SURVEYING

ESCI 4701: GEOMORPHOLOGY

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Land surveying is an important skill when studying the Earth's surface, and can be applied to a broad range of studies in the Earth and Environmental sciences. This introduction will cover both simple, lower-tech approaches and higher-tech surveying methods. The old but still-relevant book, Compton's *Geology in the Field*, has a useful basic introduction to some of these topics on pp. 16–21, 135–161, and 229–238.

1. Measuring and marking positions

The simple question of, "where is it?" requires knowledge of how one's position relates to other objects around the globe. As a result, many surveys do not include any information to relate them to such an absolute coordinate reference frame. Instead, a relative system of coordinates often sufficies, with sufficient information to connect a survey to a global coordinate system later if desired.

A relative coordinate system can be made with respect to any feature, but these are typically (a) recognizable natural or human-made points that are (b) expected to be permanent relative to the duration of the survey, and that may be marked more accurately by surveying benchmarks.

In surveying, we typically mark positions with stakes, colored non-adhesive tape, and nails. The stake is pounded into the ground at the desired point. If you do not have tape and nails, then you may simply use a marker or pen to place a dot on the stake. Ideally, though, you have both. You can punch through a piece of tape using the nail, and then pound the nail into the head of the stake, which is already in the ground. Specialized surveying nails have divots in their heads that can guide a survey rod into place for precise measurement of the location of the marker.

Figure 1. Space to sketch a survey nail → brightly colored tape, with both pounded into a stake that is in turn pounded into the ground.

Obtaining an absolute position requires one of a few methods. The first is a precise measurement with respect to known benchmarks (Figure 2). The second is using GNSS (Global

Navigation Satellite System) networks and receivers[1]. GNSS use is becoming increasingly common. By combining measurements from stationary base stations and mobile receivers ("differential" or "real-time kinematic" GNSS), it becomes possible to correct for atmospheric noise and obtain absolute positions to within a few centimeters. By combining these absolute-position measurements with much more precise relative measurements between points, it is possible to build consistent and georeferenced data sets.

FIGURE 2. Survey benchmark in the USA. Their locations are measured and recorded very accurately, and can be accessed in local and national databases.

Some local surveying methods, indicated below, are higher-precision than these absolute-position surveying methods, although improvements in GNSS are bringing these absolute measurements close to – or better than – traditional analog surveying equipment (measuring ropes or tapes, compasses, and clinometers). Digital survey equipment, especially **total stations** (Section 8), retain higher precision than differential or real-time kinematic GPS.

2. Measuring distance

2.1. **Taping.** A long measuring tape or surveyor's "rope" can be used to measure distance in the field. These provide a direct measure of distance. When taut, they give a straight-line distance measure between two points. When crossing the ground, they give the longer (land-surface) measure between those two points. Ideally, over distances that you use the tape or rope, you can approximate it to be straight either by holding it taut or by "taping" across distances that can be approximated as straight lines. (Think about calculus and the definition of a derivative: such a straight-line approximation becomes easier when taping across short distances, but this then takes more time to survey.)

Let's imagine that you are taping up a slope that you know to be 5 degrees. If your tape reads 10 meters, what is the horizontal distance between these points? Write out the trig function by hand; this is more important than actually calculating the answer.

[1] "GNSS" comprises all satellite positioning systems, including the Global Positioning System (GPS, USA), Globalnaya navigatsionnaya sputnikovaya sistema (GLONASS, Russia), and some capabilities of the BeiDou Navigation Satellite System (BDS, China) and Galileo (European Union).

