7-01   Classifications of Accuracy

All surveys performed by WSDOT or others on all WSDOT-involved transportation improvement projects must be classified according to the standards shown in Figures 7-1 and 7-2. Standards shown are minimum standards for each order of survey.

In addition to conforming to the applicable standards, surveys must be performed using field procedures that meet the specifications for the specified order of survey. Specifications for field procedures are provided in Chapter 8, "Global Positioning System (GPS) - Survey Specifications," Chapter 9, "Total Station System (TSS) - Survey Specifications" and Chapter 10, "Differential Leveling - Survey Specifications." Surveying accuracy standards are meaningless without corresponding survey procedure specifications. Without the use of appropriate specifications, chance and compensating errors can produce results that indicate a level of accuracy that has not been met.

The order of accuracy to use for a specific type of survey is listed in Figures 7-1 and 7-2. Tolerance requirements for setting construction stakes are in Chapter 15, "Construction Surveys." Tolerance requirements for collecting data are in Chapter 14, "Location Surveys."

7-02   Precision and Accuracy

Accuracy is the degree of conformity with a standard or a measure of closeness to a true value.

Accuracy relates to the quality of the result obtained when compared to the standard.

The standard used to determine accuracy can be:

- An exact value, such as the sum of the three angles of a plane triangle is 180 degrees.

- A value of a conventional unit as defined by a physical representation thereof, such as the US survey foot.

- A survey or map deemed sufficiently near the ideal or true value to be held constant for the control of dependent operations.

Precision is the degree of refinement in the performance of an operation (procedures and instrumentation) or in the statement of a result. The term precise also is applied, by custom, to methods and equipment used in attaining results of a high order of accuracy, such as using 3-wire leveling methods or a one second theodolite. The more precise the survey method, the higher the probability that the survey results can be repeated.

Survey observations can have a high precision, but still be inaccurate. For example, observing with a poorly adjusted instrument.

WSDOT Order	Standard	*Monument Spacing	Survey Method	Application
First (1:100,000)	Network Accuracy 0.05 ft. - 0.12 ft (15 mm – 35 mm). Local Accuracy less than 0.05 ft. (15 mm)	Rural Areas 6 miles (10 km) Urban Areas 3 miles (5 km)	GPS: Static Fast Static	Brass disks with PRN designation. First densification layer of NGRS
Second (1:20,000)	Network Accuracy 0.12 ft. - 0.22 ft. Local Accuracy less than 0.08 ft.	Rural Areas 3 miles Urban Areas 1000 feet	GPS: Fast Static Total Station: Traverse	Brass disks with region designation or equivalent Densification of DOT Primary Ref. Network
Third (1:10,000)	Network Accuracy 0.22 ft. - 0.34 ft. Local Accuracy less than 0.17 ft.	As Needed	GPS: Fast Static Kinematic RTK Total Station: Traverse Resection **Double Tie	Rebar and cap with WSDOT designation or equivalent Photo targets, topo, as-builts, const., pits and quarry quantities
General	As required	As required	GPS: Kinematic RTK Total Station: Radial	Temporary monument Resource mapping Stockpile volumes Environmental needs

Notes:

* Refer to other chapters for detailed procedural specifications for specific survey methods and types of surveys.

** Instead of including a point as a network point, certain survey points may be positioned by observations from two or more control points (i.e., double tied). If survey points are not included in a network, double ties must be performed to ensure that blunders are eliminated and the positions established are within the stated accuracy. Double tie procedures may be used only when appropriate.

‡ For definitions of Network and Local Accuracy see next page.

WSDOT Horizontal Control Orders of Accuracy
Figure 7-1

**WSDOT Order	Minimum of BM Ties	*Monument Spacing	Survey Method	Application
First (1:100,000) $e = 5\sqrt{E}$	6	Less than 2 miles	Bar Code	Brass disks with PRN designation First densification layer of NGRS
Second (1:20,000) $e = 8\sqrt{E}$	4	Less than 2 miles	Bar Code 3 wire Total Station: Trig levels	Durable monuments with region designation Control for Major Structures
Third (1:10,000) $e = 12\sqrt{E}$	4	Less than 2 miles	Bar Code Single wire Total Station: Trig levels	Rebar and cap with WSDOT designation or equivalent Photo control, topo Project control Construction staking Durable monuments with region designation
General	N/A	As required	GPS: Kinematic RTK Total Station: Trig levels Single wire	Topographic data Resource mapping Stockpile volumes Environmental needs

Notes:

*   Refer to other manual chapters for detailed procedural specifications for specific survey methods and types of surveys.

