCC, a U.S. interagency committee, is officially responsible for the adoption of standards and specifications for geodetic control networks. (See appendix A.)

BACKGROUND

GPS satellite surveying is a three-dimensional measurement system based on observations of the radio signals of the NAVSTAR Global Positioning System. The GPS observations are processed to determine station positions in Cartesian coordinates (X,Y,Z), which can be converted to geodetic coordinates (latitude, longitude, and height-above-reference ellipsoid). With adequate connections to vertical control network points and determination of the height of the geoid, orthometric heights or elevations can be computed for the points with unknown elevations.

The present GPS system is made up of the Block I satellites. The Block II system of 21 to 24 satellites is expected to be in full operation by about 1991. There are three primary modes of access to the GPS satellite signals: the "Standard Positioning Service" (SPS), the "Precise Positioning Service" (PPS), and codeless. The SPS is based on the Course/Acquisition Code (C/A Code) for the L1 frequency only while the PPS will be based on access to the P-code for the L1 and L2 frequency. With the proposed encryption of the PPS for the Block II system allowing only restricted access, SPS and codeless may be the only options for most users. Receiver designs that incorporate codeless technology can observe the two frequencies without access to either the SPS or PPS codes. Another receiver design combines SPS tracking capability for the L1 signal and codeless technology for the L2 frequency.

There are two methods by which station positions can be derived: point positioning and relative positioning. In the point positioning method, data from a single station are processed to determine three-dimensional coordinates (X,Y,Z) referenced to the WGS-84 earth-centered reference frame (datum). The present accuracy for GPS point position determinations ranges between 50 cm to 10 m (one sigma) depending on the accuracy of the ephemerides and period of the observations.

To perform geodetic surveys at the decimeter-level or better, one must employ GPS relative positioning techniques. In relative positioning, two or more GPS geodetic receivers receive signals simultaneously from the same set of satellites. These observations are processed to obtain the components of the base line vectors between observing stations (station coordinate differences (dX,dY,dZ)).

When the coordinates for one or more stations are known, the coordinates for new points can be determined after adjusting for the systematic differences between the reference system for the GPS satellites and local geodetic network control.

The specifications in this document are presently limited to fixed or static mode of relative positioning survey operations. In the static mode receiver/antennas are not moving while data is being collected. Future versions of this document will include specifications for kinematic modes of operation where one or more receiver/antennas are moving (possibly stopping only briefly at survey points) while one or more other receivers are continuously collecting data at fixed locations.

Proposed selective availability (sa) and encryption restrictions should have very little or no effect on static relative positioning techniques.

Since January 21, 1987, the orbital coordinate data for the GPS satellites are computed in the World Geodetic System 1984 (WGS-84), an Earth-centered and Earth-fixed coordinate system (DMA 1987).

There are at least four GPS signal measurement types that have been used for relative positioning techniques: pseudorange, code phase, integrated Doppler, and carrier phase. Although these observables have different characteristics, they are all functions of the instantaneous ranges between satellite and ground stations and their time derivatives. The most precise measurement type is the carrier phase.

Carrier phase measurements are made by "beating" the satellite carrier signal with the signal from the local receiver oscillator. The frequencies of these signals differ, primarily, by the amount of the Doppler frequency. Carrier phase observations are measurements of the phase difference of received signals emitted by the satellite's oscillator and the nominal carrier signal generated by the receiver's oscillator (Remondi 1985). There are several receivers capable of measuring the carrier phase of the L1 signal (1575.42 MHz) and or both the L1 and L2 (1227.6 MHz) signals (McDonald et al. 1987).

There are numerous approaches to processing carrier phase measurements. They are generally referred to as single, double, triple, or undifferenced methods. Each can be designed for either single- or multi-baseline processing (Goad 1985, and DMA and NGS 1986). In the multiple base line data processing mode, the data are processed for a single observing session or for multiple observing sessions in a single adjustment. The multiple session mode is also called a network solution and is only practical if there are adequate links or common stations between the observing sessions.

The major factors affecting accuracy of relative position determinations in the static (land survey) mode are: accuracy of the satellite positions, capability to model atmospheric (ionospheric and tropospheric) refraction errors, receiver timing bias, and field procedural errors (Beutler et al 1987 and Kinlyside 1988). Although stable weather conditions should not degrade the results substantially, severe storm fronts passing over one or more of the survey sites during an observing session can substantially degrade the results. Development of methods and techniques to bring these error sources under control will enhance survey capability in terms of accuracy, logistics, and, therefore, economy.

The present estimated accuracy of the precise ephemeris for the GPS satellites is 1 part-per-million (ppm) or better. The accuracy of the broadcast ephemeris is estimated to be 2 to 3 ppm. When the GPS orbit coordinates are fixed in the data processing, the errors in the orbits will propagate proportionately into each component of the base line determinations. To obtain precise base line vectors at the 0.01 or 0.1 ppm level, the average allowable orbital errors will have to be much smaller than are presently available. Should such accuracies be required and the post-computed orbit is not accurate enough, then data from fiducial stations (continuous tracking stations) will be processed with the project's GPS observations. In this method, the satellite orbital coordinates are adjusted while simultaneously solving for the station coordinate differences.

STANDARDS

Classification Standards

Six "orders" of geometric relative positioning accuracy standards are specified. These are summarized in table 1. These standards, reflecting a wide range of accuracy requirements, augment the present distance accuracy standards found in the 1984 FGCC document (FGCC 1984). Potential uses or applications for each of the orders are included in the table. The accuracy standards at the 95 percent confidence level for the six orders range from a very stringent standard in centimeters of $\pm\sqrt{((0.3)^2+(0.1d0.01)^2)}$ to $\pm\sqrt{((5.0)^2+(0.1d100)^2)}$ for the lowest order (d is the vector baseline length in kilometers). The three highest accuracy orders are called AA, A and B, respectively.

The highly stringent accuracy standard of order AA has been achieved for projects where data was processed in conjunction with continuous tracking data collected at stations of the Cooperative International GPS Network (CIGNET). The data were processed using orbital adjustment techniques. The distances generally ranged between 500 to 5000 km. The orders for 1 and lower accuracy standards are comparable (except for exclusion of Order 3, Class II) to the orders provided in the FGCC September 1984 document. Thus, the standards are defined in reasonable conformance with present GPS surveying capabilities.

Although the concept of "order/class" is retained, it should not be used for specifying the accuracy for a survey and for final station classification purposes. The user of these standards should determine the real accuracy needs and the cost implications. The accuracy needs should be specified in terms of accuracy values in distance units and parts per million. In specifying the accuracy values, the range of distances between adjacent stations should be included. Given this information, appropriate procedures for meeting these specified standards can be proposed.

Table 1. -- Geometric relative positioning accuracy standards for three-dimensional surveys using space system techniques.

Survey categories	Order	(95 percent confidence level) Minimum geometric Accuracy standard		
		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	(C)			
	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:

$$s = \pm[\sqrt{e^2 + (0.1d \cdot p)^2}]/1.96. \qquad \text{(See appendix B.)}$$

Where, d is the length of the baseline in kilometers. 5-26-88

In defining the accuracy standards, it was assumed that each component of the baseline determined by GPS relative positioning techniques are much alike, i.e. error sources that are highly correlated. Thus, no particular component has characteristics making it desirable to treat it differently from the other two components. It was also a premise that optimum accuracies achievable with GPS satellite surveying techniques are routinely and economically possible if the survey is carried out carefully and with adequate control of error sources.

The accuracy standards are not based on the technical training or ability of a surveyor, but instead they are based on the capabilities of the GPS measurement systems. As we approach the date when the Block II GPS satellites become fully operational, the cost of survey systems is expected to continue to decrease. Equipment costs as it relates to the economics of conducting a GPS survey will be an insignificant factor in determining overall project costs. Rather, the cost for a survey project will largely depend on costs for labor, logistical support, and other factors.

When specifying an accuracy standard for a survey there may be an "intended" standard that is substantially more stringent than a minimally "acceptable" accuracy standard. Today, GPS satellite geodetic survey systems (with carrier phase measurement capability) operated in the relative positioning static mode can yield vector baseline results with one-sigma uncertainties that are typically better than $\pm\sqrt{((1.0cm)^2+(0.1d2ppm)^2)}$ from data sets collected for periods of about 1 hour. Periods of less than 60 minutes can yield comparable results, but with lower reliability. Even with about 30 minutes of data consisting of 4 or more satellites, good geometric distribution, very few or no cycle slips, and an accurate ephemerides, it is possible to achieve results comparable to 60 minute data sets. Even though the present constellation is not optimized for getting reliable accuracies, the final classification for a GPS survey may still be within an "acceptable" standard.

In practice, scheduling the observing units to collect simultaneous data for less than 30 minutes can increase the risk of achieving unsuccessful observing sessions, particularly when there may be factors that would affect the quantity and/or quality of the observations. Furthermore, when operating in the static mode, the difference in operating costs between a 60 minute and 30 minute observing span is insignificant.

In developing the specifications for orders 1, 2, and 3, these orders were grouped with a single set of criteria. Thus, the specification criteria for design and field procedures were defined for four primary orders: AA, A, B and C (1, 2I, 2II, and 3). The only exception to this are the specifications for office procedures where a unique set of criteria was defined for each of the six orders.

There may be two "final" classifications for a GPS relative positioning survey project. The first, a "geometric" classification, would be determined by analysis of the internal consistency for a GPS relative positioning network. Data for this classification would be based on analysis of loop misclosures, repeat baseline results, and minimally constrained (free) least-squares network adjustments (independent of the local network control). The "geometric" classification is especially important for surveys that are designed to meet high-accuracy requirements such as for establishment of a high-precision primary networks, deformation measurement investigations (crustal motion, subsidence monitoring, motion of structures, etc.) and other special high precision engineering surveys.

The second classification for a GPS project would be based on the results of a constrained 3D adjustment where published coordinates for existing stations of the National Geodetic Reference System (NGRS) are either fixed or given weighted constraints. When a survey is adjusted into the local network control system, it would receive an "NGRS" classification that would depend on the accuracy of the existing horizontal network control. In the constrained adjustment, the existing network is "assumed to be correctly weighted and free of significant systematic error." The "NGRS" classification may also depend on the accuracy standard specified for the orthometric heights determined from the GPS relative positioning data. In turn, this would depend on the accuracy of the geoidal height differences.

Relative position accuracy denotes the relative accuracy of the various components between one station and other stations of a network. The concept of relative position accuracy can be applied to networks established by single-dimensional conventional measurements or by three-dimensional space system measurements. The accuracy standards in table 1 apply to both single-dimensional conventional terrestrial measurement techniques and three-dimensional GPS relative positioning techniques.

For each geometric relative position accuracy standard, the maximum allowable linear error in centimeters (at the 95 percent confidence level) can be computed for a corresponding station spacing by (see appendix B):

$$s = \sqrt{(e^2 + (0.1pd)^2)} \qquad (1)$$

where, s = maximum allowable error in centimeters at 95 percent confidence level
d = distance in kilometers between any two stations
p = the minimum geometric relative position accuracy standard in parts-per-million (ppm) at the 95 percent confidence level.
e = base error in centimeters (this includes station-dependent setup error)

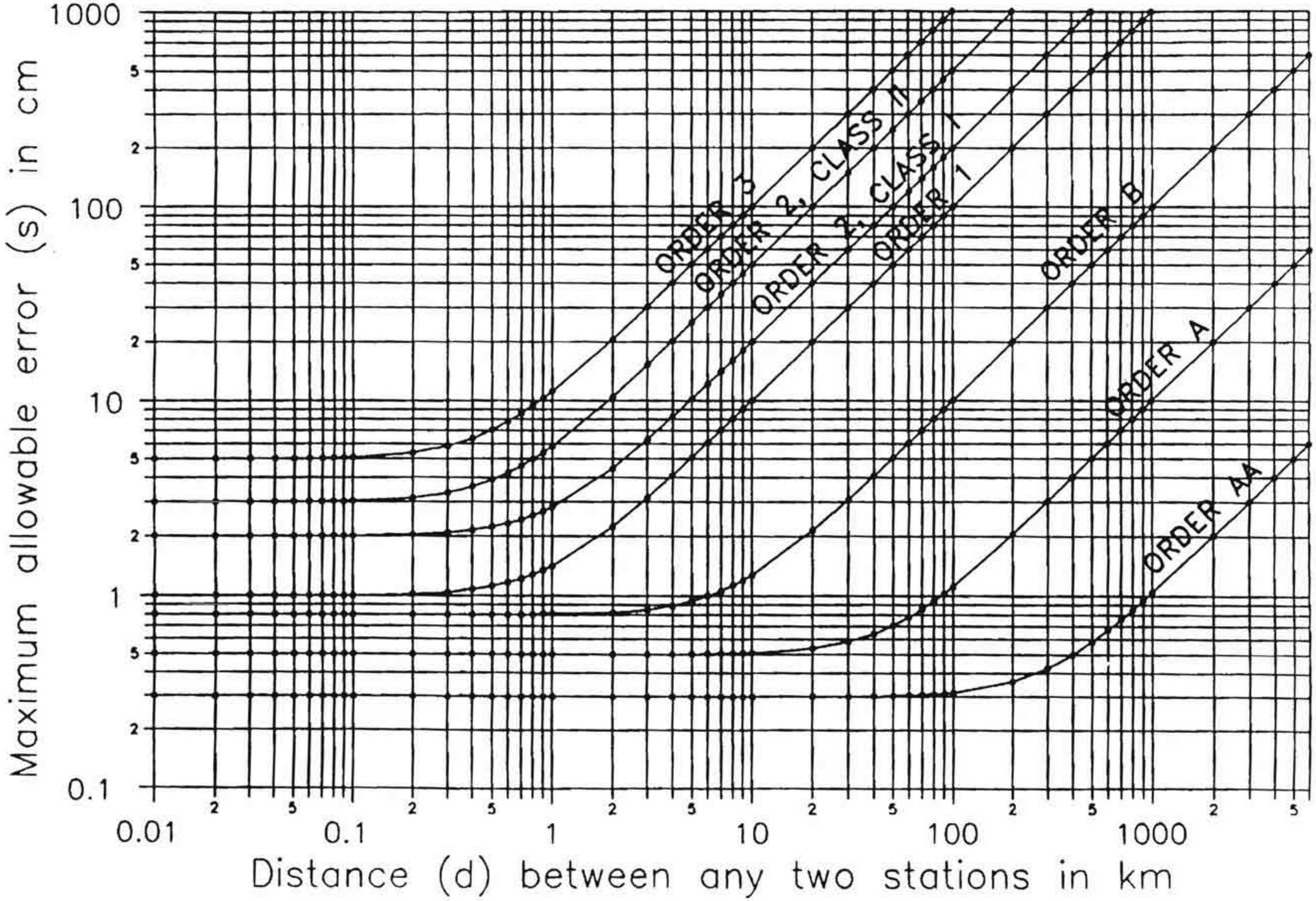
Figure 1 is a graph of the maximum spherical or linear error at the 95 percent confidence level for each order and class of the standards against the distance between any two stations.

Appendix C is a tabulation of one-sigma minimum standard errors computed from the minimum relative position accuracy standards given in table 1.

A survey station of a network is classified according to whether the propagated error at the 95 percent confidence region is less than or equal to the maximum allowable error "s" specified for the project. In the case of GPS determined baseline vectors, typically, the error propagation proceeds linearly for distances greater than about 20 km. The magnitude of the line-length dependent error will depend on the quality and quantity of the observations and the effectiveness of the baseline processing software for minimizing linearly dependent error sources.

For example, two stations are spaced 10 km apart and the accuracy standard for the baseline measurement is specified as order 1. The maximum allowable geometric relative error (at the 95 percent confidence level) between stations 1 and 2 is 10 cm. In this example, the value for s of 10 cm is 10 times greater than the base error of 1 cm. Thus, the base error (e) does not contribute significantly to the total value for s. On the other hand, if order B is specified, s = 1.3 cm. In this case, s is less than a factor of 2 greater than the value for e, thus the base error e is significant.

Geometric relative positioning accuracy standards
Maximum allowable error at 95% confidence level



This shows the importance of taking extra precautions to minimize the contribution to the base error caused by problems with antenna setup, antenna phase center stability, and signal multipath.

The minimum geometric relative position accuracies in table 1 represent present capabilities for making GPS baseline measurements. This includes any significant errors due to antenna setup (plumbing or centering, and measurement of height of antenna phase center above the station mark). The setup error can be the dominant error when establishing closely spaced stations for any of the accuracy standards. It may be the most significant error source when measuring widely spaced stations at the high accuracy orders. To control this potentially significant error source, a range of setup errors for corresponding accuracy standards and distances between stations are presented in appendix D. The errors were computed using a factor of 0.05 for the critical region (100 minus 95 percent confidence level). The setup error (k) in each component (N,E,U) at the 95 percent confidence level can be computed from:

$$k = 0.1pd(0.05), \text{ where, } k_{min} = 0.3 \text{ cm, and } k_{max} = 10 \text{ cm.}$$

The value for k_{min} is based on current realistic estimates for expected setup errors. The value for k_{max} is a worst-case setup error; in practice, it should be much smaller than 10 cm, typically less than 1 cm.

Although the accurate measurement of geometric quantities is important, in practice, orthometric heights or elevations may be desired in addition to ellipsoid heights. In many areas, the geoid slopes are usually less than most required accuracies for the orthometric height differences. For example, in most areas of the conterminous US, the slopes are well within 25 ppm. However, in some areas, such as mountainous regions, it might exceed 75 ppm. This may not be tolerable except for very low elevation difference accuracy standards. Most applications requiring either geometric order AA or A are concerned with changes with time rather than spatial differences, and hence are not sensitive to the difference between orthometric and ellipsoid heights since the two will generally change together in time (Kaula 1986).

