Section G

POSITIONAL ACCURACY DEFINITIONS AND PROCEDURES

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1. INTRODUCTION

Modern surveying standards use the concept of positional accuracy instead of error of closure. Although the concepts of positional accuracy are well known and completely discussed in surveying textbooks, it is important that the concepts and procedures be discussed as part of national standards.

The surveying methods used by the professional surveyor (Surveyor) vary with the purpose of survey to be made and the equipment available. Also, surveying technology is constantly changing, therefore a national standard for a particular type or class of survey cannot specify methods or equipment lest it become obsolete even before it is adopted. A modern standard must be limited to a general description of the survey along with reporting and accuracy requirements. A national survey standard should tell (1) what the survey is to accomplish and what items are to be investigated, (2) how the results are to be reported, and (3) how accurate the results are to be.

It is the responsibility of the Surveyor to select the appropriate procedures and equipment to obtain the accuracy required by the standard. In other words, the surveyor is expected to design a survey measurement specification that will obtain the required accuracy. A standard should not specify surveying procedures but only results.

The NSPS Model Standards use two types of accuracy standards. Relative Positional Accuracy is used in property surveys, construction surveys and topographic surveys. Geospatial Positional Accuracy is used in mapping, geographic information systems (GIS), and geodetic control surveys.

2. RELATIVE POSITIONAL ACCURACY

A. Definitions

Relative Positional Accuracy is a value expressed in feet that represents the uncertainty of the location of any point in a survey relative to any other point in the same survey at the 95 percent confidence level. Therefore it is also the accuracy of the distance between all points on the same survey.

Relative Positional Accuracy may be tested by comparing the relative location of points in a survey as measured by an independent survey of higher accuracy. The comparison should include the measurement of both distances and directions. Relative Positional Accuracy may also be tested by the results from a minimally constrained, correctly weighted least squares adjustment of the survey data. Note that sufficient redundancy in the survey measurements is required, if accuracy is to be tested this way, so as to make the application of the least squares adjustment a valid process.

B. Design of a measurement specification

The NSPS Standards prescribe the level of accuracy that should be obtained in the survey and not survey procedures. Accuracy is the deviation of survey measurement of quantities such as distances, angles or elevations from the correct values. The Surveyor has two responsibilities with regard to the accuracy of a survey. First, the Surveyor must use his or her judgment and experience to determine what procedures and equipment are necessary to obtain the required accuracy. Second, the Surveyor must test the accuracy of the completed survey measurements.

The Surveyor is the expert in land measurements and this expertise is used to develop a measurement specification for the survey. This specification describes the equipment and procedures to be used in the field survey. The equipment to be used will, to a large extent, determine the methods that are to be followed. The surveyor should be guided by experience, computations and the recommendations of the equipment suppliers in the development of this specification. Error analysis computations can be used to determine what accuracy can be expected with the procedures and equipment prescribed in the specification. The Surveyor is not expected to make these computations for every survey. The scope, extent, requirements and objectives of many surveys are of a repetitive nature and therefore the same specification can be used on similar surveys. The error analysis computations are completely discussed and examples are given in many surveying texts and printed articles.

The measurement specifications should be designed so that the accuracy of the measurements meet or exceed the positional accuracy required in the NSPS Standards. It is very likely that each Surveyor will have a specification for various sizes and types of surveys**.** In any event the Surveyor should know what accuracy he or she can expect with the procedures and equipment selected.

Survey measurement specifications must cover some of following items:

1. Periodic testing of EDM equipment over an approved base line.
2. Accurately taking into account atmospheric condition.
3. Periodic testing of optical plumbing.
4. Using the correct prism constant for the equipment.
5. Calibration and testing of steel tapes.
6. Examination and testing of the adjustment and performance characteristics of survey equipment and accessories to verify that the errors resulting from using them according to the Surveyor's procedures are within the error that the specifications allow.

7. Periodic adjustment of equipment by the surveyor or workshops specializing in such work, when examination and testing indicates a need for such adjustment or when good practice indicates that sufficient time has elapsed since the last adjustment.

C. Testing the completed survey

The Surveyor must check the survey work to assure that the intended accuracy is being achieved. Most standards in the past used relative error of closure as a measure of the quality of the survey. That was because many surveys were based upon traverse procedures. Many standards were issued by federal and other agencies for the same reason.

The Surveyor in private practice today performs many surveys that contain measurements that do not result in a closed traverse. This is a result of new equipment and changes in the computing capability available today. Relative error of closure is primarily a measure of the consistency of measurements, but it also can be a valuable tool in testing for accuracy.

Relative Positional Accuracy does not pertain to the location of a particular point or corner in the world but to the accuracy of the measurements used in the survey. Therefore a good test of the relative positional accuracy is to take check measurements of some of the distances in the survey.

The Surveyor should check his or her survey fieldwork by making redundant measurements whenever possible. This is not a new concept. It has always been one of the best ways to make sure that the fieldwork has met the quality that was expected. This does not mean that every survey must have a series of detailed checks. The Surveyor must realize that when a statement is made or inferred that the survey meets a specific standard, the Surveyor has the responsibility to be certain that it actually does meet that standard.

