## *Section III*

# Measurements and Errors

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# III. Measurements and Errors

## A. Introduction

The purpose of this section is to discuss the different types of surveying measurements, identify error sources, and describe procedures to minimize errors. Using common sense and developing sound surveying practices cannot be over-emphasized. In addition to specific surveying procedures, the surveyor will often be required to use their judgment to make important decisions affecting the survey.

Different types of surveying instruments used or the methods in which they are employed will result in measurement differences. The defined error tolerances of the survey will usually dictate the equipment or methodology required to achieve the best possible results. Often, surveys involving critical elevations will require the use of a digital level or optical total station over GPS equipment. The field conditions encountered will also influence the survey. For example, excessive heat waves or strong winds may make it nearly impossible to accurately perform some operations. Refer to Section VIII, Survey Standards, in this manual for specific error tolerances for each feature code.

## B. Surveying Measurements

Measuring distances and angles from a known reference are fundamental surveying operations. Through the use of trigonometric calculations, the distance and angle measurements are used to establish three dimensional (3-D) coordinates for each surveyed point. The coordinates are then plotted to create planimetric maps and digital terrain models (DTM's). The five common types of survey measurements are horizontal distances and angles, vertical distances and angles, and slope distances.

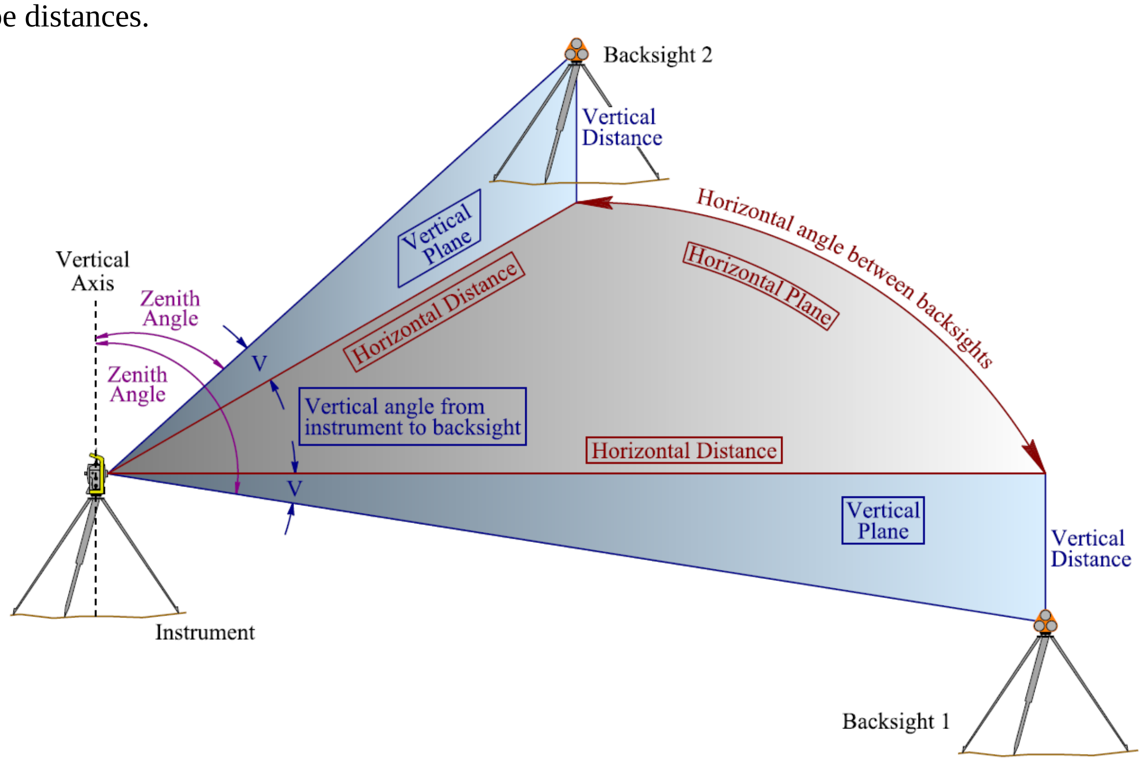


*Figure III-1. Surveying measurements.*

## 1. Horizontal and Vertical Planes

Angles and distances are measured relative to either a horizontal or vertical plane. The horizontal plane is a level surface radiating outward from the point of observation and is perpendicular to the vertical axis. The vertical axis (or plumb line) is always parallel to the direction of gravity. The vertical plane runs in a direction parallel to the vertical axis and perpendicular to the horizontal plane. A vertical plane is established whenever the instrument rotates along the horizontal plane to face a new direction.

### a. Horizontal Distances and Angles

A linear measurement on the horizontal plane determines the horizontal distance between two points. However, the true horizontal distance is actually curved like the Earth's surface. Due to this curvature, the direction of gravity is different at each point. Subsequently, vertical axes are not parallel to each other. Figure III-2 shows a representation of the curved surface and the parallel horizontal distance.