In consideration that standards of accuracies for vertical control by spirit leveling should be different from those by GPS relative positioning and other 3-D geometric techniques. In appendix E, elevation (orthometric height) difference accuracy standards for geometric relative positioning techniques are proposed. The minimum accuracies for the geoid height differences that are required to achieve the desired elevation difference accuracy standard are also given. This, in effect, separates the accuracy standard for allowable geometric relative positioning error from the accuracy standards for elevation differences.

Specifications for a survey might include only a geometric accuracy standard but not an elevation difference accuracy standard. For example, one might perform a purely geometric survey if primarily interested in changing geometry such as plate motion investigations, subsidence monitoring, dam deformation studies, etc. The geometric relative position measurements can be evaluated to meet these high-precision purposes independent of the geoid.

In summary, the heights produced from GPS surveys are with respect to a reference ellipsoid. To convert these ellipsoid (also known as geodetic) heights to orthometric heights or elevations, the survey must include adequate connections to network control points with orthometric heights established by differential leveling techniques and referenced to the National Geodetic Vertical Datum (NGVD). When reliable estimates for the geoid height differences between all stations of the project are available, orthometric heights derived from the GPS survey results can be computed. The accuracy of the GPS derived orthometric heights will depend on the accuracy of the GPS ellipsoidal height differences, the accuracy of the orthometric heights for the vertical control, and the accuracy of geoid height differences.

The maximum azimuth accuracy from GPS relative position determinations is based on a minimum spacing between a pair of stations that are intervisible. The azimuth between a station pair is determined after adjustment of the vector baseline in the satellite reference system to the local datum reference system. For a specified azimuth accuracy and expected accuracy for the GPS vector baseline determinations at the 95 percent confidence level, a minimum spacing between a pair of stations can be computed. More discussion on azimuth determinations from GPS relative positioning surveys is contained in the next section.

These accuracy standards were developed in consideration of a critical need for statistically-based positional accuracy standards that is appropriate for three-dimensional measurement techniques such as use of the GPS. There is also recognized that statistically-based positional accuracy standards need to be developed for property and cadastral surveys (Vonderohe 1986). In Vonderohe's paper, it was indicated that relative error ellipses may be viable as standards. There is also a critical need for positional accuracy standards when making deformation measurements (monitoring vertical and horizontal movement) or for other precise engineering surveying applications.

As noted by Vonderohe (1986), discussion of positional accuracy standards should consider the practicality of users implementing them. The use of these standards requires a fundamental understanding of statistics and adjustments. But these educational requirements are not unique for the implementation of these standards. If the surveyor wants to help ensure successful use of GPS surveying techniques in a variety of applications, it would be prudent to acquire appropriate knowledge in statistics, adjustments, and analysis of observations.

Research or studies into the appropriate definition of statistically-based positional accuracy standards is clearly needed. Thus, as such research or studies bear new information, modification and refinements of these geometric accuracy standards are expected during the next few years.

Monumentation

With the increasing use of space system measurement techniques, such as use of GPS, it is important that station markers have the properties of permanence and stability. The markers must be stable in all three dimensions.

Factors that may affect the stability of a monument include frost heave action, changes in groundwater level, and settlement (Sliwa 1987). When selecting sites for stations of a high-precision primary network or for monitoring deformation, it is recommended that soil and geotechnical specialists be consulted.

Markers for existing network control should show no historical evidence of significant movement. If an existing network control marker does not exhibit adequately the properties of permanence and stability, it may have to be replaced by a new marker. The decision to replace old markers will depend on there use and purpose in future surveys.

The type of marker best suited for a given type or condition of terrain will depend on such factors as local conditions, transportation, materials available, equipment available for setting marks, and cost. Sites for new markers will, whenever possible, be located on public property such as road right-of-ways, public building grounds, school yards, etc.

To meet the requirements for permanent and stable monumentation, the markers are usually corrosion-resistant metal disks that may be set in a rock outcrop or large masses of concrete such as bridge abutments and other structural foundations.

When bedrock or large, massive structures are not available, it is more difficult to ensure the marker has the properties of permanence and stability. Traditional concrete monuments, with or without an underground mark, are not recommended as a suitable choice for preserving the three-dimensional coordinates.

The recommended alternative is a three-dimensional rod mark (Beard 1986). The principle component of the mark is a 9/16-inch stainless steel rod driven into the ground until the driving rate with a gasoline powered reciprocating hammer slows to 60 seconds per foot or slower. When in position, the top of the rod is just below ground level. The top of the rod is rounded and centerpunched, to mark the exact point to be positioned.

A grease-filled, 1-inch PVC pipe (sleeve) surrounds the rod from just below its top to a depth of at least 3 feet. It is preferable that the sleeve depth is equal to the depth of maximum frost penetration. Extreme depths of frost penetration for the conterminous U.S. is shown in figure 2. A hole must be dug for the sleeve during installation. The 1-inch sleeve reduces vertical stress to the rod caused by frost heave or other soil movements. It also helps restrict horizontal movement to an insignificant amount. The grease used to fill the sleeve should be an insoluble, non-corrosive, cold-weather type such as that conforming to U.S. military specification G-10924D. The grease is contained within the sleeve with pipe caps center drilled to 9/16 inch + 0.005 inch, allowing the rod to penetrate.

A 5-inch PVC pipe and cap with access cover is placed in concrete around the top of the assembly for protection and to aid in locating the mark. It is installed at or slightly above ground level The space between the 1-inch and 5-inch PVC pipe is filled with fine grain sand. (See appendix H for detailed setting procedures.)

When the sites for new points are being selected, surveyors should attempt to locate the new points on existing bench marks tied to the National Geodetic Vertical Network. Besides being prudent and cost-saving, this procedure will help

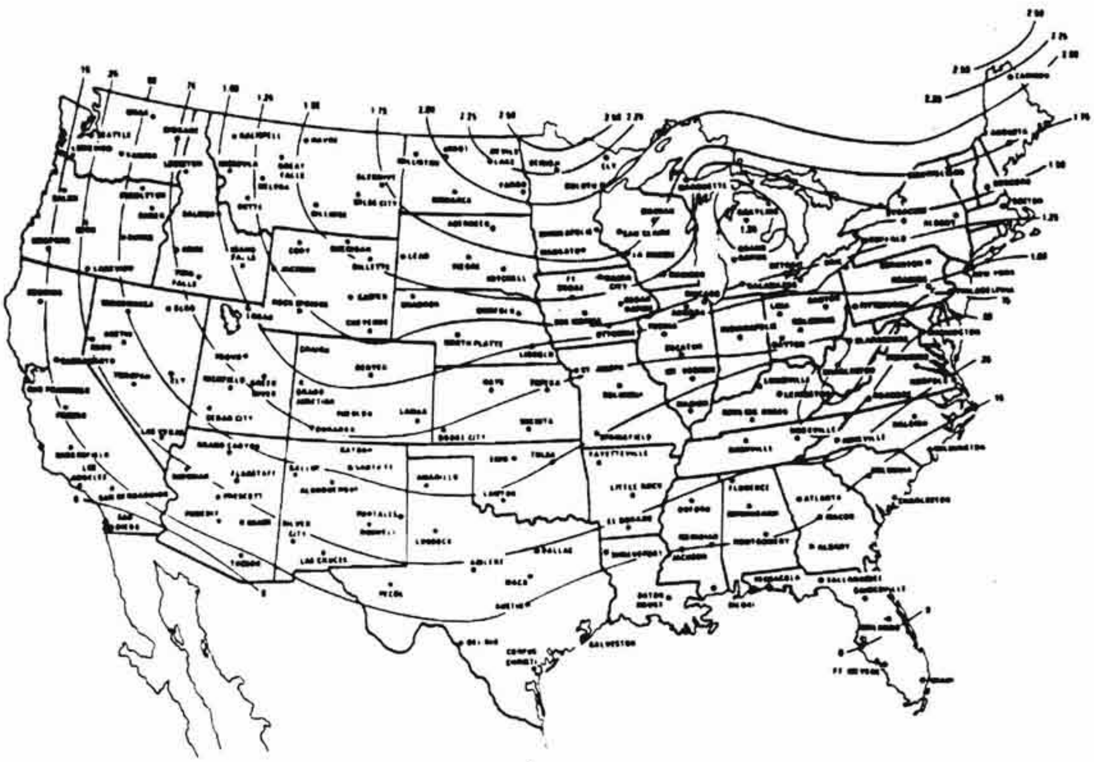


Figure 2.--Extreme depth of frost penetration (in meters) for conterminous U.S.

meet the requirements for connecting the markers with unknown elevations to the existing vertical network control. Should the permanency and/or stability of the bench mark be questionable, an offset marker may need to be set.

Reference marks are optional except in special circumstances. These circumstances could include: stations established for the National Crustal Motion Network, the primary National Geodetic Reference System, or other precise geodetic applications where recovery of a primary station is important for historical or legal reasons.

Whenever it is not possible to occupy a station directly and an offset point must be established, the offset point will be monumented and connected to the control station by survey techniques consistent with the accuracy standard specified for the GPS survey.

When practical, new stations should be located at sites that are accessible by ground transportation.

SPECIFICATIONS

The specifications recommended in the following sections are based on considerable practical experience. Some of the parameters may still reflect conservation estimates and will require further studies before they can be refined.

Development of the specifications is an evolutionary process that is not expected to stabilize before 1992 or after the Block II constellation of GPS satellites are launched and fully operational. Appendix J summarize the proposed Launch Dates, for the Block II GPS Satellites as of February 1988.

Network Design, Geometry, and Connections

The location and relative disposition of the control points do not depend significantly on factors such as network shape or intervisibility (except when establishing azimuth reference points) but rather on optimum layout for carrying out the intent of the survey.

Table 2 summarizes the specifications for the network design and connection factors, including minimum station spacing, ties to existing horizontal and vertical network control points, and direct connection requirements.

Checks should be made to ensure that no existing network control points have been moved or disturbed. It may be necessary to occupy more than the minimum number of network control points to ensure the survey is tied into points with sufficient accuracy or internal consistency.

If bench marks are located in areas subjected to vertical motion, it may be necessary to perform a vertical survey by differential or precise trigonometric leveling methods to ensure all bench marks are connected to a common epoch.

It is stated in the present FGCC specifications that whenever the distance between two unconnected survey points is less than 20 percent of the distance between those points traced along existing or new connections, a direct connection should be made between those survey points (FGCC 1984). The enforcement of this rule is optional depending on circumstances for stations located within the area of the GPS survey project.

At least three factors should be considered when determining whether direct connections between adjacent stations is desirable: (1) if an existing station, can it be recovered, (2) is the station reasonably accessible (i.e., it is quite likely it may be occupied during future surveys), and (3) what is the distance between the adjacent stations? When direct connections are desirable, table 2 provides guidelines for corresponding accuracy standards. If enforcement of the 'adjacent-station' rule is not practical, appropriate statements about those stations affected must be included in the project report.

If azimuth marks are required, the azimuth reference can be established by GPS surveys. There are at least four factors to consider when establishing azimuth references by GPS relative positioning techniques rather than using conventional

Table 2. -- Guidelines for network design, geometry and connections

Geometric accuracy standards		AA	A	B	C
	Group	AA	A	B	C
	Order	AA	A	B	1,2-I&II,3
	ppm	0.01	0.1	1.0	10,20,50,100
	base(cm)	0.3	0.5	0.8	1 2 3 5
Horizontal network control of NGRS[a], minimum number of stations:					
When connections are to orders AA, A or B....		4	3	3	2
When connections are to order 1..............		na[b]	na[b]	na[b]	3
When connections are to orders 2 or 3........		na[b]	na[b]	na[b]	4
Vertical network control of NGRS[a], minimum number of stations[c][d]..........		5	5	5	4
Continuous tracking stations (master or fiducials), minimum number of stations....		4	3	2	op
Station Spacing (km):					
Between "existing network control" and CENTER of project:					
Not more than..........................		100d	10d	7d	5d
50 percent not less than................		$\sqrt{5d}$	$\sqrt{5d}$	$\sqrt{5d}$	d/5
Between "existing network control" located outside of project's outer boundary and the edge of the boundary, not more than.		3000	300	100	50
Location of network control (relative to center of project); number of "quadrants", not less than..............		4	4	3	3
Direct connections should be performed, if practical, between: ANY adjacent stations (new or old, GPS or non-GPS) located near or within project area, when spacing is less than (km)..........		30	30	10	5

Legend: d - is the maximum distance in (km) between the center of the project area and any station of the project.
NGRS - National Geodetic Reference System
CL - Confidence level; na - not applicable; op - optional

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Table 2. -- Guidelines for network design, geometry and connections (continued)

NOTE: If it is not practical to plan a survey that is within the criteria, minor adjustments may be made provided that it is authorized by the agency requesting the survey.
Remarks: (a) Consult National Geodetic Survey officials whenever it is necessary to consider exceptions to these criteria, particularly, when the GPS survey project data are to be submitted to NGS for incorporation in the NGRS.
(b) If a survey with an accuracy standard of AA, A, or B is specified and one objective in the survey is to upgrade the existing network, then connections to a minimum of four stations are required or at least one station in each one-degree block with a minimum of four stations.
(c) First choice is vertical network control established and/or maintained by the National Geodetic Survey. When it is not possible to occupy the minimum number of NGRS points, non-NGRS control points may be used. This should be documented in the project report.
(d) If it is expected that the constrained adjustment for determination of the elevations within the project area will be based on more than one "bias group" (see discussion under section on Office procedures, Analysis and Adjustments) then the minimum number of stations specified is that which is required within the area for each "bias group." For example, if there two bias groups and ties required to four bench marks, then four bench marks will be incorporated within each area of the "bias group" for a total of 8 bench marks.

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astronomical methods. They are: (1) cost, (2) a pair of stations will be located close to each other with coordinates established at the same order of accuracy, (3) repeat observations between the azimuth and main station can be used to verify the relative stability of the two marks in all three dimensions, and (4) check observations or redundancy is not possible when azimuth reference is determined from only a single set of astronomic observations.

Table 3 summarizes minimum spacings between station-pairs for corresponding relative position accuracies possibly achieved from a GPS survey and for a range of azimuth accuracy standards.

Table 3. -- Guidelines for minimum spacings for establishing pairs of intervisible stations to meet azimuth reference requirements.

Spacing between a "pair" of stations, not less than (meters)	Azimuth accuracy required in seconds of arc (95 percent confidence level)				
	1	2	4	6	10
	GPS relative position precision (mm) (95 percent confidence level)				
100	-	-	2	3	5
200	-	2	4	6	10
300	-	3	6	9	14
400	2	4	8	12	19
500	3	5	10	14	24
600	3	6	12	18	29

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Example: If the expected relative position precision from a GPS survey between two marks spaced less than 1000 meters apart is 2 mm at the 95 percent confidence level, then to achieve an azimuth accuracy of 2 seconds at the 95 percent confidence level, the minimum spacing between the pair of stations is 200 meters.

Instrumentation

GPS geodetic receivers may receive one or both carrier frequencies transmitted by the GPS satellites. Two frequency receivers are required for the most precise surveys to correct for the effects of ionospheric refraction where the magnitude of the error may range from 1 to 10 ppm. The receivers must record the phase of the satellite signals, the receiver clock times, and the signal strength. Data collected with different receivers may be combined in the processing, however, observations need to be taken approximately simultaneously.

Generally, GPS satellite geodetic surveying equipment will consist of three major components: the antenna, receiver/processor, and recording unit. Depending on type of cable used, the lengths will usually range from 10 to 60 meters. The maximum length and type of cable may depend on the manufacturer's specifications. The receiver should have the capability to track a minimum of four GPS satellites.

Some receivers may have multiple data ports for handling printer output, data input from automatic weather instruments, and remote control operations. It should be possible to operate the receiver in the unattended mode. However, when commanded, information should be available for display to ensure that the receiver is functioning normally and the data quality meets acceptable standards.

The receivers may be codeless or have the capability to receive and decode the P and/or CA coded data. If it is codeless, the receiver must have the appropriate output and input ports for synchronizing the clocks among instruments and with respect to UTC (Universal Coordinated Time).

The required stability of the reference frequency of the GPS receiver is dependent on the receiver design. The amount of the initial time offset between receivers and the relative drift which can be tolerated is highly dependent on the sophistication of the processing software (i.e., the physical model). All GPS receivers should have a signal input port for an external frequency standard.

For high precision results, while allowing the widest choice of processing software, it is recommended that codeless receivers be initially synchronized and the relative drift rates be maintained to less than 10 microseconds per hour. (This is equivalent to approximately 4.4 Hz difference in the GPS receiver's L1 frequency.) It is generally recommended that codeless receivers be compared again at the end of the surveying day. This is not strictly required; it is possible to perform the clock check the following day prior to synchronization.

For codeless sets it is recommended that a high quality wrist watch be standard equipment. In rare cases, the receiver clock may experience a time problem on the way to or at the survey site. In such a case a synchronization of the receiver clock to the wrist watch will likely result in a successful survey. The final processed results may be somewhat degraded, however.

The height of the "phase" center (L_1) or centers (L_1 and L_2) above a defined reference point on the antenna or an adaptor connected to the antenna is usually predetermined by the manufacturer. This will be a constant for a particular antenna model. Combining this height constant with the height of the defined reference point above the station mark will give the total height used to reduce the baseline measurements from phase-center to phase-center down to mark-to-mark. The location of the phase center may not be marked on the antenna.

Using the appropriate constant for a particular antenna model is very important when different antennas are used during the same project. If the bias in height between different antenna models is not well known, it is recommended that test surveys be conducted between nearby marks which have accurately known height differences. Then the constant for one of the antennas will be adjusted for any significant height bias between different antenna models.

Calibration

Field calibration is necessary to control systematic errors that may be critical to GPS satellite surveys. This will verify the adequacy of the GPS survey equipment, observation procedures, the processing software, and steps implemented in the data analysis. The field calibration consists of testing the GPS equipment performance and the associated base line processing software on a three-dimensional test network.