There are many opportunities to check the quality of the survey. For example, in laying out a rectangle (stake out of a building), one of the final checks the Surveyor will probably use before concluding that the work is correct is to measure and compare the diagonals of that rectangle. The Surveyor can easily compute the length of the diagonals and this can be compared with what was measured. In fact just comparing each of the diagonal measurements against each other is important. The allowable variation between the computed diagonal and the measured diagonal or the allowable variation between the two diagonals is a measure of the accuracy of the survey work. The variation should be less than the positional accuracy specified in the standard. The surveyor will also know from developing the measurement specification and from experience what variation can be expected, and anything that is greater than that value would cause the original measurements to be suspect.

There are many instances when distances are obtained by indirect measurements. For example a radial survey used to lay out the lot corners in a subdivision. The actual distance between the exterior corners and the corners of lots are not directly measured in the field. The Surveyor can check the quality of work by directly measuring some of the lines that were indirectly determined. When radial survey procedures are used the

Surveyor recognizes that the distances to be shown on the plat are indirectly determined. As many as possible of those indirect distances should be directly measured to check that the procedures have produced the required accuracy.

The positional accuracy standard is a yardstick by which the Surveyor can judge the quality of the work. The result of the Surveyor's comparison between the computed measurement and the actual measurement must be within the guidelines given in the standards. This comparison not only checks the quality of the distance measurements but also the quality of the angles.

An example of this type of a check is as follows:

The Surveyor uses a total station having an angle quality of 10 seconds (DIN) and a distance quality of 5 mm plus 5 ppm. One corner of the property is measured to be 100.00 feet from the instrument and the other is 200.00 feet. The angle between the corners is measured to be 20 degrees 0 minutes and 0 seconds. The distance between the corners is computed to be 111.41 feet. As a check the distance is directly measured and is 111.37 feet. The variation is 0.04 feet or approximately 0.08 feet at the 95 % confidence level. The required accuracy according to the Standards is 0.08 feet for Urban or 0.14 feet for Suburban Survey. The survey appears to be acceptable for both classes of survey.

The required procedure is to test the quality of the survey by making selected measurements and comparing those measurements with the intended or computed distances. It also stands to reason that the check measurements must have a quality at least equal to or better than the work that it is intended to be check.

Another application of positional accuracy can be seen in the following example:

The Surveyor is to measure a closed traverse having a total length of 1400 feet. The equipment used will be a total station having an angle accuracy of 5 seconds (DIN) and distance quality of 5 mm plus 3 ppm. The survey is to meet Urban Standards and therefore the required positional accuracy is computed to be 0.14 feet. The actual traverse closure is computed to be 0.05 feet and this is similar to a closure of 0.10 feet at the 95 percent confidence level of the NSPS Standard. The survey appears to be in compliance with the standards. If the actual closure had been 0.10 feet or 0.20 at 95% it would not have appeared to meet the standard. In this latter situation one of the diagonals should be computed and measured. The diagonal is computed to be 500 feet and the computed positional accuracy from the standard for an Urban survey will be 0.10 feet. Therefore the measured and computed diagonals should not vary by not more than 0.05 feet or ½ of the required value. If the Surveyor is using a computer program that adjusts the traverse by least squares it probably will analyze the traverse. The error ellipses from these programs should be compared for compliance with the positional accuracy standard.

D. Confidence levels

Most standards in use today are specified at the 95 percent confidence level. This means that if we have a measured distance of 1000 feet with stated reliability of plus or minus 0.10 feet at 95 percent confidence level we can be confident that a measurement of that line will be between 999.90 feet and 1000.10 feet 95 out of 100 times.

As an example, a Surveyor establishes two corners by a radial survey. The distance between the corners is computed and shown on the plat. As a check the Surveyor measures directly between the corners not once, but 100 times. The measurements are made on different days and under different conditions. If all corrections for systematic error are made, the average of those measurement probably approaches the correct length of that line and the standard deviation of those measurements is a good measurement of the accuracy of that distance. If the value of the standard deviation is 0.05 feet, then we would say that the line length is equal to the average distance, plus or minus 0.05 feet at the 68 percent confidence level. In other words, of the 100 measurements there could have been 32 measurements that differed by more than 0.05 feet from the average. At the 95 percent confidence level we can expect that there will be 5 measurements that are 2 times 0.05 feet or 0.10 feet more or less than the average distance. As a practical matter a Surveyor does not measure a line 100 times. The Surveyor makes one high quality check measurement. The Surveyor makes the assumption that this check measurement is the correct value. The difference between the correct distance and the calculated distance is assumed to be an approximation of the standard deviation. The 95 percent confidence interval value will be 2 times the approximate standard deviation. This double value is the value that is compared in the NSPS Standard**.** It must be pointed out again that the check measurements should be a very reliable measurement based on a specification that will provide accuracy above those being checked.