Horizontal angles are measured on the horizontal plane and establish the azimuth of each survey measurement. An azimuth is a horizontal angle measured clockwise from a defined reference (typically geodetic north). Horizontal distance and angle measurements are then used to calculate the position of a point on the horizontal plane.

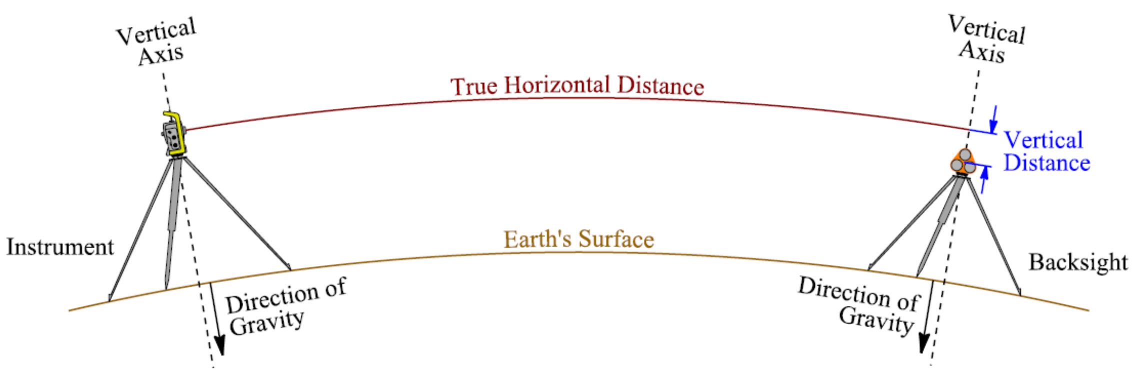


***Figure III-2. Horizontal distance.***

### b. Vertical Distances and Angles

Vertical distances are measured along the vertical axis to determine the difference in height (or elevation) between points. Vertical angles are measured in the vertical plane either above or below the horizontal plane of the instrument. Zenith angles, used as a reference for measuring vertical angles, are defined as 0° directly overhead and 90° at the horizontal plane.

### c. Slope Distance

The slope distance is the shortest distance from the instrument to the target. This distance is the hypotenuse of the horizontal and vertical distances. The horizontal and vertical distances can be calculated if the slope distance and vertical angle is known.

## 2. Accuracy and Precision

Accuracy and precision are two different, yet equally important surveying concepts. Accuracy is the degree of conformity of a given measurement with a standard value. Precision is the extent to which a given set of measurements agree with their mean.

These concepts are illustrated in Figures III-3 through III-5 with a target shooting example. In Figure III-3, all five shots are closely grouped indicating good precision due to the degree of repeatability. However the accuracy is poor because the shots are far from the center of the target. In Figure III-4, the five shots appear randomly scattered about the target indicating neither accuracy nor precision. In Figure III-5, all five shots are closely spaced about the target's center indicating both precision and accuracy.