The three-dimensional test network should be composed of four or more stations spaced approximately 50 m to 10 km apart. The location of the stations should permit base lines to be measured which are nearly at right angles to each other.

Three-dimensional relative position measurements will be established to be accurate in any component to within $\pm\sqrt{((3mm)^2+(0.1d1ppm)^2)}$ at the 95 percent confidence level.

The field procedures found in table 4 for order B will be used to establish the test network. The data will be reduced in the fixed orbit mode using precise ephemerides available from the National Geodetic Survey (Remondi 1986). Single base line, multiple base line (session) processing software, or other software that will give results with comparable precision shall be used. The network shall be established with a minimum of four receivers collecting three observing days.

A special three-dimensional geodetic test network established by the FGCC has been used to test GPS survey systems since 1983. This network is located in the vicinity of Washington, D.C. (Hothem and Fronczek 1983).

If different receivers and/or different model antennas are used in a survey, it will be necessary to conduct calibration tests to determine whether significant biases exist. For example, if the markings for the location of the phase center are not at the true location for different antennas, this will cause a bias in the height component of the GPS base line measurements. Other tests may be needed to determine procedures to ensure optimum orientation of the antenna and to determine the error contribution due to multipath.

Field Procedures

The precision of the GPS vector base line results depends on the number of satellites visible simultaneously from each station during an observing session, their geometric relationships, duration of the period when the desired number of satellites can be observed simultaneously, the uncorrected effects of ionospheric and tropospheric refraction, and the length of line. The number of possible observing sessions per observing day is a function of the required survey accuracy, satellite availability, and project logistical considerations such as travel and set up time required between observing sessions.

The specifications for field procedures will be common for all surveys with "intended" accuracies specified as 1:100,000 or lower. This is because vector base lines can be measured routinely with uncertainties of better than 10 ppm (1:100,000) using data sets from collection periods of 30 to 60 minutes. Even data collection periods of a few minutes can also produce good results during optimal satellite visibility conditions.

Although there are no differences in the field procedures for 1:100,000 and lower order surveys, there will be different criteria for each standard in the section on office procedures. The criteria for establishing the "final" classification will differ significantly to take into account factors which affected the results and either were not known at the time the observations were being collected or they could not be controlled by altering the field procedures.

Factors possibly affecting the results include: unexpected degraded accuracy for the orbital coordinates, satellite transmission problems, significant atmospheric disturbances, and receiver problems that went undetected before the survey team departed from the project area. It will be possible from the office procedures to evaluate surveys affected by unexpected problems and determine a final classification that, although maybe lower than the "intended" accuracy, may still meet minimum criteria for a project.

Currently, the Block I GPS satellite constellation includes only seven usable satellites. Depending on the location of the project, this limits the observing period when four or more satellites are available to approximately 5 hours each day. When the Block II 21- to 24-satellite constellation becomes operational in the 1990's (See appendix I), in general at least six satellites will be available for simultaneous observations from anywhere on Earth 24 hours a day.

Table 4 summarizes the field procedures that should be followed to achieve the desired accuracy standards. These field procedures are valid only for relative positioning surveys and are subject to change as more satellites become available and processing techniques are refined.

Although there has not been any report of interference affecting quality of data, it advisable that the antenna be located where potential radio interference is minimal for the 1227.6 and 1575.42 MHz frequencies (GPS L1 and L2 signals). The distance between the potential radio interference and the GPS survey system may be an important consideration. For example, stations located adjacent to high-powered radio and high frequency, high-powered radar and transmission antennas should be avoided.

If one or more of the stations in a project network is continuously reoccupied during each session, these stations are generally called "master" or "fiducial" stations. In this observing scheme, the observations for the "master" station(s) are in common to most or all the other observing sessions for a project. The data for observing sessions linked by a master station can be processed simultaneously either in the fixed orbit or adjusted orbit mode. This is usually called a network base line solution.

Other procedures for processing the simultaneous observations include processing single or session base line solutions. In a session base line solution, all data collected simultaneously during an observing session are combined for simultaneous multiple-base line determinations.

Depending on the number of receivers available, project observing schemes that include one or more "master" stations may result in less efficient operations compared with the so-called "leapfrog" approach to planning the observing schemes. For example, efficiency is improved 20 to 35 percent when four receivers are operated in the "leapfrog" observing scheme rather than if one of the four receivers was used for continuous deployment at a "master" station.

On the other hand, the "master" station approach (also referred to as fiducial stations) might be highly desirable if the highest accuracy is required. For example, GPS observations might be collected continuously at the "master" stations located at sites of other space systems such as Very Long Baseline Interferometry (VLBI) or satellite laser ranging. These data can be processed while holding fixed the "master" station coordinates determined from the other space systems.

Table 4. -- Guidelines for GPS field survey procedures

Geometric relative positioning standards — Group / Order / ppm	AA / AA / 0.01	A / A / 0.1	B / B / 1.0	C / 1,2-I&II,3 / 10,20,50,100
Two frequency observations (1 and L2) required[a]: Daylight observations[b].....	Y	Y	Y	op
Recommended number of receivers observing simultaneously, not less than:·.·.........	5	5	4	3
Satellite Observations: RDOP values during observing session (meters/cycle)[d]....... [TO BE ADDED IN FUTURE VERSION]				
Period of observing session (observing span), not less than (min):				
[4 or more simultaneous satellite observations][e]				
Triple difference processing[f]..........	na	na	240	60-120
Other processing techniques[g]: General requirements[h][i].............	240	240	120	30-60
Continuous and simultaneous between all receivers, period not less than[i][j].	180	120	60	20-30
Data sampling rate - maximum time interval between observations (sec)...............	15	30	30	15-30
Minimum number of quadrants from which satellite signals are observed...........	4	4	3	3 or 2[k]
Maximum angle above horizon for obstructions[v] (degrees)................	10	15	20	20-40
Independent occupations per station(l):				
Three or more (percent of all stations, not less than)..............................	80	40	20	10
Two or more (percent of stations, not less than):				
New stations...........................	100	80	50	30
Vertical control stations...............	100	100	100	100
Horizontal control stations.............	100	75	50	25
Two or more for each station of "station-pairs"(m)........................	Y	Y	Y	Y

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Table 4. -- Guidelines for GPS field survey procedures (continued)

Geometric relative positioning standards — Group / Order / ppm	AA / AA / 0.01	A / A / 0.1	B / B / 1.0	C / 1,2-I&II,3 / 10,20,50,100
Master or fiducial stations(n):				
Required, yes or no(o)......................	Y	Y	Y	op
If yes, minimum number......................	4	3	2	-
Repeat base line measurements, about equal number in N-S and E-W directions, minimum not less than (percent of total independently [nontrivial] determined base lines)..........	25	15	5	5
Loop closure, requirements when forming loops for post-analyses:				
Base lines from independent observing sessions, not less than...................	3	3	2	2
Base lines in each loop, total not more than.	6	8	10	10
Loop length, generally not more than (Km)....	2000	300	100	100
[NOTE: Also, see table 5]				
Loop closure (Continued):				
Base lines not meeting criteria for inclusion in any loop, not more than [percent of all independent nontrivial lines(p)]..........	0	5	20	30
Stations not meeting criteria for inclusion in any loop, not more than (percent of all stations)................................	0	5	10	15
Direct connections are required: Between ANY adjacent (NGRS and/or new GPS) stations (new or old, GPS or non-GPS) located near or within project area, when spacing is less than (Km)..........................	30	10	5	3
Antenna setup:				
Number of antenna phase center height measurements per session, not less than...	3(q)	3(q)	2	2
Independent plumb point check required(r)....	Y	Y	Y	op

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Table 4. -- Guidelines for GPS field survey procedures (Continued)

Geometric relative positioning standards — Group / Order / ppm	AA / AA / 0.01	A / A / 0.1	B / B / 1.0	C / 1,2-I&II,3 / 10,20,50,100
Photograph (closeup) and/or pencil rubbing required for each mark occupied.............	Y	Y	Y	Y
Meteorological observations:				
Per observing session, not less than.........	3(s)	3(s)	2(t)	2(t) or op
Sampling rate (measurement interval), not more than (min).........................	30	30	60	60
Water vapor radiometer measurements required at selected stations?......................	op	op	N	N
Frequency standard warm-up time (hr)(u):				
Crystal.....................................	12	12	(u)	(u)
Atomic......................................	1	1	(t)	(t)

LEGEND: nr - not required, na - not applicable, op - optional

REMARKS:

(a) If two-frequency observations can not be obtained, it is possible that an alternate method for estimating the ionospheric refraction correction would be acceptable, such as modeling the ionosphere using two-frequency data obtained from other sources.

Or, if observations are during darkness, single frequency observations may may be acceptable depending on the expected magnitude of the ionospheric refraction error.

(b) When spacing between any two stations occupied during an observing session is more than 50 km, two frequency observations may need to be considered for Accuracy Standards of Order 2 or higher.

(c) Multiple baseline processing techniques.

(d) Studies are underway to investigate the relationship of Geometric Dilution of Precision (GDOP) values to the accuracy of the base line determinations. Initial results of these studies indicate there is a possible correlation. It appears the best results may be achieved when the GDOP values are changing in value during the observing session.

(e) The number of satellites that are observed simultaneously cannot be less than the number specified for more than 25 percent of the specified period for each observing session.

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(f) Absolute minimum criteria is 100 percent of specified period.

(g) "Other" includes processing carrier phase data using single, double, nondifferencing, or other comparable precise relative positioning processing techniques.

(h) The times for the observing span are conservative estimates to ensure the data quantity and quality will give results that will meet the desired accuracy standard.

(i)

(j) Absolute minimum criteria for the data collection observing span is that period specified for an observing session that includes continuous and simultaneous observations. Continuous observations are data collected that do not have any breaks involving all satellites; occasional breaks for individual satellites caused by obstructions are acceptable, however, these must be minimized. A set of observations for each measurement epoch is considered simultaneous when it includes data from at least 75 percent of the receivers participating in the observing session.

(k) Satellites should pass through quadrants diagonally opposite of each other

(l) Two or more independent occupations for the stations of a network are specified to help detect instrument and operator errors. Operator errors include those caused by antenna centering and height offset blunders.

When a station is occupied during two or more sessions, back to back, the antenna/tripod will be reset and replumbed between sessions to meet the criteria for an independent occupation. To separate biases caused by receiver and/or antenna equipment problems from operator induced blunders, a calibration test may need to be performed.

(m) Redundant occupations are required when pairs of intervisible stations are established to meet azimuth requirements, when the distance between the station pair is less than 2 km, and when the order is 2 or higher.

(n) Master or fiducial stations are those that are continuously monitored during a sequence of sessions, perhaps for the complete project. These could be sites with permanently tracking equipment in operation where the data are available for use in processing with data collected with the mobile units.

(o) If simultaneous observations are to be processed in the session or network for base line determinations while adjusting one or more components of the orbit, then two or more master stations shall be established.

Table 4. -- Guidelines for GPS field survey procedures (Continued)

(p) For each observing session there are r-1 independent base lines where r is the number of receivers collecting data simultaneously during a session, e.g. if there were 10 sessions and 4 receivers used in each session, 30 independent base lines would be observed. (See appendix F and I.)

(q) A measurement will be made both in meters and feet, at the beginning, mid-point, and end of each station occupation.

(r) To ensure the antenna was centered accurately with the optical plummet over the reference point on the marker, when specified, a heavy weight plumb bob will be used to check that the plumb point is within specifications.

(s) Measurements of station pressure (in millibars), relative humidity, and air temperature (in°C) will be recorded at the beginning, midpoint, and end depending on the period of the observing session.

(t) Report only unusual weather conditions, such as major storm fronts passing over the sites during the data collection period. This report will include station pressure, relative humidity, and air temperature.

(u) The amount of warm-up time required is very instrument dependent. It is very important to follow the manufacturer's specifications.

(v) An obstruction is any object that would effectively block the signal arriving from the satellite. These include buildings, trees, fences, humans, vehicles, etc.

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One or more of the orbital parameters may be free in the adjustment while simultaneously solving for the base line vectors.

If a network solution is desired for ultimate accuracy, the observing scheme must include two or more "master" stations. The "master" stations should be located on opposite sides from the center of the project. All other criteria for the field procedures for either the "master" or other observing schemes are given in table 4. Which observing scheme is best, "leapfrog" or the "master" approach, will depend on the accuracy standard for the survey, the accuracy of the orbit coordinate data, and number of receivers available for the project. These and other factors will dictate the final observing strategy for the project.

For all surveys, the antenna must be stably located over the station mark for the duration of the observations within the allowable antenna setup error specified in appendix D. The height differences will be measured in feet and metric units and all will be recorded. Experience has demonstrated that blunders can be minimized by making this double measurement before and after each survey session.

The antenna phase center will be plumbed over the survey point using an optical plummet, collimator or similar instrument for control surveys. The each station occupation. The adjustment of optical plummets should be checked frequently, at least once per week or whenever there is an indication the plumb error exceeds the tolerance specified in appendix D. This check is for the purpose of determining gross plumb errors of 1 cm or more.

If an antenna is moved during an observing session, the set of observations for that session may not be acceptable. This will depend on such factors as the total data collection span before or after the antenna was moved, the quality of the data, and the quality and completeness of the data collected at the other observing stations.

The power source for the survey equipment should be stable and continuous especially for the high-accuracy surveys to minimize unnecessary breaks in the observations or damage to the equipment that would affect the quality of the data.

When observations of temperature and relative humidity are specified, these data shall be collected near the location of the antenna and at approximately the same height above the ground. Observations of wet-bulb and dry-bulb temperature readings should be recorded to the nearest 1.0°C. The relative humidity should be determined to the nearest 5 percent. Barometric readings at the station site should be recorded to the nearest millibar and corrected for any significant difference in height between the antenna phase center and location of the barometer. The meteorological instruments should be brought together and compared at least once per week and compared against a standard at least once per month. The logs shall include the name of manufacturer, model, and serial numbers of instruments used.

Office Procedures

Data Processing

Software to process the raw tracking data has been developed to handle either single or multiple base line input. The software incorporates a variety of models and differences in capabilities. Software adopted for processing the raw data must be certified as capable of producing results that meet the accuracy standards specified for a survey. Software can be certified by processing test data sets collected on FGCC 3-D test networks.

Numerous groups are investigating improvements to processing software. Major areas of work underway include: (a) orbit refinement modeling, (b) difference (single, double or triple) versus nondifference processing of carrier phase observations, (c) improved techniques for resolving carrier phase ambiguity and cycle-slips, and (d) improved atmospheric refraction modeling (ionosphere and troposphere).

All software must be able to produce from the raw data relative position coordinates and corresponding variance-covariance statistics which in turn can be used as input to three-dimensional network adjustment programs.

Criteria for processing and determining the quality of GPS relative positioning results are as follows (Remondi 1984 and Beutler et al. 1987):

1. The cutoff angle for data points should be no greater than 20.

2. The point position (absolute) coordinates for the station held fixed in each single, session, or network base line solution must be referenced to the datum for the satellite orbital coordinates (ephemerides). This datum is now called the World Geodetic System 1984 (WGS-84) (DMA 1987).

   The accuracy required for these coordinates will depend on the order of the survey. The order and corresponding accuracies are:

Order AA:	± 0.5 meter
Order A:	± 0.5 meter
Order B:	± 2.5 meter
Order 1 and lower:	± 25 meter

   In order of descending accuracies, the following are acceptable methods for estimating the fixed coordinates:

   a. Point position reduction of the GPS observations using Doppler smoothed pseudorange (code phase) measurements.

   b. Point position coordinates determined from unsmoothed GPS pseudorange measurements.

   c. Point position reduction of Transit Doppler observations using the precise ephemerides and transformed to WGS-84.

   d. Use of NAD 1983 published coordinates.

   e. Transformation of coordinates in a non-geocentric datum (e.g. NAD 1927) to the WGS-84 datum. In this method, the surveyor must be careful in obtaining transformation values that reflect with sufficient accuracy the differences between the non-geocentric local datum and the WGS-84 system.

3. Processing must account for the offset of antenna phase center relative to the station mark in both horizontal and vertical components.

4. As a rule of thumb, the number of simultaneous phase observations rejected (excluding those affected by cutoff angle and nonsimultaneous observations) for a solution should be less than 5 percent for accuracy standards AA, A and B, and 10 percent for the remaining standards.

5. Depending on the number of observations, quality of data, method of reduction, and length of base lines, the standard deviation of the range residuals in the base line solution should be between 0.1 and 2 cm for orders A, B, and 1; 1 to 4 cm for order 2; and, 1 to 8 cm for order 3.

6. The maximum allowable formal standard errors for the base line components may

depend on the particular software. With proper weighting in a fixed orbit solution, the values should be less than the expected accuracy for the orbit data. Typically, these range within 2 cm for base lines with lengths of less than 50 km.

Analysis and Adjustments

In practice, there will be two classifications for a GPS relative positioning survey. One would be based on the internal consistency of the GPS network adjusted independently of the local network control. This would be called the "geometric" classification. The second classification, if required, would be based on the results of a constrained adjustment where stations of the GPS survey network connected to the local network control are held fixed to vertical and horizontal coordinates in the National Geodetic Reference System (NGVD 1929 and NAD 1983). This is referred to as the "NGRS" classification.

Table 5 summarizes the specifications to aid in classifying the results for a GPS survey project.

Loop closures and differences in repeat base line measurements will be computed to check for blunders and to obtain initial estimates for the internal consistency of the GPS network.

Error of closure is the ratio of the length of the line representing the equivalent of the resultant errors in the base line vector components to the length of the perimeter of the figure constituting the survey loop analyzed. The error of closure is valid for orders A and B surveys only when there are three or more independently determined base lines (from three or more observing sessions) included in the loop closure analysis. For orders 1 and lower, independently determined base lines from a minimum of two observing sessions are required for a valid analysis. Loop closures incorporating only base lines determined from a common observing session (simultaneous observations) are not valid for analyzing the internal consistency of the GPS survey network.