** $e = N\sqrt{E}$ indicates closure between established control; e = maximum misclosure in millimeters, E = distance in kilometers, and $\sqrt{}$ indicates "square root", where N is a constant for the order of work.

WSDOT Vertical Control Orders of Accuracy
Figure 7-2

The Federal Geographic Data Committee defines Network Accuracy and Local Accuracy as follows:

The *Network Accuracy* of a control point is a value expressed in centimeters that represent the uncertainty in the coordinates of the control point with respect to the geodetic datum at the 95-percent confidence level. For NSRS network accuracy classification, the datum is considered to be best expressed by the geodetic values at the Continuously Operating Reference Stations (CORS) supported by NGS. By this definition, the local and network accuracy values at CORS sites are considered to be infinitesimal, i.e., to approach zero.

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 reported local accuracy is an approximate average of the individual local accuracy values between this control point and other observed control points used to establish the coordinates of the control point.

Local Accuracy is best adapted to establishing new control points for a local project. Network Accuracy is better used for constructing a Geographic or Land Information System (GIS/LIS) positional tolerance with a set of coordinates. Network accuracy measures how well coordinates approach an ideal, error-free datum

The number of decimal places to which a computation is carried and a result stated indicates precision. However, the use of tables or factors of more decimal places do not necessarily make calculations more precise. The actual precision is governed by the accuracy of the source data and the number of significant figures rather than by the number of decimal places.

The accuracy of a field survey depends directly upon the precision of the survey. Although by chance (for example, compensating error) surveys with high order accuracies might be attained without high order precision, such accuracies are not valid. Therefore, show all measurements and results with the number of significant figures that are commensurate with the precision used to attain the results. For instance, distances measured with an EDM will be shown to the nearest hundredth of a foot, while distances scaled on a USGS 7½ minute quad map will be shown to the nearest 20 feet. Similarly, all surveys must be performed with a precision that ensures that the desired accuracy is attained.

Carefully show computed values with attention to the accuracies of the measurements. For example, in the case of a distance measured as 9.36 feet with a steel tape:

- 9.36 feet x Pi = 29.41 feet, not 29.40531feet

7-02.1   Significant Figures

The significant figures of a measurement are those digits that are known, plus one estimated digit following the known digits.

Recorded numerical values, measured and computed, must contain only those digits that are known, plus one estimated digit. Recorded field measurements must never indicate a precision greater than that used in the actual survey. For example, when measurements are made with a cloth tape, values can only be recorded to the nearest 0.1 ft rather than 0.01 ft.

7-03   Errors

Field measurements are never exact. Observations contain various types of errors. Often some of these known errors can be eliminated by applying appropriate corrections. Even after correcting all known errors , all measurements still have error associated to them by some unknown value. It is the responsibility of the Survey Team to perform surveys so that errors fall within certain acceptable standards.

7-03.1   Types of Errors
7-03.1(a)   Blunders

Blunders, which are unpredictable human mistakes, are not technically errors. Examples of blunders are: reading and recording mistakes, transposition of numbers, and neglecting to level an instrument. Blunders are generally caused by carelessness, misunderstanding, confusion, or poor judgment. Blunders can usually be detected by computing survey closures, carefully checking recorded and computed values and checking observations. Blunders must be found and eliminated from the work before errors are identified and minimized by adjustment procedure.

7-03.1(b)   Systematic Error

Systematic errors, given the same conditions, are of the same magnitude and algebraic sign. Because systematic errors have the same sign, they tend to be cumulative. Thermal contraction and expansion of a steel tape and refraction of angular observations are examples of systematic errors. Systematic errors can be eliminated by procedures such as balancing foresights and backsights in a level loop or by applying a correction, such as a temperature correction to a taped measurement. All detected systematic errors must be eliminated before adjusting a survey for random error.

7-03.1(c)   Random Error

Random errors do not follow any fixed relationship to conditions or circumstances of the observation. Their occurrence, magnitude, and algebraic sign cannot be predicted. An example of random error is instrument pointing. Because of the equal probability of algebraic sign, random errors tend to be compensating. Procedures and corrections cannot compensate for random error. Random errors must be distributed throughout the survey based on most probable values by adjustment procedures.

Some systematic errors, if undetected, act like random errors. For instance, centering error caused by an optical plummet maladjustment is a systematic error, but the error appears random because the orientation of the tribrach to the line of sight is random. In actuality, even a well-adjusted instrument has some amount of error that is treated as systematic random error.

7-04   Least Squares Adjustment

The least squares method of observation adjustment is used for the adjustment of most types of WSDOT Network survey data, whether collected by levels, total stations, or GPS receivers. Other methods of adjustments should be used on non network surveys. To be performed correctly, the adjustment is a two-part procedure. First, an unconstrained or free adjustment is done allowing the new observations to be analyzed, their quality determined, and errors detected. Second, a constrained adjustment is performed, which fits the observations to the reference system, thereby determining the coordinate values of the points observed.

