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Directions

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In surveying, direction is the term used to denote the course or heading of a line. Here, a line is defined by its end points, giving it a magnitude (length) and direction, much like a vector. By convention, direction is specified in terms of angles and is separated into horizontal and vertical components. This chapter deals primarily with the horizontal component of direction within the context of **plane surveys.** In **geodetic surveys,** where the earth's curvature is taken into account, the fundamental concepts of direction still apply, though their use in subsequent calculations is far more complex.

Traditionally, direction has been established through astronomic observations or compass readings. Although these traditional approaches may still be applicable in certain situations, the **Global Positioning System** is now preferred due to its accuracy and convenience.

146.1 Angles

Angles form the basis for quantification of direction. There are several conventions available for specification of angular units. In the U.S., the sexagesimal system is currently the most commonly used for surveying applications. In this system a full circle is divided into 360 degrees, with further subdivisions into minutes and seconds. Sixty minutes is equivalent to one degree and sixty seconds is equivalent to one minute. Thus, an angle can be expressed in degrees ($^\circ$), minutes ($'$), and seconds ($''$), much like time is expressed in terms of hours, minutes, and seconds. As an alternative, angles can be expressed in terms of degrees and a decimal fraction thereof, though this is not conventional surveying notation.

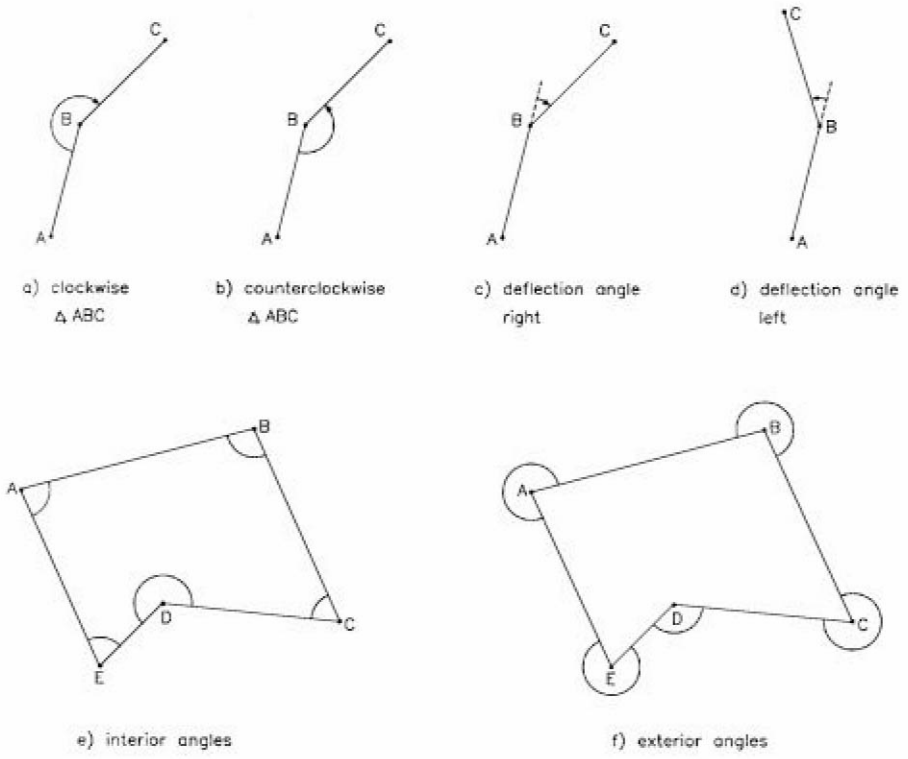
Other angular units are available, such as radians, grads, or mils [see Eq. (146.1) for unit equivalents]. The radian is a dimensionless unit that utilizes the ratio of the length of a circular arc to its radius to express the magnitude of the subtended angle. The grad (or *gon*) is a unit of measure in the centesimal system (widely used in Europe) that corresponds to 1/400 of a full circle. The mil is an angular unit corresponding to 1/6400 of a full circle and is used by the U.S. military,

primarily in artillery applications. These three alternate systems are decimal based, as opposed to the base-sixty approach of the sexagesimal system.