After adjusting for any blunders, a minimally constrained (sometimes called a "free") least squares adjustment should be performed and the normalized residuals examined. The normalized residual is the residual multiplied by the square root of its weight, i.e. the ratio of the residual to the *a priori* standard error. Examining the normalized residuals helps to detect bad baseline vectors. In the "free" adjustment, one arbitrary station is held fixed in all three coordinates and the four bias unknowns (3 rotations and one scale parameter) are set to zero values (Vincenty 1987). The observation weights should be verified as realistic by inspecting the estimate of the variance of unit weight, which should be close to 1. However, in practice, it may be higher, perhaps in the range of 3 to 5 because for a particular GPS baseline solution software, the formal errors from the base line solutions may be too optimistic.

Vector component (relative position) standard errors computed by error propagation between points in a correctly weighted minimally constrained least squares adjustment will indicate the maximum achievable precision for the "geometric" classification.

Table 5. -- Office procedures for classifying GPS relative positioning networks independent of connections to existing control

Geometric relative positioning standards — Order: / ppm :	AA 0.01	A 0.1	B 1.0	1 10	2-I 20	2-II 50	3 100
<u>Ephemerides</u>:							
Orbit accuracy, minimum (ppm)	0.008	0.05	0.5	5	10	25	50
Precise ephemerides required?	Y[a]	Y[a]	Y	op	op	N	N
<u>Loop closure analyses(b)</u> - When forming loops, the following are minimum criteria:							
Base lines in loop from independent observations not less than	4	3	2	2	2	2	2
Base lines in each loop, total not more than	6	8	10	10	10	15	15
Loop length, not more than (Km)	2000	300	100	100	100	100	100
Base lines not meeting criteria for inclusion in any loop, not more than (percent of all independent lines)	0	0	5	20	30	30	30
In any component (X,Y,Z), "maximum" misclosure not to exceed (cm)	10	10	15	25	30	50	100
In any component (X,Y,Z), "maximum" misclosure, in terms of loop length, not to exceed (ppm)	0.2	0.2	1.25	12.5	25	60	125
In any component (X,Y,Z), "average" misclosure, in terms of loop length, not to exceed (ppm)	0.09	0.09	0.9	8	16	40	80
<u>Repeat base line differences</u>:							
Base line length, not more than (Km)	2000	2000	500	250	250	100	50
In any component (X,Y,Z), "maximum" not to exceed (ppm)	0.01	0.1	1.0	10	20	50	100
<u>Minimally constrained adjustment analyses</u>:							
(Criteria is being developed and will appear in an updated version of this document)							

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Table 5. -- Office procedures for classifying GPS relative positioning networks independent of connections to existing control (continued)

REMARKS:
(a) The precise ephemerides is presently limited to an accuracy of about 1 ppm. By late 1989, it is expected the accuracy will improve to about 0.1 ppm. It is unlikely orbital coordinate accuracies of 0.01 ppm will be achieved in the near future. Thus to achieve precisions approaching 0.01 ppm, it will be necessary to collect data simultaneously with continuous trackers or fiducial stations. (see criteria for field procedures, table 5.) Then the all data is processed in a session or network solution mode where the initial orbital coordinates are adjusted while solvinmg for the base lines. In this method of processing the carrier phase data, the coordinates at the continuous trackers are held fixed.
(b) Between any combination of stations, it must be possible to form a loop through three or more stations which never passes through the same station more than once.

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The constrained least squares adjustment will use models which account for: the reference ellipsoid for the network control, the orientation and scale differences between the satellite and network control datums, geoid-ellipsoid relationships, the distortions and/or reliability in the network control, and instability in the control network due to horizontal and/or vertical deformation. A survey variance factor ratio will be computed to aid in determining the "NGRS" classification of the adjustment. The classification for the adjustment into the NGRS should not exceed the order for the combined control network.

The constrained adjustment determines the appropriate orientation and scale corrections to the GPS Baseline vectors so it with conform to the local network control. Because of possible significant inconsistencies in the network control between sections of the project area, it may be necessary to compute several sets of orientation and scale corrections. This is done by dividing the project area into smaller "bias groups", provided that in each such group there is sufficient existing control with adequate distribution that is tied to the GPS network (Vincenty 1987).

If reliable geoid height data are available, the adjustment to determine elevations should be done in terms of heights above the ellipsoid. However, useful estimates for elevations above mean sea level can be determined if geoidal height data are not available by fixing in an adjustment at least three stations with elevations. The stations with elevations must be well-distributed to permit fitting a plane through the three heights. The effect of ignoring the slope means that the geoidal slope is absorbed by two rotation angles (around the north and east axes in a horizon system) and geoidal heights are absorbed by the scale correction in a constarined 3-D adjustment (Vincenty). If there is one or more significant changes in the geoidal slope within the project area, the project can be divided into smaller "bias groups", provided there is at least three vertical control stations appropriately distributed within the "bias group" area.

The discussion related to "bias groups" points out the importance in the planning for a GPS survey project to insure there is included in the survey adequate connections to the horizontal and vertical control network.

See appendix G for examples of a network of points surveyed by GPS, each designed to meet different classification criteria. The field survey statistics are also summarized.

SUMMARY

Geometric relative positioning accuracy standards have been developed to meet classification requirements for control surveys and high-precision engineering surveys performed by GPS relative positioning techniques and other three-dimensional measurement systems such as VLBI. Relative positioning accuracies at the 1.0 cm + 1-2 ppm level can be achieved routinely from GPS carrier phase observations. The proposed standards augments the FGCC horizontal distance accuracy standards.

The specifications for geodetic surveys performed by GPS relative positioning techniques are based on extensive field and office experience gained at NGS, from special test surveys, and from reports prepared by numerous researchers within and outside of the United States. Much of the criteria reflects conservative estimates and will require further research and studies before they can be refined.

Development of the geometric accuracy standards and GPS relative positioning specifications is an evolutionary process that will continue for the foreseeable future or at least until after the Block II constellation of GPS satellites are deployed and fully operational in the early 1990's.

This document is presently undergoing a review by the U.S. Federal Geodetic Control Committee and will be considered for formal adoption. This process is expected to reach a conclusion by late summer 1988.

Until this document is formally adopted and published by the FGCC, users are cautioned to use this as only a guideline for the planning and execution of GPS relative positioning surveys.

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APPENDIX A.--FEDERAL GEODETIC CONTROL COMMITTEE MEMBERSHIP

The Federal Geodetic Control Committee (FGCC), chartered in 1968, assists and advises the Federal Coordinator for Geodetic Control and Related Surveys. The Federal Coordinator for Geodetic Control is responsible for coordinating, planning, and executing national geodetic control surveys and related survey activities of Federal agencies.

The Methodology Subcommittee of FGCC is responsible for revising and updating the Standards and Specifications for Geodetic Control Networks.

MEMBER ORGANIZATIONS

Department of Commerce
Department of Agriculture
Department of Defense
Corps of Engineers, U.S. Army
Department of Energy
Department of Housing and Urban Development
Department of Interior
Department of Transportation
National Aeronautics and Space Administration
Bureau of Land Management
International Boundary Commission

APPENDIX B.--ONE-DIMENSIONAL AND THREE-DIMENSIONAL (ELLIPSOIDAL AND SPHERICAL) ERRORS

Suppose the value m quantifies one of the components of the relative position between two marks, which may be, for example, relative height or the east-west base line component. Then the term "relative accuracy" for m will be defined as the ratio, ε/d, where the interval m- to m+ corresponds to the 95% confidence region for m while d equals the distance between two marks and ε equals the component error.

For a network of stations surveyed by GPS relative positioning techniques the three components of the relative position can be determined. The term "relative position accuracy" denotes the relative accuracy of the various components for a representative pair of network marks.

Consequently, a GPS network is said to have a relative positioning accuracy of 1 ppm (1:1,000,000) when each component of a representative base line has a relative accuracy of at least 1 ppm. The concept of relative position accuracy can be applied to networks where relative positions have been determined either by single-dimensional measurements or by three-dimensional space-based measurements (R. Snay, NGS, 1986 personal communications).

Accuracy standards for geometric relative positioning are based on the assumption that errors can be assumed to follow a normal distribution. Normal distribution applys only to independent random errors, assuming that systematic errors and blunders have been eliminated or reduced sufficiently to permit treatment as random errors.

Although, truly normal error distribution seldom occurs in a sample of observations, it is desirable to assume a normal distribution for ease of computation and understanding.

A three-dimensional error is the error in a quantity defined by three random variables. The components of a vector base line can be expressed in terms of dX, dY, and dZ. It is assumed that the spherical standard error (σ_s) is equal to the linear standard error for the components or $\sigma_s = \sigma_x = \sigma_y = \sigma_z$.

A one-sigma spherical standard error (σ_s) represents 19.9 percent probability. This compares to a one-sigma linear standard error (σ_x) which represents 68.3 percent probability.

At the 95 percent probability or confidence level, the spherical accuracy standard is $2.79\sigma_s$ compared to $1.96\sigma_x$ for a linear accuracy standard (Greenwalt and Shultz 1962).

The probability level of 95 percent is consistent with the Standards and Specifications for Geodetic Control Networks (FGCC 1984). On page 1-2 of this document, it is stated "... a safety factor of two ..." is "... incorporated in the standards and specifications." Since those accuracy standards were based on one-dimensional errors that exist in such positional data as elevation differences and observed lengths of lines, the factor of two, a $2\sigma_x$ linear accuracy standard, is a probability or confidence level of about 95 percent.

APPENDIX C.--CONVERSION OF MINIMUM GEOMETRIC ACCURACIES AT THE 95 PERCENT CONFIDENCE LEVEL FROM TABLE 1 TO MINIMUM "ONE-SIGMA" STANDARD ERRORS

The "one-sigma" three- and one-dimensional standard errors are computed by:

$$\sigma_s = p/2.79 \quad \text{and,} \quad \sigma_x = p/1.96$$

where, p = minimum geometric relative accuracies in (ppm) at the 95 percent confidence level

σ_s = "one-sigma" three-dimensional minimum error (ppm)

σ_x = "one-sigma" one-dimensional minimum error (ppm)

Tabulation of "one-sigma" errors for corresponding minimum geometric accuracies at the 95 percent confidence level.

Order	Class	Relative accuracies (95 percent) confidence level		Minimum geometric "One-sigma" standard errors			
				Three-dimensional (σ_s)		One-dimensional (σ_x)	
		p (ppm)	a (1:a)	(ppm)	(1:T)	(ppm)	(1:L)
AA	-	0.01	1:100,000,000	0.0036	1:279,000,000	0.005	1:200,000,000
A	-	0.1	1:10,000,000	0.036	1:27,900,000	0.05	1:20,000,000
B	-	1	1:1,000,000	0.36	1:2,790,000	0.5	1:2,000,000
1	-	10	1:100,000	3.58	1:279,000	5	1:200,000
2	I	20	1:50,000	7.17	1:140,000	10	1:100,000
2	II	50	1:20,000	17.9	1:56,000	25	1:40,000
3	I	100	1:10,000	35.8	1:28,000	50	1:20,000

APPENDIX D.--EXPECTED MINIMUM/MAXIMUM ANTENNA SETUP ERRORS

k = the repeatable setup error in (cm) for any component (horizontal and vertical) at the 95 percent confidence level

$k = 0.1pd(\beta)$, where, k_{min} = 0.3 cm and k_{max} = 10 cm

NOTE: The value for k_{min} is based on current estimates for expected setup errors when the antenna is set on a tripod at a total height of less than 5 m. When the antenna is set on a mast or twoer where the height is greater than 5 m, the esimated minimum value for k may be greater than 0.3 cm. On the other hand, if the antenna is mounted on a fixed or permanently installed stand, then K_{min} should be less than 0.1 cm.

The value for k_{max} is the expected largest value for the setup error; in practice, it should be much smaller than 10 cm, typically less than 1 cm.

p = minimum geometric accuracy standard in parts-per-million (ppm) (See table 1.)

d = distance between any two stations of a survey (km)

β = 0.05 = critical region factor for the 95 percent confidence level (1.00 - 0.95 = 0.05)

To convert setup error at the 95 percent confidence level to standard error (one-sigma), divide k by: 1.96 for 'linear' standard error, or 2.79 for 'spherical' standard error.

Tabulation of setup errors (k) in centimeters at 95 percent confidence level

Class		d = Distance between stations (km)										
	ppm	0.01	0.05	0.1	0.5	1	5	10	50	100	500	1000
AA	0.01	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
A	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
B	1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	2.5	5
1	10	0.3	0.3	0.3	0.3	0.3	0.3	0.5	2.5	5	(10)	(10)
2-I	20	0.3	0.3	0.3	0.3	0.3	0.5	1.0	5	10	(10)	(10)
2-II	50	0.3	0.3	0.3	0.3	0.3	1.2	2.5	(10)	(10)	(10)	(10)
3-I	100	0.3	0.3	0.3	0.3	0.5	2.5	5	(10)	(10)	(10)	(10)

APPENDIX E.--ELEVATION DIFFERENCE ACCURACY STANDARDS FOR GEOMETRIC RELATIVE POSITIONING TECHNIQUES

An elevation difference accuracy is the minimum allowable error at the 95 percent confidence level. For simplicity and ease of computations, elevation differences (dH) are assumed to be equal to orthometric height differences.

The height differences determined from space survey systems, such as GPS satellite surveying techniques, are with respect to a reference ellipsoid. These ellipsoid (geodetic) height differences (dh) can be converted to elevation differences (dh) by the relationship:

$$(dh) = (dH) - (dN)$$

where (dN) is the geoid height difference.

With accurate estimates for (dN) and adequate connections by GPS relative positioning techniques to network control points tied to National Geodetic Vertical Datum, elevations can be determine for stations with unknown or poorly known values.

> NOTE: If GPS ellipsoid height differences are being measured for the purpose of monitoring the change in height between stations, then it is not necessary to have any accurate information on the shape of the geoid. Thus, the accuracy of the height differences depends <u>only</u> on the accuracy of the GPS ellipsoid height differences.

The accuracy of the GPS derived elevations for points in a survey will depend on three factors: (1) accuracy of the GPS ellipsoid height differences, (2) accuracy of the elevations for the network control, and (3) accuracy of the geoid height difference estimates.

In the following table, elevation difference accuracy standards at the 95 percent confidence level are proposed. The order/class correspond to the proposed geometric relative position accuracy standards. At the high orders, the error is dominated by the accuracy for the (dN) values, whereas, for the lower orders, the major source of error is in the ellipsoid height differences.

> NOTE: In developing these standards, it is assumed that errors or inconsistencies in the vertical network control are negligible. Of course, this may not be true in many cases.

Elevation difference accuracy standards for geometric relative positioning techniques.

(95 percent confidence level)							
Order	Class	Minimum elevation difference accuracy standard		(From table 1) Minimum geometric relative position accuracy standard	Minimum geoid height difference accuracy standard	
		p_H (ppm)	1:e	p (ppm)	p_N (ppm)	1:n
AA	-	2	1:500,000	0.1	2	1:500,000
A	-	2	1:500,000	0.1	2	1:500,000
B	-	5	1:200,000	1	5	1:200,000
1	-	15	1: 67,000	10	10	1:100,000
2	I	20	1: 50,000	20	10	1:100,000
2	II	50	1: 20,000	50	20	1: 50,000
3	I	100	1: 10,000	100	40	1: 25,000

NOTE: THESE ELEVATION DIFFERENCE ACCURACY STANDARDS ARE TO BE USED ONLY FOR ELEVATION DIFFERENCES DETERMINED INDIRECTLY FROM ELLIPSOID HEIGHT DIFFERENCE MEASUREMENTS.

FOR DIRECT VERTICAL MEASUREMENT TECHNIQUES SUCH AS DIFFERENTIAL OR TRIGONOMETRIC LEVELING, USE ONLY THE ACCURACY STANDARDS GIVEN IN THE FGCC 1984 DOCUMENT, SECTION 2.2, PAGES 2-2 and 2-3.

5-11-88

r = The number of GPS receivers used for each observing session

n = Minimum number of independent occupations per each station of a project

- If n = 1, (no check, no redundancy)
- If n = 1.5, (50 percent or more stations with 2 or more occupations)
- If n = 1.75, (75 percent or more stations with 2 or more occupations)
- If n = 2, (100 percent check, adequate redundancy)
- If n = 3, (excellent check, highest confidence)

NOTE: when, r = 2, n will always be 2 or greater.
when, r>2, then n = 1, 2, 3, or more occupations.

m = Total stations for the project (existing and new)

s = Number of observing sessions scheduled for the project

d = Average number of observing sessions scheduled per observing day (e.g. 1 per day, 2 per day, 2.5 per day, etc.)