7-04.1   Data Preparation

7-04.1(a)   Coordinates

In order to perform a least squares adjustment, positional values must be assigned to each point in a two or three-dimensional network. In a one-dimensional network, such as in leveling, only one point is assigned an elevation. These values can be approximate if their true values are unknown. In some programs, the approximate value can be incorrect by several thousand feet or meters depending on our units of measurements. However, the closer the approximate values are to the true positions the quicker the adjustment can be solved. Also, the chances that a solution cannot be calculated increases as the amount of error in the approximate values increases. Some adjustment programs including Star*Net and WSDOT Design / Survey Software (CAiCE) have the ability to use the network observations to calculate approximate values.

7-04.1(b)   Observations

Each observation used in the network adjustment has an associated weight. The weight of an observation indicates how much influence it is to have on the final solution. Most programs allow the user to assign an accuracy or precision value, called the "observation standard error" (σ), to each observation. The program then calculates the observation weight using the following equation: $\text{Weight} = 1.0/\sigma^2$. The point to make is, the smaller the standard error, the higher the weight.

There are two ways weights can be assigned to an observation. The first, and least desirable way, is to assign weights to observational groups. For example, weighting all angular observations to the accuracy of the total station used and all distances to the accuracy of the electronic distance measuring devise. This method may be employed only if no other information is available.

The better method is to weight each observation individually. Normally, this is done by calculating the standard deviation (standard error) of the observation. Some design/ software programs employ a procedure that combines both methods. First, it calculates the standard deviation of all observations. Next, it compares the calculated standard deviation with predefined minimum standard error values for each type of observation from the specifications of the instrument used for the observations. The larger of these two values is then used in the least squares adjustment.

7-04.1(c)   Errors

Figure 7-3 illustrates the methods for handling the three types of errors found in surveying observations.

Type	Action	Examples
Blunders	This type of error must be removed before the least squares solution is obtained.	Misnaming an observed point
Systematic	The effects of this type of error must be eliminated by procedures, adjustments, or weighting.	EDM Offset Corrections
Random	These errors will be distributed by the adjustment.	Small Observation Errors

Handling Errors
Figure 7-3

7-04.2 Unconstrained Adjustment

The unconstrained or free adjustment is used to evaluate the observations which comprise the network and the weights and observation standard errors assigned to them. In order to effectively evaluate the network, the network must be a closed system. That is, all points in the network have been observed from at least two other points. This means that a closed traverse or level loop is acceptable, but an open ended traverse or level run is not.

Note:
This does not mean that least squares cannot be used to adjust these types of networks, it simply means that the least squares adjustment will produce a minimal amount of analysis information.

Procedure

1. As shown in Figure 7-4, adjust no more information than the minimum required to perform the unconstrained adjustment (also called a minimally constrained adjustment).

Network Type d=dimensional	Adjust
1d – Levels	The elevation of one point.
2d – Conventional Network or Traverse	The northing and easting of one point and any bearing or azimuth in the network.
3d – Conventional Network or Traverse	The northing and easting of one point and any bearing or azimuth in the network. The elevation of one point in the network.
3d – GPS Network	Nothing required to be fixed; however, one point can be fixed if desired.

Network Adjustments
Figure 7-4

2. Run the adjustment. Normally, a two dimensional adjustment is run first to analyze the horizontal component of the network and make any needed modifications. After a satisfactory resolution of the horizontal data is obtained, a three dimensional adjustment is performed. Problems with the three dimensional adjustment indicate errors in the vertical component (e.g. vertical angle pointing, H.I., and target height measurements). These "vertical" errors can be found more easily when using this two-step unconstrained adjustment process.

3. Analyze the statistical results of the adjustment. There are four main areas that to be analyzed to determine the quality of the network adjustment. These areas are:

   • Standard Deviation of Unit Weight: (Also called Standard Error of Unit Weight, Error Total, Network Reference Factor, etc.) The closer this value is to 1.0 the better your network is weighted. The acceptable range is 0.8 to 1.2. In general if all blunders have been removed, a value greater than 1.0 indicates that the observations are not as good as their weights, while a value less than 1.0 indicates that the observations are better than their weights.

   • Observation Residuals: Usually the adjustment output will include a listing that includes observations, residuals, standard errors, and a warning value or factor. The residual is the amount of adjustment applied to the observation to allow it to best fit the network. Many programs compare the residual to the observation standard error and then flag excessively large residuals. Both CaiCE, or WSDOT design/survey software, and STAR*NET should flag observations when the residual is greater than three times the standard error. Large residuals might indicate blunders that were not previously identified and eliminated.