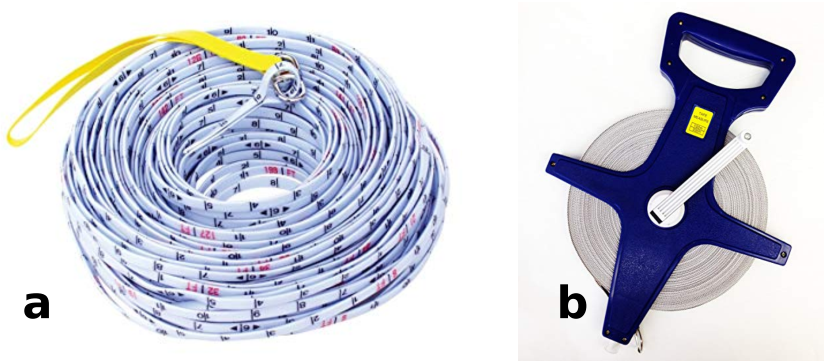


Figure 3. **(a)** Surveyor's "rope". **(b)** open-reel measuring tape, also often used in surveying.

2.2. **Pacing.** Taping takes time. However, someone skilled at *pacing* can estimate distance to 1% accuracy by just walking. How do you do this?

(1) Lay out a 100-meter tape or rope (or another distance of your choice). The longer the tape, the more precise the result. If you do not have a measuring tape, map out 100 meters (or a convenient and walkable distance between two recognizable points) using Google Earth and replace later mentions of this "tape" with this imaginary line.
(2) Walk along this tape, keeping count of how many steps you have taken. It is very important to keep your stride natural: walk how you normally would! (For me, it helps to count only when my right leg takes a step, to keep from needing to increment in my mind so quickly. Just either multiply this by two, or make sure to note how you are defining your "pace"!)
    (a) When complete, write this number down
    (b) Repeat this two or more times until you feel like you have a consistent idea of how many steps it takes.
(3) Sum the total number of steps you took in all of the pacing trials that you consider to be representative of your normal walk (this will probably be all of them, but you might skip one if you feel you were walking strangely, stumbled, etc.)
(4) Divide 100 meters (or whatever distance you chose), times the total number of "good" pacing trials, by the total number of paces that you took during these trials. This is the length of your pace. You may now use this to estimate distance.
(5) Realize that your pace will change on slopes, in rough terrain, etc. If you feel that you are not walking in the same way as you did during this calibration, re-calibrate your pace in this new terrain.

If you are practicing pacing using these instructions, and do not have another sheet with you, use the table below to record your paces. Then, use the boldfaced headings below to compute and record your pace. Save this number! It can be useful for activities that range from your field work to ensuring that the apartment you're thinking of renting is the same size that the landlord is advertising it to be!

Total distance:

Total paces:

Length of pace:

Pace defined as one step or two steps?

Table 1. Pacing.

Distance walked	**Number of paces**	**Pace = 1 or 2 steps**

2.3. **Rangefinders. Laser rangefinders** have becoming reasonably common. Handheld models can typically mark distance to ±10 cm. High-precision ones, such as those in a "**total station**" (survey instrument that can measure angles and distance) can be precise to ∼1 mm.

More recently, high-precision laser rangefinders have been integrated into **LiDAR** (or lidar) technology. These rangefinders are responsible for distance measurements for robots – including assistive and self-driving vehicles – and for high-resolution topographic surveys. This includes **airborne lidar** – used, for example, to make high-precision maps of terrain (including Minnesota: see `http://arcgis.dnr.state.mn.us/maps/mntopo/`) and even-higher-precision maps of small areas using **terrestrial laser scanners**. Each of these latter instruments includes information on angles and positions that can help to create a three-dimensional map, and this kind of information will be the topic of the following sections.

Figure 4. Handheld laser rangefinder.

3. Measuring inclination

The **inclination** is the **angle from vertical**. This can be measured with a variety of analog and digital instruments. We will focus mostly on the analog instruments here, and consider the digital ones more thoroughly in Section 8.

3.1. **Clinometers in compasses.** Both the Brunton Pocket Transit and the Sylva Ranger contain clinometers. These are bubble levels that may be rotated in place, such that once level, an arm attached to them gives the angle from the vertical of a particular slope.