NOTE: Depends on required observing span, satellite availability, and transportation requirements.

x = Number of observing days, where x = s/d

y = Number of observing days scheduled per week, generally 5 to 7.

w = Number of workweeks, where $w = x/y = s/(d \cdot y)$

p = Production factor (based on historical evidence of reliability; ratio of proposed observing sessions for a project versus final number of observed sessions)

$$p = f/i,$$

where: f = final number of observing sessions required to complete the project

i = Proposed (initial) number of observing sessions scheduled for the project, where:

$$i = (m \cdot n)/r$$

FORMULAS:

$$s = (m \cdot n)/r + (m \cdot n)(p-1)/r + k \cdot m$$

where, k is a safety factor: k = 0.1 for local projects; within 100 km radius.
k = 0.2 for all other

x = estimated number of observing days for a project: $x = s/d$

w = estimated number of work-weeks for a project: $w = x/y$

v = estimated total vectors for a project: $v = r \cdot s(r-1)/2$

b = estimated independent vectors for a project: $b = (r-1)s$

EXAMPLE:

If	n =	1.75	independent occupations per station
	m =	50	total stations for project
	y =	5	observing days per week
	k =	0.2	safety factor
	r =	4	number of GPS receivers per observing session
	d =	2.5	average observing sessions per day
	p =	1.1	production factor
Then	s =	22 + 3 + 10 = 35 observing sessions	
	x =	14 observing days	
	w =	2.8 workweeks	
	b =	105 independent vectors	

COMMENTS:

In the equation to compute the number of observing sessions (s), if there were no sessions lost due to receiver malfunctions, and no additional sessions required to cover such factors as human error and irregular network configuration, then

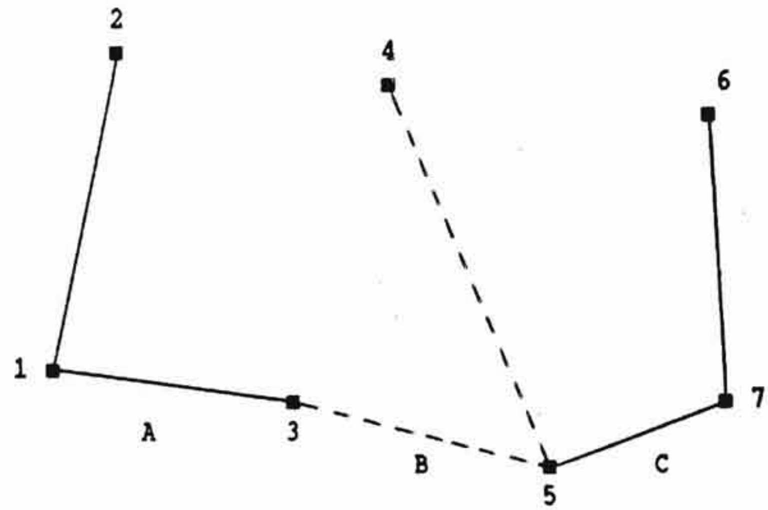
$$s = (m \cdot n)/r$$

However, the second part of the equation for computing "s" is to allow for additional sessions to offset scheduled sessions that may be lost due to equipment breakdown.

The third part of the equation, k(m), allows for additional sessions that may be required due to human error, irregular network configuration, etc.

APPENDIX G.--EXAMPLES OF GPS SURVEYS WITH SUMMARY OF STATISTICS USED TO CLASSIFY THE ORDER OF SURVEY BASED ON THE OBSERVING SCHEME AND DATA COLLECTION PROCEDURES

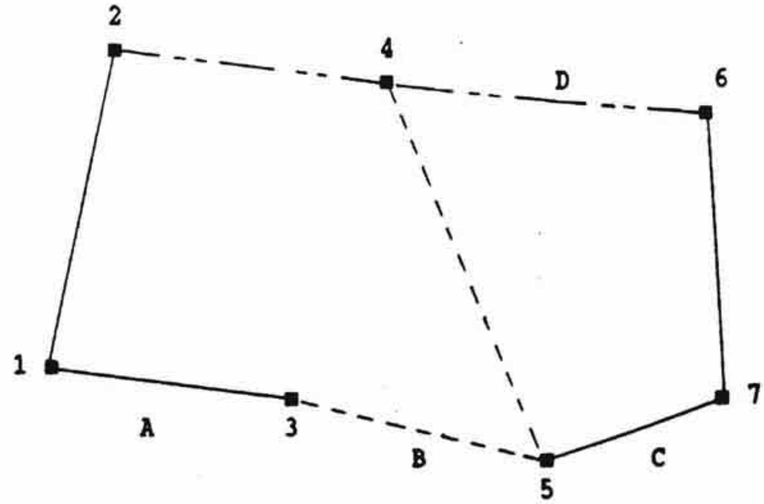
Example 1:



NOTE: Only nontrivial (independent) base lines are shown.

Observing sessions, total number (A,B, and C)	3
Receivers observing simultaneously	3
Stations, total number	7
Station occupations:	
Single occupations (no redundancy)	5
Two or more occupations, number/percent of all stations	2/29
Three or more occupations, number/percent of all stations	0/0
Base lines determined:	
All (trivial and nontrivial)	9
Independent (nontrivial)	6
Repeat base lines (N-S/E-W/percent of nontrivial)	0/0/0
Loop closure analyses:	
Valid loops formed?/Number of stations that can't be included	No/7
Loops containing base lines from (2 or)/(3 or more) sessions?	0/0
Geometric relative position classification (based on table 4)	None

Example 2:

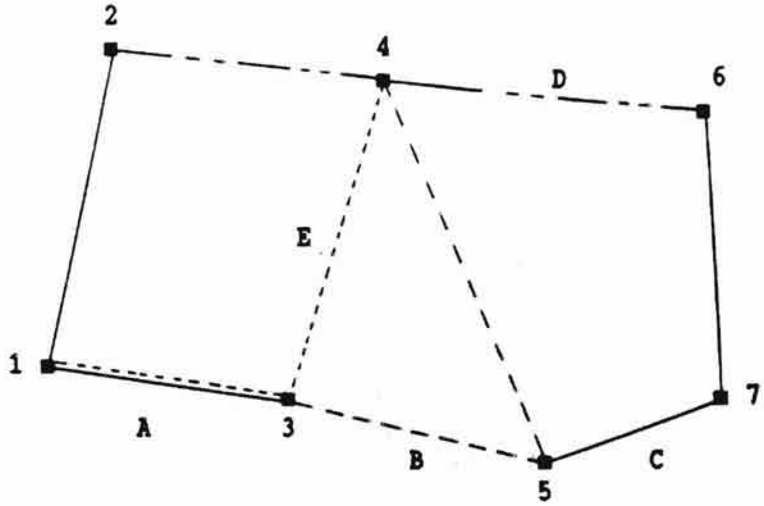


NOTE: Only nontrivial (independent) base lines are shown.

Observing sessions, total number (A,B,C, and D)	4
Receivers observing simultaneously................................	3
Stations, total number..	7
Station occupations:	
Single occupations (no redundancy)...............................	2
Two or more occupations, number/percent of all stations..........	5/71
Three or more occupations, number/percent of all stations........	0/0
Base lines determined:	
All (trivial and nontrivial).....................................	12
Independent (nontrivial)...	8
Repeat base lines (N-S/E-W/percent of nontrivial).................	0/0/0
Loop closure analyses:	
Valid loops formed?/Number of stations that can't be included....	Yes[a]/0
Loops containing base lines from (2 or)/(3 or more) sessions?....	0/2
Geometric relative position classification (based on table 4)......	Order "2-II"

(a) Loops formed: 1- 1(A)3 + 3(B)5 + 5(B)4 + 4(D)2 + 2(D)1 Includes 3 sessions
2- 5(C)7 + 7(C)6 + 6(D)4 + 4(B)5 Includes 3 sessions

Example 3:

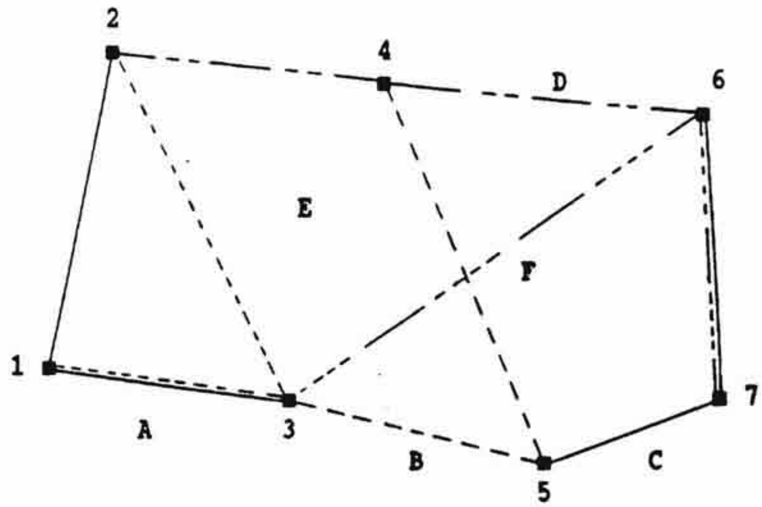


NOTE: Only nontrivial (independent) base lines are shown.

Observing sessions, total number (A,B,C,D, and E)..................	5
Receivers observing simultaneously.................................	3
Stations, total number...	7
Station occupations:	
Single occupations (no redundancy).............................	1
Two or more occupations, number/percent of all stations..........	6/86
Three or more occupations, number/percent of all stations........	2/29
Base lines determined:	
All (trivial and nontrivial)...................................	15
Independent (nontrivial).......................................	10
Repeat base lines (N-S/E-W/percent of nontrivial)..................	0/1/10
Loop closure analyses:	
Valid loops formed?/Number of stations that can't be included....	Yes[a]/0
Loops containing base lines from (2 or)/(3 or more) sessions?....	1/2
Geometric relative position classification (based on table 4)......	Order "1"

(a) Loops formed:
1- 1(A)3 + 3(E)4 + 4(D)2 + 4(A)1 — Includes 3 sessions
2- 3(B)5 + 5(B)4 + 4(E)3 — Includes 2 sessions
3- 5(C)7 + 7(C)6 + 6(D)4 + 4(B)5 — Includes 3 sessions

Example 4:



NOTE: Only nontrivial (independent) base lines are shown.

Observing sessions, total number (A,B,C,D,E, and F)	6
Receivers observing simultaneously..................................	3
Stations, total number..	7
Station occupations:	
Single occupations (no redundancy)................................	0
Two or more occupations, number/percent of all stations..........	7/100
Three or more occupations, number/percent of all stations........	3/43
Base lines determined:	
All (trivial and nontrivial)......................................	18
Independent (nontrivial)..	12
Repeat base lines (N-S/E-W/percent of nontrivial).................	2/1/25
Loop closure analyses:	
Valid loops formed?/Number of stations that can't be included....	Yes[a]/0
Loops containing base lines from 2 or / 3 or more sessions?......	0/4
Geometric relative position classification (based on table 4)......	**Order "B"**

NOTE: If one additional session was observed where session G would include stations 1,2 and 5 (or 7), then the survey would be classified with an Order of "A".

(a) Loops formed:	1-	1(A)3 + 3(E)4 + 4(D)2 + 2(A)1	Includes 3 sessions
	2-	3(B)5 + 5(C)7 + 7(C)6 + 6(F)3	Includes 3 sessions
	3-	6(D)4 + 4(B)5 + 5(C)7 + 7(F)6	Includes 3 sessions
	4-	1(E)3 + 3(B)5 + 5(B)4 + 4(E)2 + 2(A)1	Includes 4 sessions

APPENDIX H.--SPECIFICATIONS AND SETTING PROCEDURES FOR THREE-DIMENSIONAL MONUMENTATION

May 11, 1988

A. Materials required for each marker:

1. Rod, stainless steel, 4-foot sections
2. Rod, stainless steel, one 4-5 inch
2. Studs, stainless steel, 3/8 inch
3. Datum point, stainless steel, 3/8 inch bolt
4. Spiral (fluted) rod entry point, standard
5. NGS logo caps, standard, aluminum
6. Pipe, schedule 40 PVC, 5 inches inside diameter, 2-foot length
7. Pipe, schedule 40 PVC, 1 inch inside diameter, 3-foot length
8. Caps, schedule 40 PVC, (Slip-on caps centered and drilled to 0.567 inch ±0.002)
9. Cement for making concrete
10. Cement, PVC solvent
11. Loctite (2 oz. bottle)
12. Grease
13. Sand (washed or play)

B. Setting procedures:

1. The time required to set an average mark using the following procedures is 1 to 2 hours.

2. Using the solvent cement formulated specifically for PVC, glue the aluminum logo cap to a 2-foot section of 5-inch PVC pipe. This will allow the glue to set while continuing with the following setting procedures.

3. Glue the PVC cap with a drill hole on one end of a 3-foot section of schedule 40 PVC pipe 1-inch inside diameter. Pump the PVC pipe full of grease. Thoroughly clean the open end of the pipe with a solvent which will remove the grease. Then glue another cap with drill hole on the remaining open end. Set aside while continuing with the next step.

4. Using a power auger or post hole digger, drill or dig a hole in the ground 12-14 inches in diameter and 3 1/2 feet deep.

5. Attach a standard spiral (fluted) rod entry point to one end of a 4-foot section of stainless steel rod with the standard 3/8 inch stud. On the opposite end screw on a short 4 to 5 inch piece of rod which will be used as the impact point for driving the rod. Drive this section of rod with a reciprocating driver such as Whacker model BHB 25, Pionjar model 120, or another machine with an equivalent driving force.

6. Remove the short piece of rod used for driving and screw in a new stud. Attach another 4-foot section of rod. Tighten securely. Reattach the short piece of rod and drive the new section into the ground.

B. Setting procedures (continued):

7. Repeat step 6 until the rod refuses to drive further or until a driving rate of 60 seconds per foot is achieved. The top of the rod should terminate about 3 inches below the ground surface.

8. When the desired depth of the rod is reached, cut off the top removing the tapped and threaded portion of the rod leaving the top about three inches below ground surface. The top of the rod then must be shaped to a smooth rounded (hemispherical) top, using a portable grinding machine to produce a datum point. The datum point must then be center punched to provide a plumbing (centering) point.

   NOTE: For personnel that may not have the proper cutting or grinding equipment to produce the datum point, the following alternative procedure should be used if absolutely necessary. When the desired depth of the rod is obtained (an even 4-foot section), thoroughly clean the thread with a solvent to remove any possible remains of grease or oil that may have been used when the rod was tapped. Coat the threads of the datum point with Loctite and screw the datum point into the rod. Tighten the point firmly with vise grips to make sure it is secure. The datum point is a stainless steel 3/8 inch bolt with the head precisely machined to 9/16 inch.

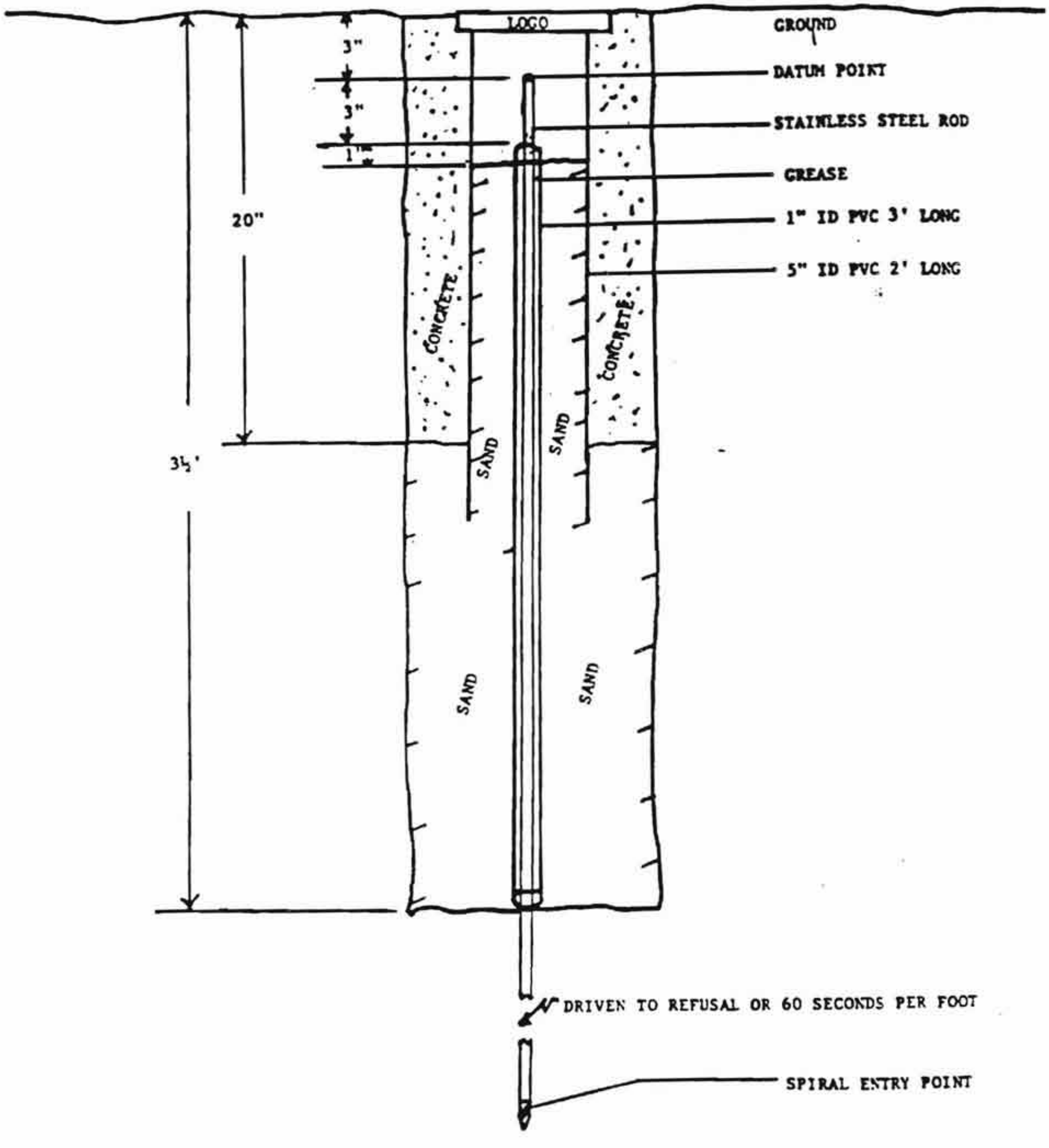
9. Insert the grease filled 3-foot section of 1-inch PVC pipe (sleeve) over the rod. The rod and datum point should protrude through the sleeve about 3 inches.

10. Backfill and pack with sand around the outside of the sleeve to 20 inches below ground surface. Place the 5-inch PVC and logo cap over and around the 1-inch sleeve and rod. The access cover on the logo cap should be flush with the ground. The datum point should be about 3 inches below the cover of the logo cap.