   • Coordinate Standard Deviations and Error Ellipses: A network with a good Standard Deviation of Unit Weight and well weighted observations with no flagged residuals can still produce points with high standard deviations and large error ellipses (due to the effect, for instance, of network geometry). Examine these values to determine if the point accuracies are high enough for their intended application.

   • Relative Errors: These values, often shown as parts per million (ppm), predict the amount of error that can be expected to be found between points in the network. However, values can also be shown as angular and distance errors (i.e. degrees, minutes and seconds and feet or meters) respectively.

     Star*Net uses a statistical test called the Chi-Square test to give a pass/fail grade to the adjustment. This test compares the actual statistical results to the expected theoretical results (that is a standard deviation of unit weight of 1.0) given the number of degrees of freedom in the network. (Degrees of freedom equal the number of observations minus the number of unknowns in the network.) Obviously, it is desirable to pass this test; however, it is not an absolute requirement. If a network has a standard error of unit weight close to 1.0, no high observation residuals, and still does not pass the Chi-square test, the network can be accepted and the Chi-square test ignored.

4. If necessary, make modifications as determined from the analysis of the adjustment statistical results. These modifications can include: (1) adding, deleting, or editing observations, (2) changing observation standard errors, and (3) modifying centering and standard H.I. errors.

- Adding, Deleting, or Editing Observations**:** At times, it is necessary to add observations to a network. If all other statistical indicators look good but some of the points have excessively large standard deviations, it is probably necessary to add additional observations to those points. Deleting observations might be required if they are proven to include blunders; that is, the observation simply does not fit the network. Sometimes a good observation is listed using the wrong point names; in which case, editing the point names will remove the blunder.

- Changing Observation Standard Errors**:** Observation standard errors are not changed without a good reason. The only justification for changing a standard error is special field conditions noted in the field notes. Normally, if an observation fits poorly and its standard error was calculated individually, it is a blunder. Justifying changing standard errors is more reasonable when the standard errors were assigned on a group basis. However, if changes are made, make them for the whole group, not for an individual observation.

- Modifying Centering and H.I. Standard Errors**:** Mistakes in assigning centering and H.I. errors is often misinterpreted as poor-observation errors, especially if the standard errors were developed for observation groups. This problem is easier to detect when standard errors are developed individually.

5. Readjust the network. The unconstrained adjustment is an iterative process. It may be necessary to adjust and modify the network several times until an acceptable solution is determined. Once this has occurred, a listing of the adjustment results can be printed out for filing and labeled as being the unconstrained adjustment.

7-04.3   Constrained Adjustment Procedure

1. Fix the coordinates of the known control points.

   Note:
   Once the unconstrained adjustment has been accepted, make no modifications of any type to the network with the exception of fixing the coordinates of the control points.

2. Run the adjustment. Analyze the effects of the fixed control on the network adjustment. This is done to determine the validity of the coordinates of the control points. The validity of the network observations was proven in the unconstrained adjustment phase. Depending on the quality of the reference system used to constrain the network, the Standard Deviation of Unit Weight of the final adjustment might not be close to 1.0 and many of the observation residuals might be flagged as being excessively large. This situation is acceptable if it has been determined that there are no blunders in the control. The surveyor in charge of the adjustment must decide if this degradation in quality is significant. If the survey network meets required accuracies, the adjustment is complete. If accuracy standards are not met, then modifications of the fixed points and readjustments might be appropriate.

3. Modify the fixed points as appropriate. There are two modification options available. First, check the fixed coordinates for errors, transpositions, and misidentifications. If required, edit the coordinates and readjust. If this is not the problem, then one or more of the control points is not in its published position. An analysis of the relationship of the control points can help determine which point or points are unacceptable.

A procedure for analyzing the control is as follows:

- Calculate the inverse distance between the published positions of all the fixed control points.

- Calculate the inverse distance between the unconstrained positions of all the fixed control points.

- Calculate the difference between the published inverse distances and the unconstrained inverse distances.

- Using these differences and the published inverse distances, calculate a ppm value for each inverse.

- Examine the ppm values. High ppm values indicate problems with the associated control. A control point that shows up in several of the inverses with high ppm values is probably not in its published position. Try running the adjustment again with this point free.

- Alternatively, control points can be held free or fixed on a trial and error basis until the problem has been detected. Once a determination about the control is made, the final adjustment is performed. After the final adjustment, a listing of the adjustment results can be printed out, labeled as the constrained adjustment, and filed along with a note about any control problems.

4. Readjust network, if necessary.