$$\text{Right angle} = 90 \text{ degrees} = 100 \text{ grads} = 1600 \text{ mils} = \pi/2 \text{ radians} \qquad (146.1)$$

Horizontal angles are measured in a plane perpendicular to the direction of gravity. There are many types of horizontal angles, such as angles to the right (clockwise) or left (counterclockwise), interior angles, exterior angles, and deflection angles. Figure 146.1 shows the various types of angles. Angles to the right—with the backsight, occupied, and foresight points specified—are recommended for modern surveys due to their applicability to electronic data collectors and computer software. An illustration of this notation is given in Fig. 146.1(a), where point A is the backsight, B is occupied, and C is the foresight point.

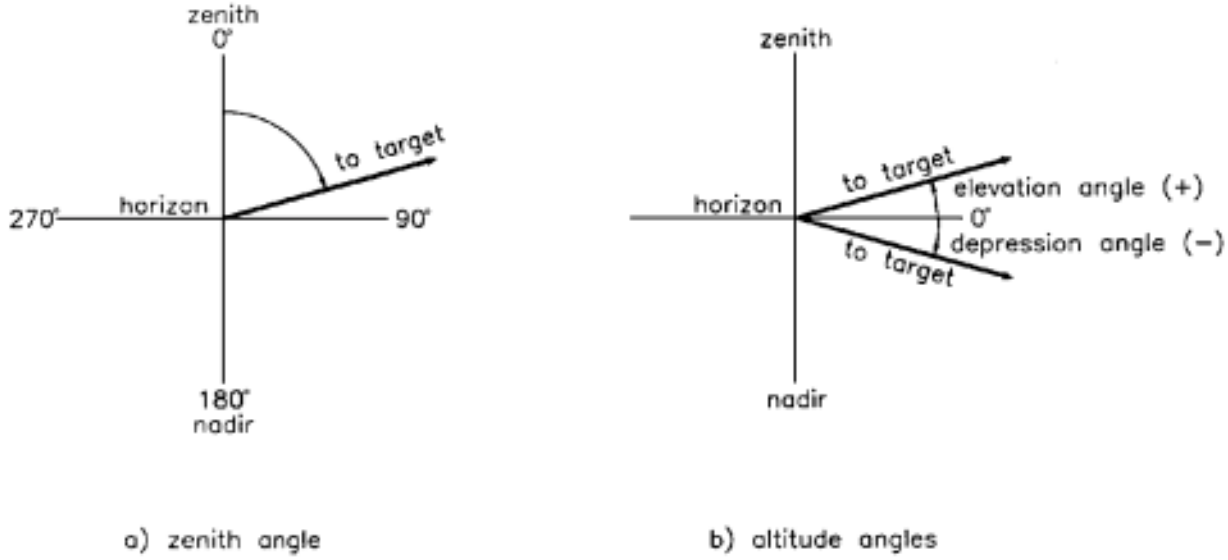
Figure 146.1 Illustration of various types of horizontal angles.



Vertical angles are measured in a plane perpendicular to the horizontal. There are two fundamental types of vertical angles: zenith angles and altitude angles. A zenith angle (or zenith distance), illustrated in Fig. 146.2 (a), is the angle from the observer's zenith direction to the target. Zenith angles range from 0° to 360°, with 90° and 270° corresponding to the direction of the horizon in the direct and reverse position, respectively. An altitude angle, illustrated in Fig. 146.2 (b), is the angle from the observer's horizon to the target. Altitude angles above the horizon are called *elevation angles* and are considered positive by convention, whereas those below the

horizon are called *depression angles* and are considered negative.

Figure 146.2 Profile view illustrating two types of vertical angles.



Surveyors determine angles with instruments known as *transits* or *theodolites.* Both instruments enable the user to perform the same basic functions, that is, to measure or establish horizontal and vertical angles. Generally, theodolites are more accurate and precise than transits, though this is not always the case. Some modern theodolites have electronic angle-reading systems and are incorporated into **total stations,** which also have the capability of measuring distances electronically. Total stations are particularly convenient due to their ability to feed recorded data directly to a field computer.