11. Place concrete around the outside of the 5-inch PVC and logo cap, up to the top of the logo cover. Trowel the concrete until a smooth neat finish is produced.

12. Continue to backfill and pack with sand inside the 5-inch PVC and around the outside of the 1-inch sleeve and rod to about 1 inch below the top of the sleeve.

13. Remove all debris and excess dirt to leave the area in the condition it was found. Make sure all excess grease is removed and the datum point is clean.



Schematic of the NGS 3-D marker

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NAD CONVERSION SOFTWARE (CORPSCON)

The National Geodetic Survey (NGS) announces the release of an improved datum transformation software package. CORPSCON allows the user to convert coordinate values between NAD 27 and NAD 83 using either State Plane Coordinates or latitude and longitude. CORPSCON was designed by the U. S. Army Corps of Engineers Engineering Topographic Laboratory. CORPSCON utilizes three existing NGS programs (GPPCGP, NADCON, and SPCS83) to complete the conversions and transformation. The conversion process is enhanced by allowing the user to specify NAD 83 State Plane Coordinate values in meters, U. S. Survey Feet, or International Feet.

CORPSCON is menu driven and screen oriented. Computation can be made interactively, or in batch mode with files of up to 150 records. Users requiring larger batch files will need to use the individual NGS programs listed above. Datum transformation results obtained with CORPSCON are identical to those obtained when using the NADCON software alone. Results from differing types of systems (i.e 286 vs. 386 vs. larger computing systems) may differ in the last decimal place written. However, in all cases the results are given to a greater accuracy than that implied by the uncertainty introduced by NADCON. That uncertainty is approximately 0.15 meter (70% confidence) in the majority of the conterminous United States. Regions of sparse geodetic control may yield less accurate results, but seldom in excess of 1.0 meter, except offshore where uncertainties of 5 meters can be expected.

CORPSCON is available for use on IBM-compatible personal computers. A hard disk with at least 1.5 Mbytes storage is highly recommended. The program is distributed on either 1.2-Mbyte, 360-kbyte, 5 1/4-inch disk, or 1.44-Mbyte, 3 1/2-inch disk (please specify your preference when ordering). CORPSCON (Version 2.1) can provide conversions within the conterminous United States, Alaska, Hawaii, Puerto Rico, and the Virgin Islands. Requests for Alaska and Hawaii require either a 1.2-Mbyte, 5 1/4-inch disk drive, or a 1.44-Mbyte, 3 1/2-inch disk drive.

CORPSCON costs $30.00 per copy. NGS requires prepayment for this product. Please make your check or money order payable to: NOAA, National Geodetic Survey. Payment may also be made by VISA, MasterCard, or American Express. A 25% surcharge, covering postage, will be added to orders sent outside the United States. To order, please write or call:

National Geodetic Information Center
N/CG174, Rockwall Building, Room 24
National Geodetic Survey, NOAA
Rockville, MD 20852
Telephone: 1-301-443-8631

DRAFT

"CORPSCON"
TECHNICAL DOCUMENTATION
AND OPERATING INSTRUCTIONS

****

DISCLAIMER

****

1. **General.**

a. **Background.**

(1) The National Geodetic Survey (NGS) developed the conversion program NADCON (North American Datum Conversion) to provide consistent results when converting between NAD 27 and NAD 83. The technique used is based on a biharmonic equation classically used to model plate deflections. NADCON works exclusively in geographical coordinates (latitude/longitude). If state plane coordinates (SPC's) are to be used, then the programs GPPCGP and SPCS83, also developed by NGS, can be used to convert between geographic and SPC's in NAD 27 and NAD 83, respectively.

(2) In order to simplify the process of performing datum transformations between NAD 27 and NAD 83 while using SPC'S, the U.S. Army Engineer Topographic Laboratories (USAETL) created a more comprehensive program called CORPSCON (Corps Convert). CORPSCON consists of the three routines listed above (NADCON, GPPCGP, and SPCS83) and an executive calling routine, CORPSCON.EXE. The user can thus perform transformations between NAD 27 and NAD 83 with the option of having inputs and outputs in state plane or geographic format. Calls between the routines are transparent to the user.

b. **Coverage.** The current version performs datum conversions for the continental U.S. (CONUS), Puerto Rico/U.S. Virgin Islands (PR/USVI), Hawaii, and most of Alaska.

2. **Source of Program and Assistance.** Copies of CORPSCON and assistance with the program can be obtained from the address below:

The National Geodetic Survey (301) 443-8631
Information Branch
N/CG174, Rockwell I, Room 019
National Ocean Service, NOAA
Rockville, Maryland 20852

3. **Program and Data Files.** CORPSCON consists of the following program files which must be present to run the program:

CORPSCON.EXE PCGP27.EXE CON2783.EXE SPCS83.EXE

The information file, READ.ME, contains information on installing and running CORPSCON. The following data files are required to perform datum conversions in the listed areas:

CONUS.LAS, CONUS.LOS - Continental United States
ALASKA.LAS, ALASKA.LOS, STGEORGE.LAS, STGEORGE.LOS, STLRNC.LAS, STLRNC.LOS, STPAUL.LAS, STPAUL.LOS - Alaska and associated areas
HAWAII.LAS, HAWAII.LOS - Hawaiian Islands
PRVI.LAS, PRVI.LOS - Puerto Rico and U.S. Virgin Islands

4. **Hardware Requirements.** An IBM Personal Computer (PC -XT/AT) with math co-processor or compatible computer with a math co-processor is required to run this program. A hard disk drive is recommended, but not required. Conversions from floppy drives take considerably longer. At least one megabyte of disk space (floppy or hard disk) is needed to accommodate the program files, datum model files, and input/output files; and at least 512 kilobytes of Random Access Memory (RAM) is needed for program execution. CORPSCON program and data files can be provided on 3.5 or 5.25 inch floppy disks, low or high density. CORPSCON is compatible with most PC monitors, although color monitors (CGA, EGA, and VGA) provide the most favorable and easily discernible menu display. If a printer is to be used, it must be interfaced through the parallel port (LPT1 or LPT2) in order to be recognized by the program.

5. **Software Requirements.** This program requires the Disk Operating System (DOS), version 3.0 or higher. All Terminant and Stay Resident (TSR) programs, such as Side Kick, must be halted to insure proper program execution. Other programs, such as spreadsheets and word processors, must be completely terminated before running CORPSCON. If these programs are still running in the background, CORPSCON will produce inaccurate results. Your CONFIG.SYS file must contain the statement "FILES = 2011 to allocate sufficient file space for program execution. Consult your DOS manual for further information on how to check and/or modify your CONFIG.SYS file.

6. **Installation Procedures.** CORPSCON program and data files should be copied to a hard disk, if available, for faster program performance and to insure ample disk space. If a hard disk is not available, then the program can be run from a high density floppy disk drive (at least 1.2 megabytes capacity). This requires that the CORPSCON program and data files for the appropriate geographic area reside on a single floppy disk for program execution.

a. **Hard Disk System.** The following instructions assume you will install CORPSCON on your C drive in a directory named CORPSCON. If you wish to install the files on another drive or another directory, change the drive and/or directory designations as appropriate.

(1) While in the root directory of the C drive, create the CORPSCON subdirectory by typing MD CORPSCON.

(2) Insert the source diskette into the floppy drive A and copy all files into the subdirectory by typing COPY A:*.* C: CORPSCON. If there is more than one source diskette, repeat this step for those disks. All program and datum files should now be in the CORPSCON subdirectory.

(3) Verify that all files are in the subdirectory by typ'ng DIR C:\CORPSCON. All four program files and the data files for the appropriate geographic area should be in this subdirectory.

b. **Floppy Disk System.** As stated above, if the program is to be executed from a floppy drive, then the drive must have at least 1.2 megabytes capacity, and all program and data files for the appropriate geographic area must reside on a single diskette. If the files need to be copied to a single disk:

(1) For a computer with dual floppy drives, place one of the source diskettes in the A drive and the destination disk in the B drive and type COPY A:*.* B:. Repeat this step for the other source diskette. All files should now be copied onto a single diskette. Verify this by typing DIR B:*.*.

(2) For a computer with a single floppy drive, place one of the source diskettes in the drive and type COPY A:*.* B:. You will be prompted to insert the destination diskette; remove the source disk and insert the destination disk. Repeat this step for the other source diskette. Upon completion, verify that all files are on the diskette by typing DIR A:*.*.

7. **Operating Instructions.** Change to the drive/directory containing the program files. Type CORPSCON <ENTER>. A single screen menu will be displayed with sections for "Input Coordinate Data",

"Input Data Source", "Output Coordinate Data", and "Output Data Destination". Menu selections are made by placing the displayed arrow at the appropriate item, using the arrow cursor keys on the right side of the keyboard, and pressing the <F2> key. Default selections, which are highlighted, are those selections that were entered during the last program run. Function keys to press for help <Fl>, update parameter <F2>, convert <F3>, title <F4> and make batch <F5> are located at the bottom of the screen.

NOTE: An identification message at the top of the menu should read "Version 2.11, for the CORPSCON version described in these instructions. Version 2.0 is the program released solely to U.S. Army Corps of Engineers Districts, and the outputs from this version may have some minor discrepancies with those obtained from programs NADCON, GPPCGP, and SPCS83 (one ten thousandth of second difference in latitude or longitude). If the message has a number lower than 2.0 or the menu has no version message at all, then this is a test version of CORPSCON and it should not be used.

a. Specification of Inputs.

(1) The "Input Coordinate Data" section of the menu features six selections to enable inputs in NAD 27 or NAD 83, in geographic or state plane values. If the state plane format is selected then the user is prompted for the numeric state plane zone code. For example, if NAD 27 state plane coordinates are to be converted to NAD 83 values, then the user places the arrow prompt at the "SPCS 27 (X-Y)" selection and presses <F2>. The user then enters the appropriate 4-digit zone code and presses <Enter>. If the zone code is not known, then a table of all state plane zone codes can be displayed by pressing the <Fl> key. Scroll up or down through the list until the arrow is at the appropriate code and type <ENTER>.

(2) Under the "Input Data Source" section, the user can specify the input mode as either "Single Keyboard Entry," "Batch File Entry," or "Strip [Geolab/Fillnet] Output". For "Single Keyboard Entry," place the arrow at this selection and use the <F2> key to toggle the on/off status to "On". Press the <F3> key to be prompted to enter the station name and coordinates (latitude/longitude or northing/easting). The format of the selected "Input Coordinate Data" selection will be displayed. Spaces and decimal points cannot be entered as the cursor will automatically advance as data is entered. Zeros may be required at the end of the entry to get the decimal point in the correct location. After entering the coordinates, the values should be checked before pressing the <ENTER> key to be certain that the numbers are correct. Pressing <ENTER> starts the conversion computation.

For "Batch File Entry" (best method if several positions are to be converted) place the arrow at this selection and use either the <F2> key to enter the name of a file previously created or <F5> to create a batch file within CORPSCON. Creating batch files outside of CORPSCON can be accomplished with other programs, e.g., word processors, spreadsheets, etc. Note that the file created by any programs such as these must be in ASCII format, and they must be created prior to running CORPSCON. The formats for batch files are shown below. West longitude is assumed positive.

For geographic Coordinates:

Column 1-30 Station Name
Column 31-32 Latitude - degrees
Column 34-35 Latitude - minutes
Column 37-44 Latitude - seconds, decimal point in column 39
Column 48-50 Longitude - degrees
Column 52-53 Longitude - minutes
Column 55-62 Longitude - seconds, decimal point in column 57

For state plane coordinates:

Column 1-30 Station Name
Column 31-42 Northing, decimal point in column 39
Column 46-57 Easting, decimal point in column 54

A maximum of 150 stations can be entered in one batch file. After the batch file is created and identified, press the <F3> key to start the conversion computation.

For "Strip [Geolab/Fillnet] Output" entry, place the arrow at this selection and press the <F2> key to be prompted for a choice of either Geolab or Fillnet. Position the arrow at either the Geolab or Fillnet selection, press <Enter> and then enter the file name.

NOTE: Points in the Alaska Aleutians that lie in east longitude, i.e., Shimya, must be entered as a west longitude exceeding 180 degrees. For example, a longitude of 1741/2 05 1 12" East would be entered as 1851/2 54 , 48 1'.

b. Specification of Outputs.

(1) The "Output Coordinate Data" section features the same options as the input section; NAD 27 or NAD 83 data in geographic or state plane format. A selection is made in the same manner; the user places the arrow at the desired selection and presses the <F2> key, followed by entry of the zone code for state plane data. A table of state plane zone codes can be displayed by pressing the <Fl> key.

(2) The user specifies output to the either the monitor, printer, or data file in the "Output Data Destination" section. The arrow is placed at the appropriate selection and the item is toggled on or off with the <F2> key. If the Disk File option is selected, then the user is prompted for the output file name. Any one, two, or three of the output selections can be activated.

NOTE: The output to monitor option is intended only for viewing single point conversions. If an input file of two or more points is used with the outputs sent to the monitor, then only the first point will be displayed in the output. The output to printer and/or output to file option must be used if a printout or a saved record of the results is needed.

c. Coordinate Output. Output data, when sent to the printer or a file, consists of a file header followed by a listing of the input and output data. The header states the form of the inputs (e.g., NAD 27 state plane) and the outputs (e.g., NAD 83 geographic). The input coordinates are listed under the "Input" column and the output coordinates are similarly listed under the "Output" column. If state plane values are used for input or output, then the convergence and scale factor are listed under the coordinates. If a datum conversion is made from NAD 27 to NAD 83, or visa-versa, then the datum shift, in seconds, is shown under the coordinates. If the inputs and outputs for a datum conversion are in state plane coordinates, then the state plane coordinate shift, in feet, is shown after the datum shift. Note that the state plane coordinate shift is a combination of the datum shift and the grid shift. If applying coordinate shifts to other positions on a state plane map sheet, then the state plane coordinate shift would be used and not the datum shift.

d. Program Execution. After all input and output parameters are specified, press the <F3> key to perform the conversion. If the "Single Keyboard Entry" mode is being used then you will be prompted to enter the input coordinates. The screen menu will be blanked out during the transformation and status messages concerning the computations will be displayed, such as "PERFORMING DATUM TRANSFORMATION TO NAD 83 ...". Status messages may be followed by the system environment message "Execution terminated;, this message has no relevance to the coordinate computations and can be disregarded. The menu screen will reappear when the conversion is complete. Note that an input file of 20 or more stations may take a minute or more to compute.

e. Program Exit. Press the <Esc> key to leave CORPSCON at any time the full screen menu is displayed. This command cannot be entered while the computations are being performed.

8. Error Messages. CORPSCON is designed to prompt the user for most cases in which a system or runtime error occurs. These errors are as follows:

a. Insufficient Memory. Occurs when there is not enough Random Access Memory (RAM) to run the program. Check to be certain that no Terminant Stay Resident program is concurrently running, i.e. CORPSCON being executed from a Lotus Spreadsheet shell.

b. No Math Co-Prccessor. A math co-processor (hardware item) must be installed in the computer to run the program.

c. No Input File. A file with the name specified was not found; enter the correct file name or create the file before running CORPSCON. Check to be certain that the file and program CORPSCON are in same directory and sub-directory.

d. **Invalid State Plane Code.** The zone code entered was not recognized as a valid parameter. Check the list of state plane codes (<Fl> key).

e. **Printer Error.** The program is unable to send the output to the printer. Check the following:

- printer connection
- printer turned on
- printer interfaced through the parallel port
- paper in printer
- printer in "on-line" or "ready-to-print" status

f. **Conversion Errors.**

(1) These error messages are shown in the data output. An "out of bounds" error or "can not converge for NAD 27 calculation" error means the coordinates do not lie within CONUS, PR/USVI, or Alaska. Check to be certain that: 1) the appropriate data files listed in paragraph 2 are present, 2) the point lies within the geographic boundaries of these areas, and 3) west longitudes are not entered as negative values. The error statement "latitude or longitude grid does not exist" means that a data file with the ,.LAS" or ".LOS" extension listed in paragraph 2 was not found. Check to be certain that the data files are in the same directory and sub-directory as the program files. The error "cannot open latitude or longitude grid" or "latitude or longitude grid corrupted" usually means that an improper data file is being used. The data files from the original disk(s) should then be re-copied to the hard disk or the program floppy disk.

(2) Less obvious errors may occur when different state plane zones are specified for input and output. If the specified input/output zones are non-adjacent or the output coordinates are negative or exceedingly large, the error can be recognized by zeros or asterisks (*) being given as the output values.

F100/F04.LHK
2/18/91

CONTRACT AND SPECIFICATIONS FOR U. S. PUBLIC LAND SURVEY SECTION AND QUARTER-SECTION CORNER RELOCATION AND MONUMENTATION

WAUKESHA COUNTY 1991 MONUMENTATION PROGRAM
WAUKESHA COUNTY, WISCONSIN

Prepared by

Southeastern Wisconsin Regional Planning Commission
P. O. Box 1607, Old Courthouse
Waukesha, Wisconsin 53187-1607

February 18, 1991

CONTRACT FOR TECHNICAL SERVICES

THIS CONTRACT, entered into this ______ day of __________________ 1991, by and between the Southeastern Wisconsin Regional Planning Commission, hereinafter referred to as the "Commission" and Mr. Claude C. Johnson, Jr., Registered Land Surveyor, hereinafter referred to as the "Surveyor,"

WITNESSETH THAT:

WHEREAS, the Commission desires to engage the Surveyor to render certain technical advise and assistance in connection with a land survey control monumentation program; and

WHEREAS, the Surveyor represents that he is qualified and experienced to undertake and perform the services required by this contract; and

WHEREAS, the Commission finds that the Surveyor is well qualified, equipped and experienced to furnish the technical services hereinafter described.