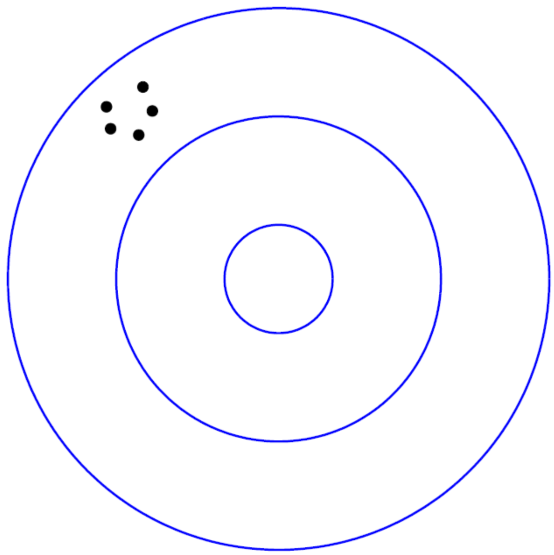

*Figure III-3. Precision without accuracy.*

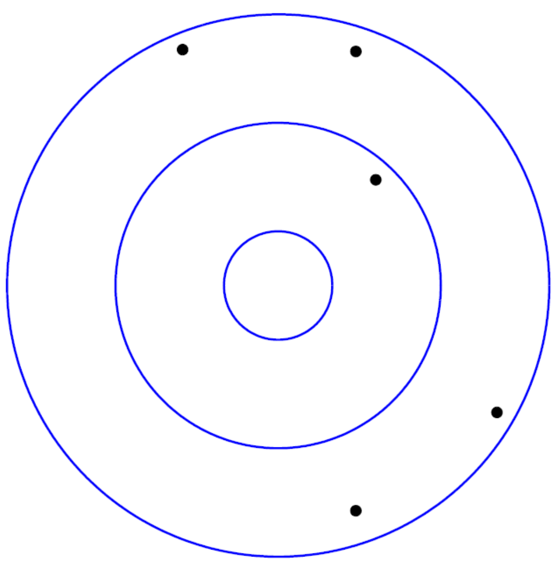

*Figure III-4. Neither precision nor accuracy.*

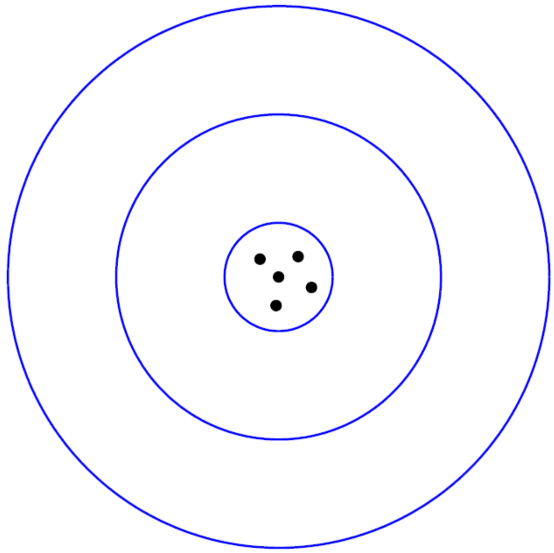

*Figure III-5. Precision and accuracy.*

The goal of any survey should be to produce accurate and precise observations. Often measurements with greater accuracy and precision requirements employ multiple observations to minimize procedural errors. Refer to Chapter 6 in the Data Collection Manual for proper data collection methods. Each measurement should be reviewed to ensure compliance with defined survey standards before storing it. Refer to Section VIII, Survey Standards, in this manual for the horizontal and vertical accuracy required for each measurement. Also located in Section VIII is a discussion of the proper surveying instrumentation required to meet the standards.

## C. Errors

A discrepancy is defined as the difference between two or more measured values of the same quantity. However, measurements are never exact and there will always be a degree of variance regardless of the survey instrument or method used. These variances are known as errors and will need to be reduced or eliminated to maintain specific survey standards.

Even when carefully following established surveying procedures, observations may still contain errors. Errors, by definition, are the difference between a measured value and its true value. The true value of a measurement is determined by taking the mean value of a series of repeated measurements. Surveyors must possess skill in instrument operation and knowledge of surveying methods to minimize the amount of error in each measurement.

### 1. Blunders

A blunder (or gross error) is a significant, unpredictable mistake caused by human error that often leads to large discrepancies. Blunders are typically the result of carelessness, miscommunication, fatigue, or poor judgment. Examples of common blunders are:

- Improperly leveling the surveying instrument.
- Setting up the instrument or target over the wrong control point.

- Incorrectly entering a control point number in the data collector.
- Transposing numbers or misplacing the decimal point.

All blunders must be found and eliminated prior to submitting a survey for inclusion in the project mapping. The surveyor must remain alert and constantly examine measurements to eliminate these mistakes. Blunders can be detected and eliminated by reacting to "out-of-tolerance" messages by the data collector when they occur. They can also be detected by carefully examining a plot of the collected survey points while in the office.

## 2. Types of Errors

There are two types of errors, systematic and random. It is important for the surveyor to understand the difference between the two errors in order to minimize them.

### a. Systematic Errors

Systematic errors are caused by the surveying equipment, observation methods, and certain environmental factors. Under the same measurement conditions, these errors will have the same magnitude and direction (positive or negative). Because systematic errors are repetitive and tend to accumulate in a series of measurements, they are also referred to as cumulative errors.

Although some systematic errors are difficult to detect, the surveyor must recognize the conditions that cause such errors. The following list includes several examples of systematic errors:

- Using incorrect temperature and/or pressure observations.
- Not applying curvature and refraction constants.
- Using incorrect instrument heights and/or target heights.
- Using an incorrect prism offset.
- Using an imperfectly adjusted instrument.

The effect of these errors can be minimized by:

- Properly leveling the survey instrument and targets.
- Balancing foresight and backsight observations.
- Entering the appropriate environmental correction factors in the data collector.
- Entering the correct instrument heights, targets heights, and prism offset in the data collector.
- Periodically calibrating the surveying equipment.

If appropriate corrections are not made, these errors can accumulate and cause significant discrepancies between measured values. By keeping equipment in proper working order and following established surveying procedures, many of the systematic errors can be eliminated.

### b. Random Errors

Random (or accidental) errors are not directly related to the conditions or circumstances of the observation. For a single measurement or a series of measurements, it is the error remaining after all possible systematic errors and blunders have been eliminated.