For many years experienced Surveyors have recognized a value that they considered an acceptable variation for their measurements in the field. This value is similar to the standard deviation, or a value at the 68 percent confidence level. Therefore this value is ½ of the value at the 95 percent confidence level that is used in the NSPS Standards. In other words, if the Surveyor's normally acceptable variation is 0.05 feet, that really is 0.10 feet at the 95 percent confidence level.

3. GEOSPATIAL POSITIONAL ACCURACY FOR SPATIAL DATA

A. Definitions

The <u>Geospatial Position Accuracy</u> shall be reported by positional accuracy as defined in two components: horizontal and vertical.

<u>Horizontal Positional Accuracy</u> is the radius of the circle of uncertainty, such that the true or the theoretical location of the point falls within that circle 95-percent of the time. Horizontal Accuracy may be tested by comparing the planimetric coordinates of surveyed ground points with the coordinates of the same points from an independent source of higher accuracy.

<u>Vertical Positional Accuracy</u> is a linear uncertainty value, such that the true or theoretical location of the point falls within the sum of the positive and negative ranges of

that linear uncertainty value 95-per cent of the time. Vertical Accuracy may be tested by comparing the elevation of surveyed ground points with the elevations of the same point determined from a source of higher accuracy.

The development of geographic information systems (GIS) and global positing systems (GPS) has created the need for the development of the National Standard for Spatial Data Accuracy. These national standards speak to the quality of data developed in and for GIS applications. The standards apply to both geographic data developed from map products (photogrammetry) and from survey data to be used in a GIS.

B. Design of a measurement specification

The design of survey measurement specification is the responsibility of the Surveyor. The equipment and methods in this area of professional surveying is new and ever changing. The Surveyor should be guided by the latest published methodologies and the recommendations of the equipment manufactures. The Surveyor should develop methods to test procedures before they are used in an actual survey situation.

C. Testing the completed survey

The geospatial data set is tested by comparing the coordinates of several points within the data set to the coordinates of the same points from a control data set of greater accuracy. The points used in the test must be well defined and easy to measure both in the field and on the digital data product.

The control data set must be of a higher quality than the data being tested. It is best that the quality of the control data set be at least twice as accurate as the expected accuracy of the data set being tested. The control data set should uniformly cover the area of the data being tested and there should be a sufficient number of points to determine valid results.

The positional accuracy statistic is computed for the data being reviewed. This statistic is a value for all the data not for individual data. It is actually the Root Mean Square Error (RMSE) for the data. The value of the statistic is compared with the positional accuracy value in the standards.

The following example illustrates the testing of this kind of data. A Surveyor is employed to provide the location of sewers (manhole lids) to a city for the inclusion in a Geographic Information System (GIS). The data to be provided is the state coordinates of the manholes. The coordinates are to be obtained by a combination of methods including GPS, total stations and laser ranging. This data is to meet the standards for a base mapping scale of 1” = 100’. In order to check compliance with the standards a higher accuracy GPS survey is conducted. The coordinates of some of the manhole covers determined in the GIS project are determined by this check survey. The GPS procedures used in the check survey should be designed to produce accuracy at least in the 0.10 feet range at 68 percent confidence level. The difference between the x and the y coordinates for the GIS data and the check data are determined. The difference in the x and y coordinates is squared and added together. The average of these values is computed. The square root of the average is the RMSE and is used to calculate the statistic for the data set. The RMSE value is multiplied by 1.7308 to obtain the accuracy statistic value at the 95% confidence level used in the standards. Note that there should be enough test points to have a statistically correct result.

As an example: One inch equal 400 feet base maps for a county level GIS were checked for compliance with the standards. The coordinates of points on the maps were compared with high quality GPS coordinates of the same points. Thirty three (33) points were used in the test and the RMSE was calculated to be 6.53 feet therefore the geospatial horizontal accuracy statistic was 11.30 feet (1.7308*6.53). The allowable geospatial horizontal accuracy statistic for this project was 13.48 feet. The project was accepted as meeting the accuracy standard for 1"= 400' mapping.

4. GEOSPATIAL POSITIONAL ACCURACY FOR GEODETIC NETWORKS

A. Definitions

The national standard is published by the FGDC as the Draft Geospatial Positioning Accuracy Standards, Part 2: Standards for Geodetic Networks - December 1996. These standards define the accuracy that is to be evaluated. They are as follows:

The **local accuracy** of a control point is a value expressed in centimeters that represents the uncertainty in the coordinates of the control point relative to the coordinates of other directly connected, adjacent control points at the 95- percent confidence level.

The **network accuracy** of a control point is a value expressed in centimeters that represents the uncertainty in the coordinates of the control point with respect to the geodetic datum at the 95- percent confidence level.

B. Design of a measurement specification

For a detailed description of this standard please refer to the FGDC standard.

C. Testing the completed survey

Accuracies of geodetic control surveys are tested by the results of a minimally constrained, least squares adjustment of the survey measurements. Both the local accuracy and the network accuracy should be reported for horizontal control, ellipsoidal height and orthometric height. For details see the FGDC standard.