NOW, THEREFORE, THE SURVEYOR AND THE COMMISSION FOR THE CONSIDERATION HEREINAFTER STIPULATED DO MUTUALLY AGREE AS FOLLOWS:

1. The Surveyor shall furnish all labor, equipment, and materials necessary to perform the services provided under this contract in connection with and respecting the project area delineated on the sketch maps attached hereto as Exhibits "A-1" and "A-2." All such services shall be performed in strict accordance with the specifications attached hereto and made a part hereof and shall be performed according to surveying practices consistent with the highest professional and technical standards.

2. The Surveyor represents that he is an independent contractor; that he has or will secure, at his own expense, all qualified personnel required to perform the services specified by this contract and that such personnel shall at all times perform their work under responsible direction. Such personnel shall not be employees of or have any contractual relationship with the Commission and the Surveyor shall not engage the services of any person or persons now employed by the Commission without the written consent of the present employer of such person or persons. The Surveyor will pay his employees for the services performed by them and will exercise and retain control and supervision over them in connection with the details of their work and the hours of their employment. It is understood that the Commission is interested only in the end result, namely, the prompt and efficient performance of this contract.

3. None of the services specified by this contract shall be subcontracted by the Surveyor without prior written consent of the Commission.

4. All materials developed, prepared, completed or acquired by the Surveyor during the performance of the services specified in this contract, including all finished or unfinished surveys, data, drawings, maps, photographs, and reports, shall become the property of the Commission and shall be

delivered to the Commission during the contract period. Such materials shall not be released by the Surveyor or used for other purposes at any other time without the written approval of the Commission.

5. No drawings, maps, photographs, documents, reports, or other data prepared or completed under this contract agreement shall be copyrighted by the Surveyor nor shall any notice of copyright be registered by the Surveyor in connection with any such material prepared or completed under this contract.

6. The Surveyor shall prepare and deliver to the Commission an itemized list of all final work completed under this contract.

7. The Surveyor shall, at all times, fully indemnify and save harmless the Commission and its officers, members, agents and employees from any and all claims and demands, actions and causes of action of any character whatsoever made by anyone whomsoever on account of or in any way growing out of the performance of this contract by the Surveyor and his employees, including but not limited to, any claims that may be made by the employees themselves for injuries to their person or property or otherwise.

8. The Surveyor shall, at all times, while this contract is being performed, provide workmen's compensation insurance, at his own expense, in compliance with the provisions of Section 102.31 of the Wisconsin Statutes so as to insure all liability under the provisions of Chapter 102 of the Wisconsin Statutes and the Surveyor will likewise provide liability and property damage insurance, for the same period, at his own expense, with limits of $1,300,000.00 for injuries to or death of any one person arising out of any one accident, $1,300,000.00 for injuries to or death of more than one person arising out of any one accident and $1,100,000.00 for damage to property arising out of any one accident and the Surveyor shall provide the Commission with certificates showing said workmen's compensation insurance and property damage insurance to be in force and effect at all times while this contract is being performed with a provision that neither of the said policies shall be cancelled without the insurer first giving the Commission a thirty (30) day written notice of cancellation prior to the effective date of the cancellation. The Surveyor assumes full responsibility to make all necessary contributions to the Unemployment Reserve Fund as defined in Section 108.16 of the Wisconsin Statutes required by the provisions of Chapter 108 of the Wisconsin Statutes, respecting all of his employees engaged in the performance of this contract. The Surveyor shall make all necessary social security and withholding tax deductions required by law for his employees engaged in the performance of this contract.

9. If, through any cause, the Surveyor shall fail to fulfill in a timely and professionally competent manner his obligations under this contract or if the Surveyor shall violate any of the covenants, agreements, or stipulations of this contract, the Commission shall thereupon have the right to terminate this contract by giving written notice to the Surveyor of such termination and specifying the effective date thereof at least five days before the effective date of such termination. In such event, all finished or unfinished documents, survey data, drawings, maps, photographs, and reports prepared by the Surveyor under this contract shall, at the option of the Commission become its

property; and the Surveyor shall be entitled to receive just and equitable compensation for any satisfactory work completed on such documents. Notwithstanding the above, the Surveyor shall not be relieved of any liability to the Commission for damages sustained by the Commission by virtue of any breach of this contract by the Surveyor, and the Commission may withhold any payments to the Surveyor until such time as the amount of such damages due the Commission from the Surveyor shall be determined.

10. The Surveyor covenants that he presently has no interest and shall not acquire any interest direct or indirect which would conflict in any manner or degree with the performance of services under this contract. The Surveyor further covenants that in the performance of the work under this contract no person having any such interest shall be employed.

11. The Surveyor shall not assign any interest in this contract and shall not transfer any interest in the same whether by assignment or novation without the prior written consent of the Commission, provided, however, that claims for compensation due or to become due the Surveyor from the Commission under this contract may be assigned to a bank, trust company, or other financial institution without such approval. Notice of any such assignment or transfer shall be furnished promptly to the Commission.

12. The scope of the services to be performed under this contract may be amended or supplemented by unanimous written agreement between the parties to the contract.

13. There shall be no discrimination against any employee who is employed in the performance of the services to be performed under this contract or against any applicant for such employment because of sex, race, religion, color, or national origin. This provision shall include, but not be limited to: employment, upgrading, demotion or transfer, recruitment or recruitment advertising, layoff or termination, rates of pay or other forms of compensations, and selection for training including apprenticeship.

14. No officer, member or employee of the Commission who exercises any functions or responsibilities in the review or approval of the undertaking of carrying out of the project of which this contract is a part shall participate in any decision relating to this contract which affects personal interest or the interest of any corporation, partnership, or association in which he is directly or indirectly interested; nor shall any such officer, member or employee of any interest direct or indirect in this contract or the proceeds thereof.

15. The terms and conditions of this contract shall be binding upon and shall enure to the benefit of the parties hereto and their respective successors and assigns.

16. The Commission shall pay to the Surveyor, at the times, in the manner and on the conditions set forth in the specifications, the amount of $20,250.00, which shall constitute full and complete compensation for the Surveyor's services hereunder. It is expressly understood and agreed that in no event will the total compensation and reimbursement to be paid exceed the amount stipulated above for all the services required.

17. When the work provided for under this contract has been fully completed in accordance with the specifications, acceptance shall be issued by the Commission stating that the work has been fully completed to its satisfaction in substantial compliance with the contract and authorizing final payment. The Surveyor shall furnish evidence acceptable to the Commission all claims for work and labor performed or materials furnished to such Surveyor in the prosecution of the work under this contract have been satisfied. From the final payment shall be retained all monies expended by the Commission according to the terms of this contract and thereunder chargeable to the Surveyor and all deductions provided by the contract, State or Federal law. Payment of the final sum and acceptance thereof by the Surveyor shall release the Commission from all claims and liabilities to the Surveyor in connection with this contract.

18. The general conditions of this contract, the specifications and attached exhibits, and this agreement shall together constitute the contract. The Surveyor hereby asserts that he has read the technical specifications and that he is thoroughly informed and familiar as to their contents and requirements.

19. All State or Federal laws insofar as applicable to municipal contracts shall be and hereby are specifically made a part of this contract as set forth herein.

IN WITNESS WHEREOF, the parties hereto have executed this contract as of the day and year first above written.

__________________________(SEAL)
Witness

__________________________(SEAL)
Claude C. Johnson, Jr.,
Registered Professional
Land Surveyor

(SURVEYOR SEAL)

SOUTHEASTERN WISCONSIN
REGIONAL PLANNING COMMISSION

__________________________(SEAL)
Kurt W. Bauer,
Deputy Secretary

__________________________(SEAL)
Frank F. Uttech,
Chairman

(COMMISSION SEAL)

DETAILED SPECIFICATIONS FOR U. S. PUBLIC LAND SURVEY SECTION AND QUARTER-SECTION CORNER RELOCATION AND MONUMENTATION

I. GENERAL

These specifications set for the requirements of Waukesha County for land surveying services. The Surveyor shall furnish all labor, materials, and equipment necessary to complete properly the work specified herein.

II. LAND SURVEYING

A. The survey work shall include the recovery or relocation and monumentation of certain U. S. Public Land Survey corners, including section and one-quarter section corners, "centers" of sections, meander corners, and correction corners. These corners, totaling 75 in all, are indicated on the sketch maps attached hereto as Exhibit "A-1" and "A-2." If the original U. S. Public Land Survey corners are not recoverable, the Surveyor shall determine the status thereof under U. S. Public Land Office definitions and shall follow the prescribed procedures of that Office in their relocation. In any case, the original land survey corners and corners as aforementioned shall be monumented and witnessed as provided under paragraph III herein.

B. All field work with respect to the location and relocation of all the aforementioned corners shall be based upon, and include the assembly of, all authoritative information, such as title documents, subdivision plats, private and public survey records, and existing monumentation and occupation, that may be useful in determining the actual position of the U. S. Public Land Survey lines and corners and all other corners, as well as the proper analysis of this information, to arrive at the best determination of the actual location of the said lines and corners. Proper performance in this regard depends largely upon a knowledge of local survey customs, conditions, and laws of boundaries and titles, and for this reason, must be properly supervised by a competent and qualified registered land surveyor.

C. With regard to the location or relocation of the "center" of the section, that point which physical or other evidence indicates to be the "used or recognized center of the section" (occupied center) shall be located or relocated in accordance with paragraph B above and monumented as provided.

D. The double corners along township lines shall be located or relocated and monumented in accordance with paragraphs A and B above; and the closing corners governing the location of the U. S. Public Land Survey lines in the northerly tier of one-quarter sections shall be set on the straight lines connecting the section and one-quarter section corners on the township line governing the location of the U. S. Public Land Survey lines in the southerly tier of one-quarter sections in the township to the north.

E. The Surveyor shall keep all field notes and office computations in a neat and orderly manner, clearly indexed, and open for inspection and checking during the course of the work. Upon completion and acceptance, duplicate copies of all field notes and computations shall be furnished the Commission and shall become its property.

F. The Surveyor shall provide for each corner within the project area, a dossier on 8-1/2 inch by 11 inch polyester base material. Exhibit "B" attached hereto illustrates the required form and content for these dossiers. The following information shall be given for each corner on the dossiers:

1. Title giving the legal description of the corner by proper reference to section, town, and range. The center of a section shall be identified as the "true" or "occupied" center as the case may be.

2. A sketch showing the monument erected in relation to the salient features of the immediate vicinity. Witness monuments set shall be shown together with their ties. A North Point shall be shown properly located thereon. The names of adjoining streets, state trunk highways, or public land shall be indicated.

3. If necessary to supplement the sketch, a clear and concise description of each corner so as to permit its ready recovery.

4. An affidavit by the land surveyor setting forth the classification assigned to the corner (existing, obliterated, or lost) during its recovery or relocation and the salient factors determining the location or relocation, with particular emphasis upon old monumentation and accessories thereto found and used in the relocation process.

III. MONUMENTING

The Surveyor shall mark or monument each section and quarter section corner surveyed as follows:

A. Where the corner falls within an existing surface traveled way (concrete, bituminous surface, gravel), by drilling or cutting a neat hole in the pavement or street surface and setting a precast concrete monument in accordance with Exhibit "C."

Where the corner falls within a concrete or bituminous surfaced traveled way, the Surveyor may erect a concrete monument similar to the one shown in Exhibit "C" by excavating a hole 9 inches in diameter by 36 inches deep and pouring the monument in place using "AA" portland cement and placing the required reinforcing steel and brass cap substantially in accordance with Exhibit "C." In all cases, the setting must be approved by the Commission or its authorized representative.

B. Where the corner falls on an earth surface, by setting a precast concrete monument as shown in Exhibit "C." In all cases, the setting must be approved by the Commission or its authorized representative.

C. Where the corner falls in a lake, stream, or inaccessible area, by setting a meander corner at the point of intersection of the section or quarter section line with a meander line established at a distance approved by the Commission away from the ordinary high water of the lake, the bank of the stream, or from an inaccessible area. Such meander corners shall be monumented by setting a precast concrete monument and the setting shall be approved by the Commission or its authorized representative.

D. In all cases, the monuments erected shall be witnessed. Witness corners shall be selected for permanence and shall preferably consist of crosses cut in concrete curbs, walks, pavements, or culvert headwalls. Railroad spikes set in trees and telephone or power poles may be acceptable, but where used shall be set no higher than one foot above the surface of the ground and shall project no more than one inch from the surface of the tree or telephone or power poles. In open field, 1-inch diameter by 36-inch long iron pipe may be used. At least four such witness corners shall be established for each corner and tied to the section or quarter section corner.

E. The brass caps shall conform to the detail shown on Exhibit "D" attached hereto and shall be stamped with the corner notation at the time of setting. The concrete monument shall conform to the details shown in Exhibit "C" attached hereto unless otherwise specified by the Commission. The concrete monuments with brass caps shall be furnished by the Commission

IV. ITEMS TO BE DELIVERED

Upon completion the Surveyor shall deliver to the Commission the following items:

A. One set of reproducible tracings of the U. S. Public Land Survey corner dossier sheets specified under Section II E herein.

B. One set of copies of the original field notes and computations as specified under Section II D herein.

V. DELIVERY DATES

A. The 75 U.S. Public Land Survey corners indicated on Exhibits "A-1" and "A-2" shall be monumented and referenced on or before December 1, 1991. All dossier sheets for the 75 aforementioned corners shall be delivered on or before December 31, 1991.

B. All copies of the original field notes and computations shall be delivered on or before December 1, 1991.

VI. BASIS OF PAYMENT

The contract price of the work, the lump sum of $20,250.00 shall include all surveying services necessary for the completion of the monumentation, and the delivery of the complete dossier sheets and all other materials and items specified herein. This total contract price shall be based upon the unit prices of $250.00 per corner for relocation, monumentation, and referencing of 69 U. S. Public Land Survey corners located in the areas to be mapped as specified; and $500.00 per corner for relocation, monumentation, and referencing of six U. S. Public Land Survey corners located in Sections 12 and 13, Township 5 North, Range 18 East, as specified.

The foregoing unit price is provided solely as a basis for computing any adjustment in the total cost of the contract that may have to be made due to any changes in the scope of the work ordered in writing by the Commission during the conduct of the project and as a basis for computing work progress payments to the Surveyor under the project.

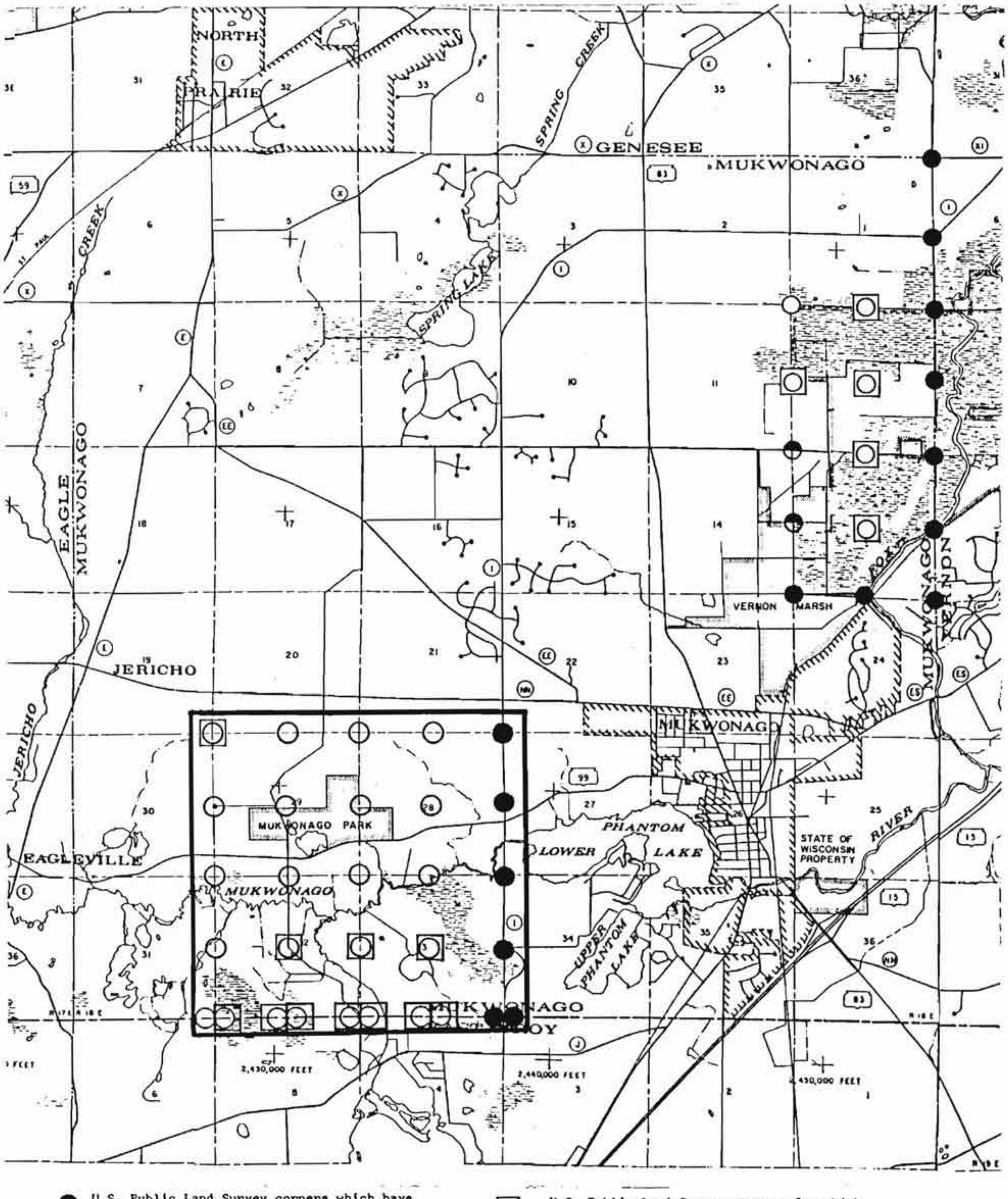
It is expressly understood and agreed that in no event will the total compensation and reimbursement to be paid exceed the amount stipulated above for all the services required as specified herein. The Surveyor must submit invoices to the Commission during the progress of the work for partial payment on account for work completed and accepted to date. Such invoices shall not be submitted more often than every 30 days. The amount shown on such invoices shall be estimated on the basis of contract prices and the quantity of work completed and accepted by the Commission. Such invoices will be checked by the Commission and payment made in an amount not to exceed 90 percent of such amount thereof as has been found by the Commission to reasonably represent the value of partially completed work, less any amounts previously paid on account. Payment of the 10 percent withheld during progress of the work shall be made upon final approval of the work by the Commission.

