

Part I: Principles of Surveying

1.1. Surveying, Defined

Surveying can be defined as “(1) The science and art of making all essential measurements in space to determine the relative positions and points and/or physical and cultural details above, on, or beneath the earth’s surface and to depict them in usable form, or to establish the position of points and/or details. Also, the actual making of a survey and recording and/or delineation of dimensions and details for subsequent use. (2) The acquiring and/or accumulation of qualitative information and quantitative data by observing, counting, classifying, and recording according to need”.¹ This broad description involves two basic practices used in surveying. The first is the measurement of data between existing phenomenon. For example, it entails the measurement of angles and distances between points in a traverse. The second activity is the location of phenomenon on the earth such as the staking of a road centerline on a highway construction project from design plans..

Placing survey data into a usable form means the mapping of the survey data. This is normally done using computer-aided drafting (CAD) techniques with software such as MicroStation. Data is usually collected in electronic form in the field and then transferred to the computer software for subsequent adjustment and analysis. Later, this data may be used by engineers to perform design. The final product of the survey is a map in hardcopy and/or digital form to the client.

1.2. Types of Survey

As the definition of surveying implies, the practice of surveying is a very extensive activity. Thus, surveys are generally broken down into their purpose. These kinds of surveys are defined in section 1.4. In general, surveying can be broken down into two general types: plane surveying and geodetic surveying.

1.2.1. Plane Surveying

Plane surveying simplifies the survey in that it treats the surface as a flat plane. The purpose of this kind of simplification is to reduce the complexity in the subsequent processing of the survey data. As a plane, Euclidean geometry can be used for calculations. This simplification of the earth does have its repercussions for larger projects. Here, the effects of the curvature must be taken into account.

¹**Definition of Surveying and Associated Terms**, American Congress on Surveying and Mapping and American Society of Civil Engineers, 1984.

1.2.2. Geodetic Surveying

Geodetic surveying encompasses the determination of the size and shape of the earth and its gravity field. Here the calculations are much more elaborate because the surface upon which the measurements are being made and reduced is a curved surface. Geodetic surveys are required for large scale projects where the effects of the earth curvature are critical or when a high degree of accuracy is necessary to complete the particular project. Surveying with the global positioning system (GPS) requires the surveyor to think in a geodetic surveying mode. This is discussed further in **Part V** of this manual.

1.3. Datums

A datum can be considered as a reference surface upon which the survey is based. With this description, any reference can be used to control a survey. In fact, for small projects, many surveyors will utilize a local control network by establishing a localized datum specific for the particular project. Unfortunately, a local datum is site specific and the incorporation of that survey into a large network of surveys is difficult, at best, without some sort of global datum control. Therefore, unless approved by the Design Survey manager, the datums used for MDOT surveys will be based on the North American Datum of 1983 and the North American Vertical Datum of 1988, both which are described in the next two sections. Generally, the datums for horizontal and vertical control are different, although with the growing popularity of GPS, three-dimensional datums are increasingly used.

1.3.1. Horizontal

The earth can be visualized as an ellipsoid of revolution. This is an ideal figure since the actual earth is more complex than that. The function of geodesists is to find that figure that best fits a particular area. In 1927, the U.S. Coast and Geodetic Survey (now the National Geodetic Survey) selected the Clarke 1866 ellipsoid because it was the best-fit surface for the U.S. Because of problems in that adjustment and with the growing use of satellite geodesy, the North American Datum of 1927 was readjusted. The new datum is called the North American Datum of 1983. This datum is an earth-centered, earth-fixed datum where the center is the center of mass of the earth. It is based on the geodetic reference system of 1980 (GRS 80). The defining parameters of this ellipse are:

$$\begin{aligned}a &= 6378137 \text{ m} \\ \omega &= 7292115 \times 10^{-11} \text{ rad/s} \\ GM &= 986005 \times 10^8 \text{ m}^3/\text{s}^2 \\ J_2 &= 108263 \times 10^8\end{aligned}$$