As the name implies, random errors are unpredictable and are often caused by factors beyond the control of the surveyor. Their occurrence, magnitude, and direction (positive or negative) cannot be predicted. Errors of this type are compensating and tend to at least partially cancel themselves mathematically. Because the magnitude is also a matter of chance they will remain, to some degree, in every measurement.

Misclosures (or residuals) are the difference in a measurement or a series of measurements from an established value. Random errors account for the misclosure when systematic errors have been corrected and blunders have been removed. Misclosures are computed when adjusting level loops, traverses, and GPS networks.

Random errors conform to the laws of probability and are therefore equally distributed throughout the survey. Because of their random nature, correction factors cannot be computed and applied as they are with some systematic errors. However, they can be estimated using a procedure based on the laws of probability known as the least-squares method of adjustment. This method computes the most probable adjusted values and the precision of the survey. The least-squares method may also reveal the presence of large blunders.

## 3. Error Sources

There are a variety of factors that can lead to measurement errors. Errors typically arise from three sources; natural errors, instrument errors, and human errors.

### a. Natural Errors

Natural errors are caused by environmental conditions or significant changes in environmental conditions. Wind speed, air temperature, atmospheric pressure, humidity, gravity, earth curvature, and atmospheric refraction are examples of natural error sources. Many of these environmental conditions can be compensated for by applying a correction factor to each measurement. Commonly used correction factors are the parts per million (ppm) and curvature and refraction constants.

The ppm correction factor is applied to slope distances to minimize the effects of atmospheric changes. The correction is determined using observed temperature and pressure readings. With each instrument setup, new temperature and pressure readings should be taken and the ppm constant revised, if necessary. The curvature and refraction constant is applied to the vertical distance measurement. The constant corrects for the Earth’s curvature and atmospheric refraction and should be applied to the survey by the data collector.

There are other natural phenomena that can lead to measurement errors. Intense, direct sunlight may cause differential expansion of the components of the instrument, resulting in minor errors. This effect can be minimized by operating on cloudy days, times of low sun angles, or using a parasol to shade the instrument. Heat waves can cause distortion in lines of sight near reflective surfaces. The effects of heat waves can be minimized by surveying in cooler, cloudy periods, taking shorter measurements, or avoiding measurements taken over asphalt or concrete in excessively hot weather.

### b. Instrument Errors

Instrument errors are caused by imperfectly constructed, adjusted, or calibrated surveying equipment. Most of these errors can be reduced by properly leveling the instrument, balancing backsight/foresight shots, reducing measurement distances, and observing direct and reverse positions (double centering).

Prolonged storage, exposure to rapid changes in temperature, and jarring during transportation may lead to instrument maladjustments. Collimation and other sighting errors can be determined and compensated for by specific instrument adjustments. Before making instrument adjustments or beginning surveying operations, allow the instrument to adapt to the ambient temperature before proceeding.

Instrument errors can be further minimized by periodically calibrating surveying instruments, prisms, rods, and tribrachs. Yearly maintenance agreements are purchased to ensure that WYDOT surveying instruments are regularly cleaned, calibrated, and adjusted by an authorized technician. Occasionally during these services visits, the data collector's operating system (firmware) will be replaced with a more current version.

It is equally important that equipment suspected of being out of tolerance is sent to the appropriate service center. The Photogrammetry & Surveys Section should be notified prior to sending equipment for unscheduled adjustment, calibration and/or repairs.

### c. Human Errors

Human errors are caused by physical limitations and inconsistent setup and observation habits of the surveyor. For example, minor errors result from misaligning the telescope crosshairs on the target or not holding the target rod perfectly plumb. These errors will always be present to some degree in every observation. However, by following established setup and collection procedures, many potential errors can be minimized.

Because any survey is only as accurate as the instrument/target setup; a secure, level tripod is paramount. A tripod should always be used to stabilize the backsight target when placing it over a control point. When positioning the tripod, firmly press the tripod feet into the ground. Place the tripod legs in a position that will reduce the amount of walking near the instrument. Minimizing movement around the tripod will reduce the chances of bumping it. In windy conditions, it may be necessary to place sandbags on the feet of the tripod to ensure stability. When setting up on steep slopes, position two tripod legs on the downhill side. Periodically check the optical plummet to verify that the instrument is still centered over the point. Periodically check the level bubble to ensure that the instrument is still on a horizontal plane. The level bubble should hold one position when the instrument is smoothly rotated through a complete revolution.

When taking an observation with an optical instrument, the center of the target should coincide with the center of the reticle (or crosshair). To obtain accurate results, consistently sight the telescope to the same part of the target. Turn the ocular (or eye piece) until the reticle is clearly focused. Then adjust the focusing knob until the target is clearly defined within the field of view. When the observer's eye moves behind the ocular, the target and reticle should not be displaced with respect to one another.