F100/F04.LHK

MAP SHOWING
AERIAL MAPPING COVERAGE AND
CONTROL SURVEY STATION LOCATION FOR

TOWN OF MUKWONAGO AREA

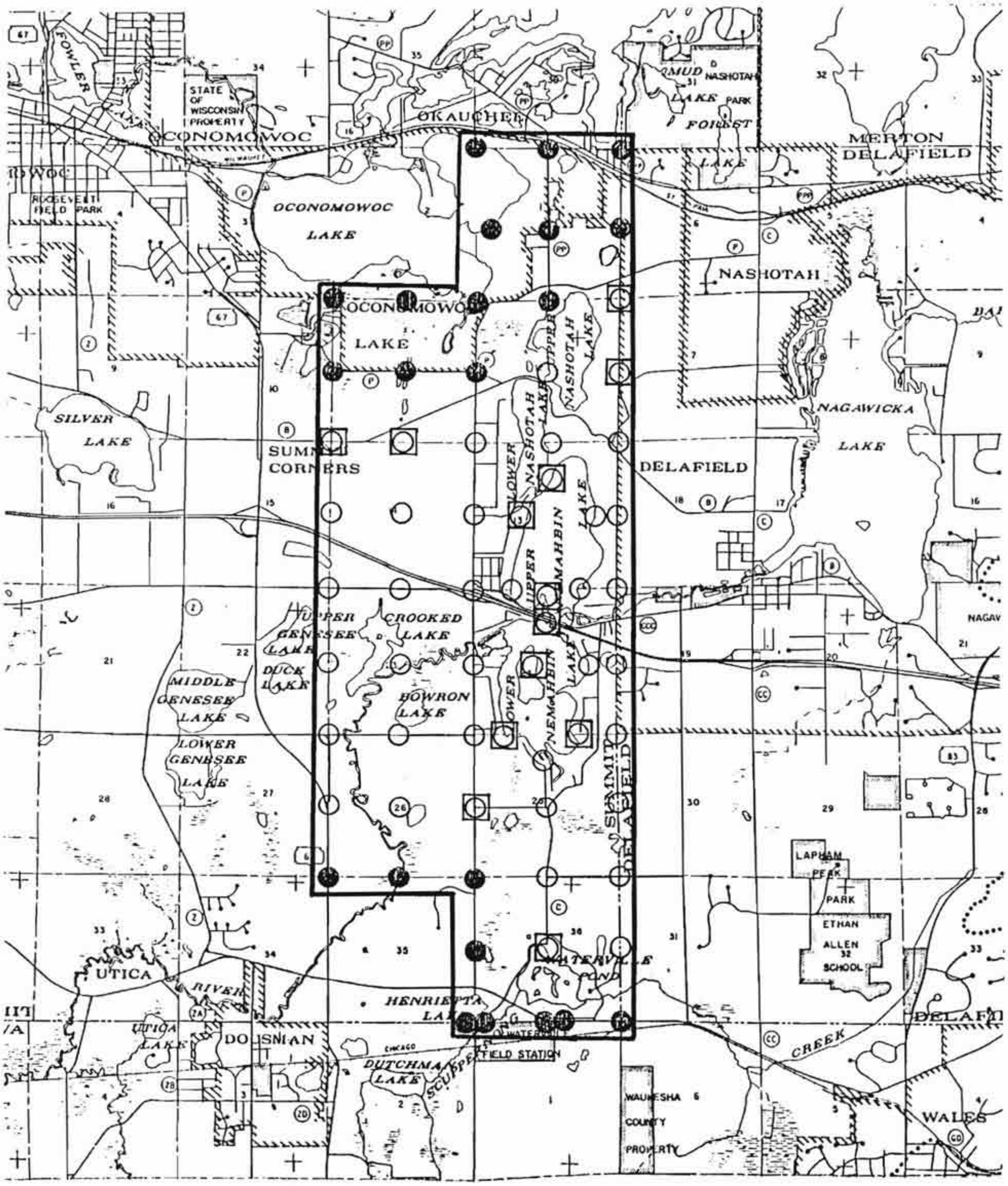
WAUKESHA COUNTY, WISCONSIN



- U.S. Public Land Survey corners which have been previously relocated, monumented, and tied into both horizontal and vertical control survey networks.
- U.S. Public Land Survey corners which have been previously relocated, monumented, and tied into the horizontal control survey network; but which are to be tied into the vertical control survey network.
- U.S. Public Land Survey corners which are to be relocated and monumented by the County Surveyor, and which are to be tied into both horizontal and vertical control survey networks by the Control Survey Engineer.
- U.S. Public Land Survey corners for which preliminary horizontal control survey work is to be completed by the Control Survey Engineer, and which in turn are to be relocated and monumented by the County Surveyor and tied into the vertical and/or horizontal control survey network(s) by the Control Survey Engineer.
- Area for which aerial photography coverage is to be provided and throughout which new 1"=200' scale, 2' contour interval, topographic maps are to be prepared.

Prepared by SEWRPC
February 18, 1991

MAP SHOWING
AERIAL MAPPING COVERAGE AND
CONTROL SURVEY STATION LOCATION FOR
TOWN OF SUMMIT AREA
WAUKESHA COUNTY, WISCONSIN



- U.S. Public Land Survey corners which have been previously relocated, monumented, and tied into both horizontal and vertical control survey networks.
- U.S. Public Land Survey corners which are to be relocated and monumented by the County Surveyor, and which are to be tied into both horizontal and vertical control survey networks by the Control Survey Engineer.
- U.S. Public Land Survey corners for which preliminary horizontal control survey work is to be completed by the Control Survey Engineer, and which in turn are to be relocated and monumented by the County Surveyor and tied into the vertical and horizontal control survey network by the Control Survey Engineer.
- Area for which aerial photography coverage is to be provided and throughout which new 1"=200' scale, 2' contour interval, topographic maps are to be prepared.

Prepared by SEWRPC
February 11, 1991

Exhibit "A-2"

RECORD OF U.S. PUBLIC LAND SURVEY CONTROL STATION

U.S. PUBLIC LAND SURVEY CORNER ┼ T____N, R____E, ____________________ COUNTY, WIS.

GEODETIC SURVEY BY: ______________________________ YEAR: __________

STATE PLANE COORDINATES OF: ____________________ ____________________

NORTH ____________________ ____________________

EAST ____________________ ____________________

ELEVATION OF STATION: ____________________ ____________________

HORIZONTAL DATUM: WISCONSIN STATE PLANE COORDINATE SYSTEM, SOUTH ZONE

VERTICAL DATUM: NATIONAL GEODETIC VERTICAL DATUM OF 1929

CONTROL ACCURACY: THETA ANGLE: ______________

HORIZONTAL: ______________________________ VERTICAL: ______________________________

LOCATION SKETCH:

SURVEYOR'S AFFIDAVIT:

STATE OF WISCONSIN) SS
____________ COUNTY)

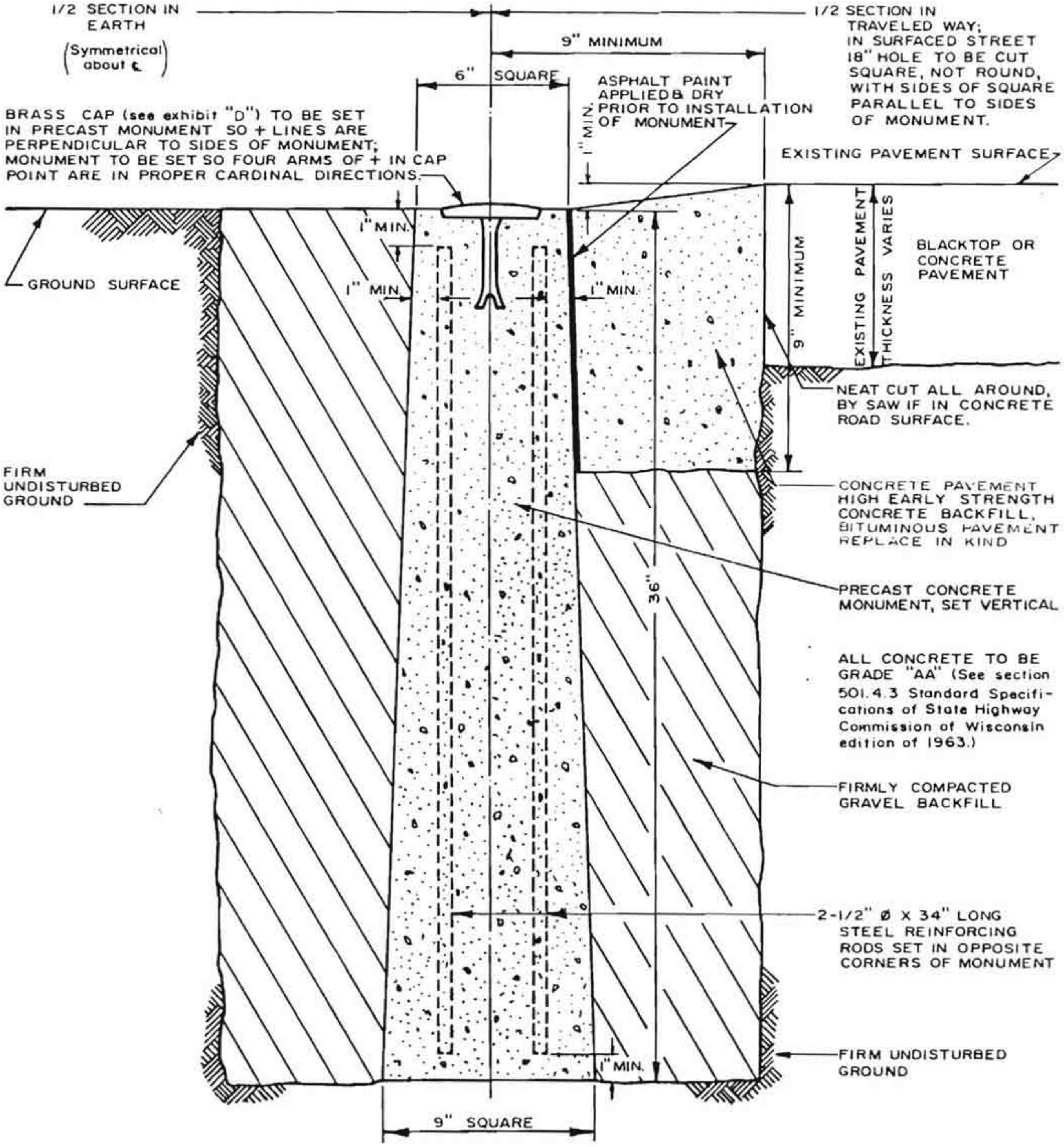
I HEREBY CERTIFY THAT ______________________________

DATE OF SURVEY: ______________ ______________________________ S - ______________
REGISTERED LAND SURVEYOR

FORM PREPARED BY SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

EXHIBIT "B"

DETAIL OF MONUMENT AND MONUMENT INSTALLATION FOR SURVEY CONTROL STATIONS



DRAWN BY: L.H.K.
CHECKED BY: D.R.B.

NOT TO SCALE

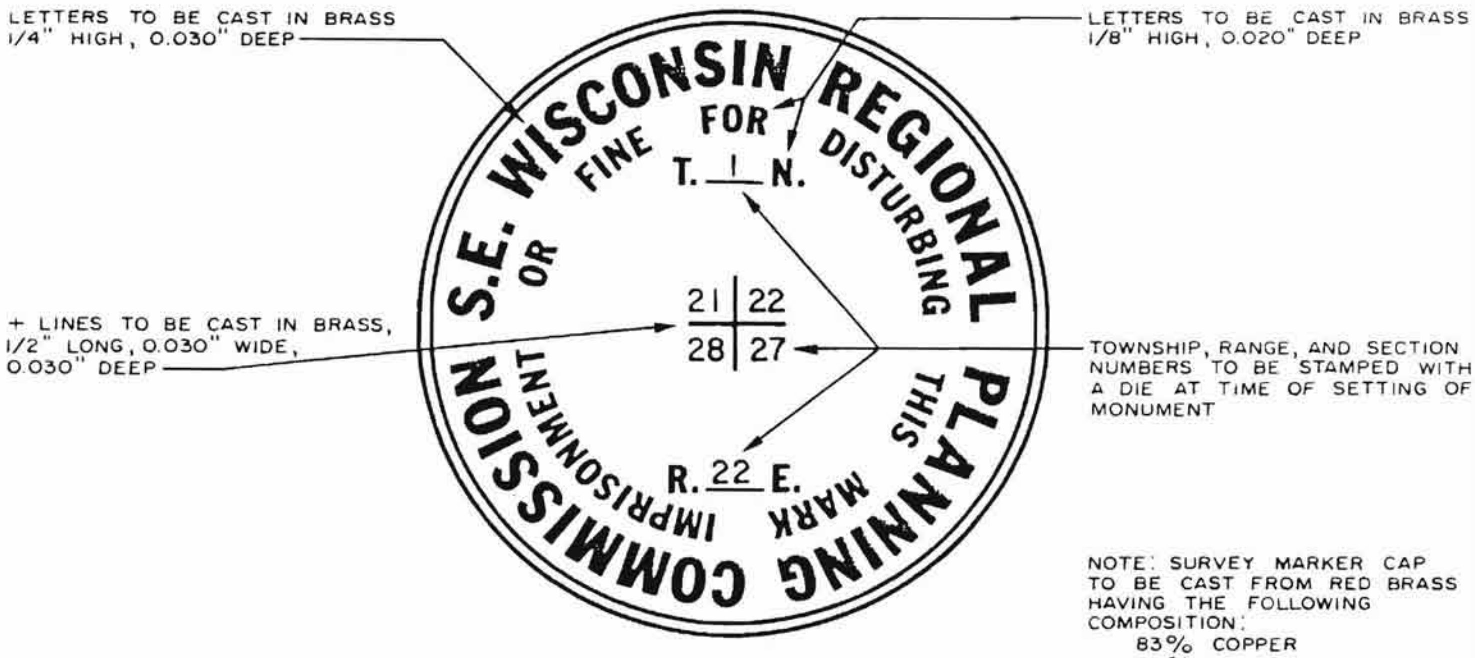
APPROVED BY: K.W.B.
DATE. NOVEMBER 1967

Source: SEWRPC.

EXHIBIT "C"

DETAIL OF BRASS SURVEY MARKER (BERNSTEN RT-1 OR APPROVED EQUAL) FOR SURVEY CONTROL STATION MONUMENTS

TOP VIEW OF CAP

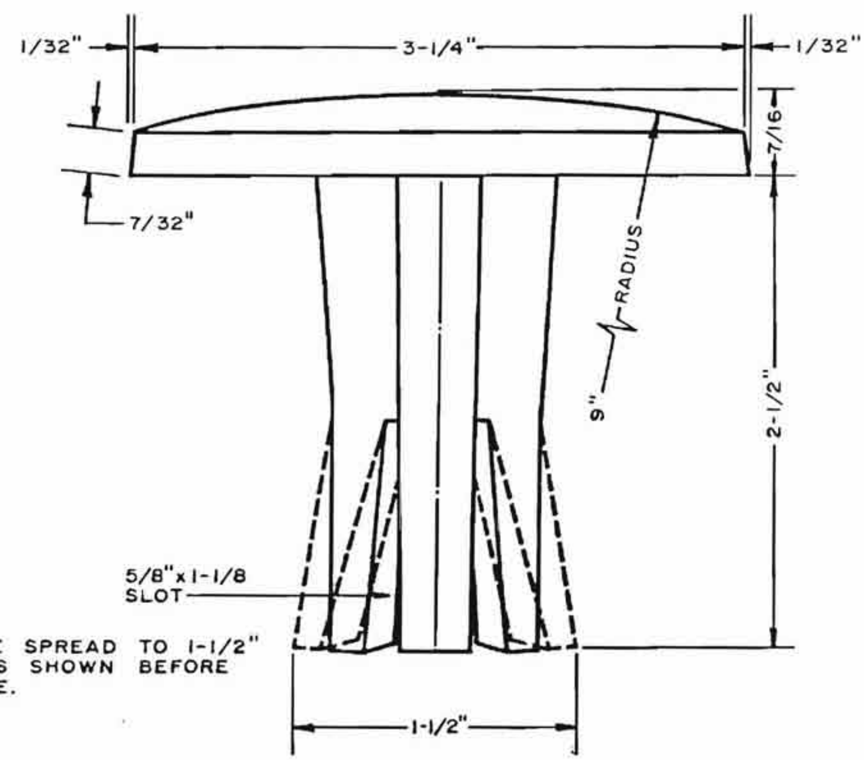


NOTE: SURVEY MARKER CAP TO BE CAST FROM RED BRASS HAVING THE FOLLOWING COMPOSITION:

- 83% COPPER
- 4% TIN
- 6% LEAD
- 7% ZINC

DRAWN BY: D. P. S.
CHECKED BY: L. H. K.
APPROVED BY: K. W. B.
DATE: FEB. 22, 1986

SIDE VIEW



WINGS OF SLOT TO BE SPREAD TO 1-1/2" OUTSIDE DIAMETER AS SHOWN BEFORE SETTING IN CONCRETE.

NOT TO SCALE

Source: SEWRPC.

EXHIBIT "D"