where a is the semi-major axis of the ellipse, ω is the angular velocity, GM is the gravitational constant, and J_2 is the unnormalized dynamic form factor. From these basic parameters, the other conventional elements of the ellipse, namely the semi-minor axis of the ellipse (b) and the flattening ($1/f$) can be derived as:

$$b = 6356752.3141$$
$$1/f = 298.257222101$$

GPS utilizes a slightly different datum, namely the world geodetic system of 1984 (WGS 84). Essentially, this is identical to the GRS 80 datum except that the normalized form factor has been slightly rounded off in the former datum, but its effects are very minor and should not affect survey operations.

1.3.2. Vertical

The North American Vertical Datum of 1988 (NAVD 88) is used as the vertical datum for elevations. Unlike its predecessor NAVD 29, this new vertical datum is not adjusted to mean sea level. Instead, the level network was adjusted to a tidal bench mark at Father Point, Rimouski, Quebec. The heights associated with this datum are called orthometric heights as opposed to the ellipsoidal heights that are derived from GPS leveling. See **Part V** for a more detailed explanation.

1.4. Definitions

1.4.1. Boundary and Right of Way Survey

Boundary surveys involve the location of the interests and rights to real property. Whether it is to determine the location of a land parcel or the determination of the right-of-way of a roadway, the surveyor is required to carefully research the history of the land in question. They are bound not only by the measurements made in the field but also upon a body of law that has been either codified or established by the courts in what is called common law. It is the surveyor's responsibility to bring this data together and to resolve ambiguities that may exist and then present an opinion of where the boundaries should be located on the ground. Often times these data may be dichotomous. Using the principles laid out in court cases and legislation, the surveyor must weigh the evidence to arrive at a conclusion. When the facts as collected by the surveyor raise legal problems for the client, it is the responsibility of the surveyor to relay those facts to the client and encourage that client to seek legal representation if necessary to resolve the problem. Boundary surveys are discussed in more detail in **Part VI**.

A right of way survey is a boundary survey that is undertaken to either locate the legal extent of a current roadway or to determine the boundaries of that roadway for new construction. The purpose is to define that area that is dedicated to vehicular traffic, either in current use or proposed. The right of way is designed to limit the construction of objects that may impede the safe flow of traffic and the law restricts the erection of permanent structures that obscure sight distances or which may introduce a danger to the motoring public.

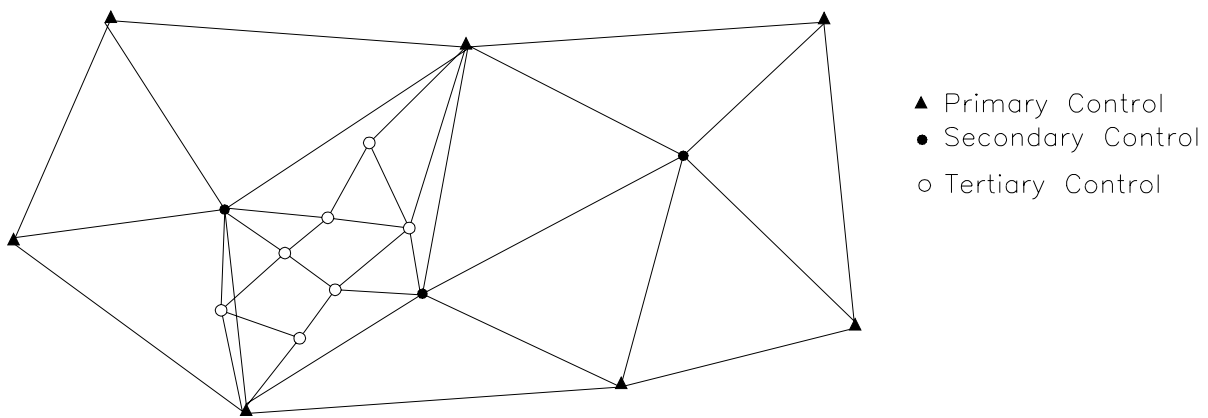
1.4.2.. Control Survey

A control survey is one that is executed to provide a basic framework for subsequent surveys on a

site. These kinds of surveys are performed at a higher degree of precision and accuracy in order to limit the accumulation of error in subsequent surveys. Control monuments are set at locations that are easily accessible to the subsequent surveyors and situated in locations which will offer some protection against vandalism and destruction.