FIGURE 5. Brunton pocket transit features, from Sanuja Senanayake (`https://sanuja.com/blog/how-to-use-a-brunton-compass`). **(A)** marks the bubble level level that is attached to **(G)** the arm used to measure slope. The inside of the arc is graduated in percent slope (rise / run × 100%), whereas the outside is graduated in angles: use one and be consistent! The arm itself has graduations to help you estimate fractions of a degree or percent, but we will focus on just the whole-number percentages; refer to a Brunton Pocket Transit manual to learn how to use these.

These clinometers may be most simply used when the transit is resting against a solid surface. The compass should typically not be directly placed on the surface, but rather placed on a clipboard, rod, or other piece of rigid material that is on the surface and can bridge across irregularities to ensure that you are measuring the mean slope along a taped section (for example), and not the local slope, which might be much more variable.

In addition to these direct-surface measurements, you may wish to measure slope from a tripod or staff. In this case, **remember that your eye elevation is above the ground surface**. If you wish to make an accurate measurement, you must either (a) shoot to a target that is at your eye's elevation above the target point (held, for example, by a partner), or shoot towards the ground at your target point and use trigonometry (based, for example, on the length of your measured distance between the points and the height of the midpoint of your transit above the ground) to correct for this. The former option – having a target of the same elevation – is easier.

3.2. **Handheld clinometers.** A handheld clinometer is a device that you can place to your eye and read an inclination. It is quick, easy, and reasonably accurate. As with the example of a transit on a tripod or rod (above), you must take into account the height of the instrument. In this case, this is the height of your eye!

To most easily survey with a handheld clinometer, find a partner who is at least as tall as your eye height. If you cannot find such a person, hand a partner who is shorter than your eye height the clinometer. Then, assuming you found a suitable person, find a distinctive portion of their body or clothing that is exactly at your eye height. You may place a piece of bright tape on them, etc.

Once this eye-height issue is resolved, your partner walks a known distance ahead of you (perhaps known because you are both holding a tape – more on this next), and then stops. At this point, you read the clinometer to measure the inclination (vertical angle) between you and your eye height on your partner. One of you has a field book to record this. You then repeat this until you are finished surveying. While performing this operation, it is important that your start/finish point be exactly identical. This can be done by your partner waiting for you to catch up with them before walking, or (more efficiently) by your partner placing a recognizable rock, etc. between their feet, and you finding the exact same point that way. Note that this step is very important: lose your position, and you have to start over at the last known point!

3.3. **Laser rangefinders with digital clinometers.** Many laser rangefinders contain clinometers. These can measure distance at and vertical angle at the same time, and their software typically includes the ability to break this into a "slope distance" (i.e. straight-line distance) and vertical angle, or into horizontal and vertical distances (solving the trigonometry internally).

3.4. **Level transits.** A **level transit** is a surveying device capable of measuring both distance and inclination. As such, it is ideal for measuring the relative vertical positions of surfaces, groundwater wells, and so forth. What it lacks compared to a **total station** is the ability to measure horizontal angles. Nevertheless, it is common that a precise vertical position is the most important piece of information to know – especially considering that GNSS provides quite precise horizontal position and relatively imprecise (though improving) vertical positions. A level transit has the additional advantage of being significantly less expensive than a total station!

4. Exercise: Leveling and error

4.1. **Leveling. "Leveling"** is the surveying term for measuring the height of one position with respect to that of another. Measuring distances and inclinations together are essential to leveling.

In the example below, you wish to know the relative heights of two different banks of a river in order to determine which side might be more susceptible to flooding, and by how much. The distance is too far for you to directly span the river with your tape, meaning that even though you can determine the angle between the two banks, you cannot determine the height difference (which requires a distance and an angle, per trigonometry). However, you can wade across it the river, allowing you to make a set of measurements that can eventually give you the height difference.

You do so, and when you return from the field, you note the following measurements in your field notebook. Your angles are from the horizontal, with positive angles being up and negative angles being down. For each measurement, you moved the the former location of your partner, and they moved to the next location. This means that you can obtain the difference in height by summing the vertical components of each of these line-segment surveys. In this small river, it is safe to assume that the tape is always taut. (Note that I allow both banks to be perfectly horizontal; this is not necessarily the case, but is intended to help you answer the question of the relative elevation difference between the two.)