146.2 Meridians

In order to specify the horizontal component of direction, it is first necessary to specify the reference meridian. A meridian is an imaginary line that is selected as the nominal north-south indicator in the observer's horizon plane. It can be based on any one of several references: geodetic, astronomic, magnetic, grid, or assumed.

A geodetic (also called *geographic*) meridian is based on the north and south poles as defined by a particular latitude and longitude reference or graticule. It has been demonstrated that the rotational axis of the earth changes slightly over time, so in essence the geographic graticule is a "snapshot" in time. This reference becomes standardized by virtue of published coordinates for a network of monumented points, based on its definition.

An astronomic meridian is based on the rotational axis of the earth and the direction of gravity. It derives its name from the means by which it is typically established: astronomic observations. The angular difference between astronomic and geodetic meridians is expressed in terms of the Laplace equation. For most practical purposes in plane surveying, this difference is negligible and both meridians are collectively referred to as the "true" meridian.

A magnetic meridian is based on the magnetic north and south poles of the earth. These poles are

distinct from the geographic poles and change appreciably over time. The angle from true north to magnetic north is called the *magnetic declination* and is a function of the observer's location with respect to the poles. The effect of magnetic declination can be quite large—for example, in parts of Alaska, magnetic declination is greater than 30° east.

A map projection is a distorted rendition of a portion of the curved earth's surface on a surface that can be laid out flat. The projection has an inherent x, y coordinate system, with y in the general direction of north. In the projection any line parallel to the y axis is a grid meridian. They are different from the three meridians previously mentioned, in that grid meridians are parallel to each other, whereas the others are not.

Assumed (arbitrary) meridians are chosen for convenience. Here, a direction is arbitrarily specified for a line connecting two survey points. This direction is often chosen so as to approximate some specific meridian; however, no actual observation of a meridian is performed. There is an inherent risk associated with assumed meridians. If one or both of the survey points is lost, the assumed meridian becomes unrecoverable.

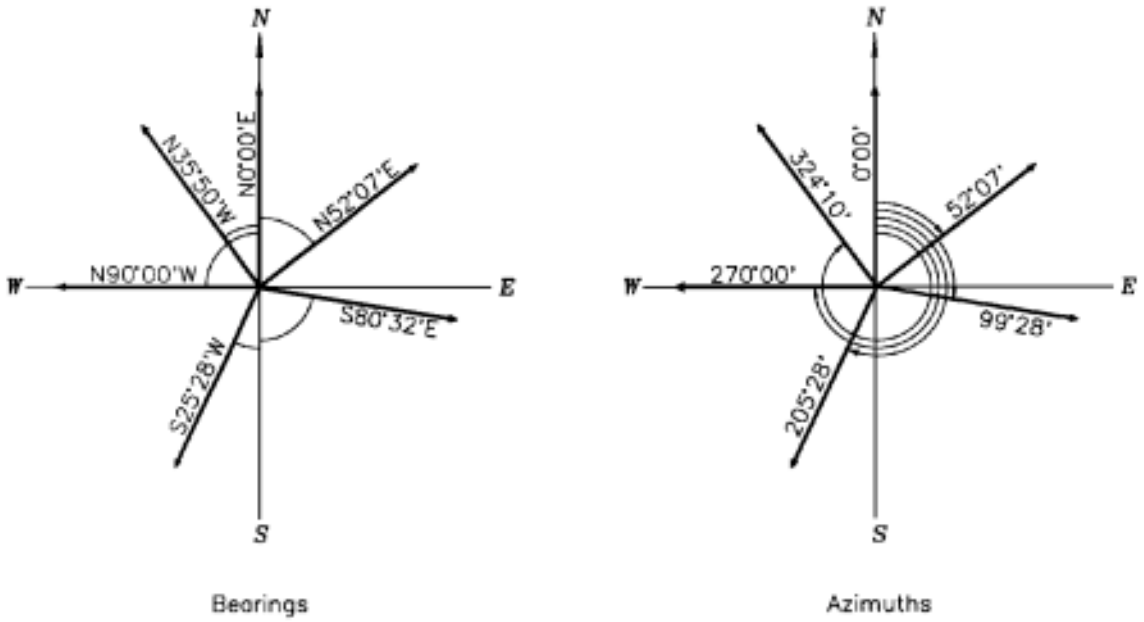
146.3 Direction

In mathematics, polar coordinates are often used to specify the position of a point. Here, the direction of the line from the origin to the point is based on the angle from the positive x axis, with counterclockwise angles being positive. In surveying, the direction of a line can be expressed either in terms of **bearing** or **azimuth.** Both forms depend on the meridian definition mentioned earlier. No matter which approach is used, it is important to clearly specify the meridian upon which the direction is based.