A properly executed control network takes on a hierarchical structure. High accuracy control monuments form a skeleton structure for the network (Figure 1.1). They are located using established standards and specifications to meet the accuracy needs of that framework. Subsequent surveys are then performed to densify and augment that basic framework. This can go down several levels. Each time the higher accuracy network is used to control the augmented network. This continues until the density of control is sufficient for the project.

Figure 1.1
Example control network with three levels of control.



Control is used to provide the location of points in the field for a host of applications such as route surveys, photogrammetric surveys, bridge surveys, topographic surveys, and more. These are described in subsequent sections of this chapter. A more detailed description of control surveys is found in [Part VII](#).

1.4.3 Route Survey

Route surveys are undertaken to either lay out or locate an existing transportation corridor. This type of survey requires knowledge of horizontal and vertical curve geometry. The purpose is to set out the roadway as designed while fitting it to the terrain conditions, making sure that safety of the driving public is paramount. The critical factor for the survey is the alignment. This has three components: survey, legal, and construction which are defined in [Part VIII](#).

Like all surveys, route surveys require the collection of facts garnered from field measurements and old records. While the coordinate geometry associated with routes is often given a lot of attention, there is also a legal component to route surveys that must also be taken into account. The lack of research into a route survey may result in subsequent problems in the design and construction phases of the roadway.

1.4.4. Photogrammetric Survey

Photogrammetry is often used to collect data for the design of roadways. Photogrammetric surveys can be divided into two broad categories: ground control to support the photogrammetric mapping process and the actual process of collecting data using photogrammetric instruments and techniques. The concept of photogrammetric control surveys is described in **Part IX**.

While it is technically feasible, and very cost effective, to perform photogrammetric surveys without the presence of ground control, this practice should not be employed without the approval of the Design Survey manager. Ground control provides quality control and assurance within the photogrammetric process and this redundancy is critical in the successful completion of a photogrammetric survey.

1.4.5. Bridge Survey

A bridge survey is required whenever a proposed bridge or the reconstruction of an existing bridge is to be incorporated into the design of a roadway. These kinds of surveys are very different from the conventional route surveys, although they may incorporate route design principles within their structure. The main function is to locate the bridge such that it meets the roadway on either end in a manner that facilitates safe vehicular traffic flow. The surveyor's duties and role in bridge surveys is given in **Part X**.

1.4.6. Litigation Survey

Litigation surveys are executed because of either impending or possible legal action in which MDOT might be a party. It is very important for the surveyor to understand that they are serving as fact finders and their work may come under legal scrutiny in court where they may be asked to testify as an expert witness. Litigation surveys are often performed after the fact and this means that the scene may have changed. Therefore, the surveyor must be keenly aware that they are to report only those facts that they discovered.

Evidence that is collected at the scene may not be in a form that most surveyors would collect under normal situations. For example, crude measurements may have been taken by other parties or amateur photographs collected as a part of the investigation. The surveyor needs to weight this evidence and not be unduly swayed by that data which they did not collect themselves. Their facts may either substantiate or refute the on-scene evidence and they are bound to report those findings regardless of the repercussions on their client. Because of this, it is imperative that the surveyor

communicate their findings to their client's legal representative and help prepare that attorney about the testimony that they will have to give. **Part XI** elaborates on the surveyor's role in litigation surveys.