Bearing of a line is specified as an acute horizontal angle between the line and meridian, along with letters specifying the proper quadrant. It is expressed in the form of the letter N or S, followed by an angle (less than or equal to 90°), followed by the letter E or W.

Azimuth is specified as the clockwise horizontal angle from the meridian to the line. The angular value is positive and less than 360° . Azimuths are commonly specified from north, though this is not a universally accepted standard. Some applications use azimuths that are referenced from south. Due to this possible ambiguity, one should clearly indicate whether a north or south reference is implied. Figure 146.3 gives examples of bearings and azimuths (from north) for selected lines.

Figure 146.3 Examples of bearings of selected lines and their equivalent azimuths.



146.4 Back Bearing and Back Azimuth

Back bearings are expressions of the opposite direction of a line. The expression is formed by starting with the original (forward) bearing and then changing the "sense" of the letters. An N is changed to an S (or vice versa), and an E is changed to a W (or vice versa); however, the angular value remains the same. For example, if the bearing from point 1 to point 2 is N47°15′ W, its back bearing (i.e., the bearing from point 2 to point 1) is S47°15′ E.

Back azimuths are also expressions of the opposite direction of a line. The expression is formed by adding $180°$ to or subtracting $180°$ from the original (forward) azimuth, keeping in mind that the result must be in the range of 0 to $360°$. For example, if the azimuth from point 1 to point 2 is $312°45'$, its back azimuth (i.e., the azimuth from point 2 to point 1) is $132°45'$.

The foregoing simple relations for back bearings and back azimuths are applicable only to plane surveys of a limited extent, where it can be assumed that all meridians are parallel. In surveys covering a large area, earth curvature and meridian convergence are appreciable factors and therefore a more complicated relation must be used.

146.5 Applications

There are many applications in surveying that call for the use of directions. Property surveys, geodetic control surveys, transportation corridor (route) surveys, and topographic surveys are but a few. Most applications involving directions utilize plane trigonometry in the solution. Computations involving addition and subtraction of angles, sine and cosine laws, right triangle relationships, and sum of angles in a closed polygon are routinely performed.

Defining Terms

Azimuth: An expression for the direction of a line consisting of the clockwise horizontal angle ($\geq 0°$ and $< 360°$) from one end of the meridian. Azimuths from north are generally used;

however, some conventions employ azimuth from south.

Bearing: An expression for the direction of a line consisting of the horizontal angle ($\leq 90^\circ$) that the line makes with the meridian in conjunction with prefixed and postfixed letters that specify the quadrant.

Geodetic survey: A survey in which the earth's true three-dimensional shape and gravity field are taken into account.

Global Positioning System: A system of satellites and ground receivers that enables users to determine geodetic coordinates of points to a high degree of accuracy. The system is under the control of the U.S. Department of Defense but has been used for civilian applications since the early 1980s.

Horizontal angle: An angle that is defined in a plane perpendicular to the direction of gravity.

Meridian: In a global context a meridian is the intersection of the plane containing the north pole, the south pole, and the observer's position with the spheroidal figure that approximates the earth. In a local context a meridian is a reference line that defines the north-south direction. This reference can be on a geodetic, astronomic, magnetic, grid, or assumed basis.

Plane survey: A survey of limited extent and accuracy in which the earth's surface is assumed to be a plane. This assumption permits the use of plane trigonometry in computations involving coordinates and other parameters.

Total station: A device used in surveying that incorporates an electronic theodolite with an electronic distance-measuring instrument and a computer. The device can automatically read and record horizontal and vertical angles and slope distances.

Vertical angle: An angle that is defined in a plane parallel to the direction of gravity.

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Further Information

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