1.4.7. Topographic Survey

The collection of terrain data is called a topographic survey. Data are collected to determine the "lay of the land" by locating, both horizontally and vertically, the contours that pass through a particular project. Topographic surveys involve not only the determination of heights in the area but also the location of natural and man-made features that will affect the intended design on the site. Therefore, a topographic survey may include a boundary survey to locate the legal extent of the site and to identify and locate both public and private easements that may impact on the design.

Generally, field surveys of the topography involve the collection of a digital terrain model (DTM). This is a collection of X, Y, and Z points throughout the site. Since interpolation software will be used to generate the terrain, it is critical that the surveyor collect a sufficient number of points to faithfully portray the ground conditions on the site. Break lines must be located and sufficient mass points within the site measured so that the contour generation program can model the terrain properly. Topographic surveys are described in more detail in **Part XII**.

1.4.8. Hydraulic Survey

The purpose of a hydraulic survey is to capture field data that can be used by the design team for bridge and culvert design characteristics. It is critical that the surveyor work with the MDOT Hydraulics Unit before undertaking such a survey to determine the extent of the data that needs to be collected. If no control is available in the site area the surveyor will be required to bring survey control onto the site for proper referencing of the survey. Part XIII describes the duties of the surveyor in a hydraulic and hydrologic survey.

1.5. Units of Measure

To provide consistency in surveys, it is important that a unified system of unit measured be used. This will be elaborated on in **Part III**. There are four different areas of measurement that will be defined: angular, linear, area, and volume.

1.5.1. Angular

Angular measurements will be made using the sexagesimal system. This system is based on the circumference of a circle being comprised of 360° (degrees) with each degree of arc consisting of 60' (minutes) and each minute containing 60" (seconds). The general form for expressing these angles in the degree-minute-second format instead of decimal degrees.

1.5.2. Linear (English and Metric)

There are numerous types of linear units used in this state. During the original surveys of the state, chains were used to mark out distances. One chain has a length of 66' (this is commonly referred to as the Gunter chain). Each chain consisted of 100 links each being 0.66' in length. There are 80 chains in a mile. It is also common to see the term rod, perch or pole used to delineate a distance. Each of these linear units is the same and they correspond to 16.5'. There are nuances to these defined lengths but, unless there is overwhelming evidence to the contrary, these conversion relationships shall be used in resurveys within the state. The conventional English (or Imperial) distance measurement is the foot which is divided into tenths and hundredths of a foot.

Metric units (which are often referred to as SI units) are the form in which distances are reported for MDOT projects. The meter is defined as 1,650,763.73 wavelengths of the krypton atom excited at a defined energy level. The important relationship to consider in metric units is the conversion of feet to meters and vice versa. Michigan's State Plane Coordinate Act (see **Part IV**) requires the International Foot to Meter conversion. This is defined as:

$$1 \text{ foot} = 0.3048 \text{ meter (exact)}$$

Prior to the revision of the State Plane Coordinate Act, the official conversion was based on the U.S. Survey Foot to Meter conversion which is defined as:

$$1200 \text{ meters} = 3937 \text{ feet (exact)}$$

When performing the arithmetic, one can see that the two conversion factors are very close and are actually insignificant on small projects with short distances. On the other hand, on projects where state plane coordinates are employed, the discrepancy is significant. Any distance conversion for MDOT projects will be done using the International Foot conversion factor.

1.5.3. Area and Volume (English and Metric)

Since area and volume measures are based on linear measurements, they can also be expressed in terms of English or metric units. The English unit for area is the acre. It consists of 43,560 square feet. Volume is generally expressed in terms of cubic yards. A cubic yard is a cube where the width, depth and height are all one yard in length. There are 27 cubic feet in one cubic yard.

The metric equivalent of area is the hectare which consists of 1,000 square meters. There are approximately 2.471 acres in a hectare. The volume measure is usually expressed as cubic meters. There are approximately 1.308 cubic yards (or 35.31 cubic feet) in a cubic meter. Hectares will be used for area and cubic meters for volume in MDOT projects.