Table 2. Example field data from hypothetical leveling across a river.

Distance [m]	**Angle [°]**	**Notes**
4.97	0	River right floodplain / bank top.
1.75	−30	Small scarp by vegetation.
5.35	−3	Point bar.
7.72	0	Channel crossing. Both my feet and my partner's are at the water's edge, on opposite sides of the river
2.05	42	Steep cut bank; eroded as we climbed it.
4.00	0	Top of river left bank (on floodplain).

When you return from the field, you use these to compare these two elevations and evaluate the flood hazard. Note that after returning from the field, you are free to use all resources at your disposal: pen/paper, computer, calculator, and/or your colleagues' expertise. (Don't forget that many computers calculate angles in radians instead of degrees.)

Take some time to solve this, and bear in mind the field logistics involved in field surveying so you can visualize what you might have to do to perform such a survey yourself.

4.2. **Error.** One important component of leveling and surveying in general is managing and propagating error in your survey. Propagating error can be done in two steps:

(1) Compute the error associated with each step
(2) Combine the errors from all steps

4.2.1. *Computing errors associated with each individual step.* Based on studies of surveying, good tape-based distances are accurate to within 0.1% (±0.05%) and your angles (using a hand-held clinometer) are likely accurate to within 1° (± 0.5°). (Note that these are my estimates, but are checked against *Geology in the Field* and are reasonable.)

Consider these error estimates to be true for two standard deviations (often noted as "2σ") – that is, approximately 95% of measurements will have errors within these bounds. This assumes that there is a **normal** or "Gaussian" distribution of errors, meaning that the errors are random and uncorrelated. If the errors are correlated – for example, because your clinometer is improperly calibrated and therefore tends to estimate a horizontal angle being slightly negative – this assumption will be broken and you instead need to correct your data by measuring the degree to which the clinometer is off, using a trusted instrument, and then adding this difference to your data (while being sure to retain your original, uncorrected data with an appropriate note about the **systematic error** caused by your instrument).

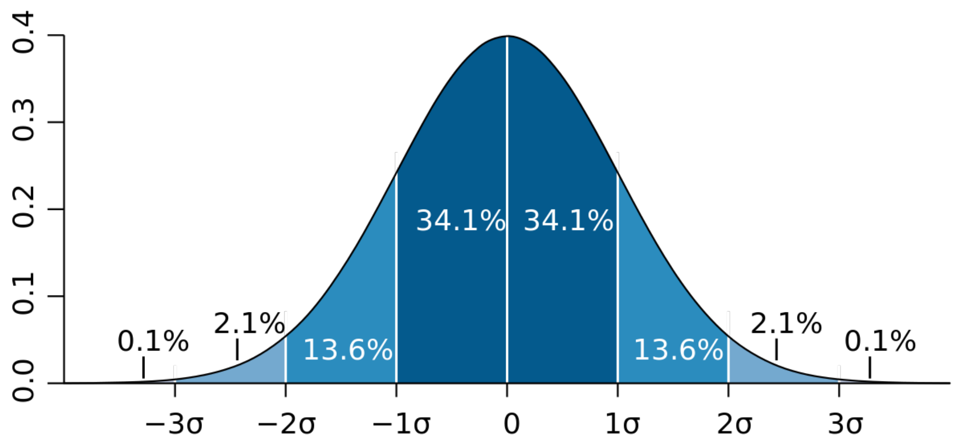


FIGURE 6. Standard deviations on a normal distribution, from M. W. Toews, Wikipedia. `https://commons.wikimedia.org/wiki/File:Standard_deviation_diagram.svg`

In order to propagate the vertical elevation error between the two measurements, you need to take into account the fact that the elevation difference, Δz is:

$$\Delta z = l \sin \alpha \tag{1}$$

where l is the taped distance and α is the vertical angle (i.e. the inclination).

To solve for the error, we first decompose each value (dummy variable x) into x_0, the value from the reading, and δx, the error from the reading. Therefore, to solve for $\delta(\Delta z)$, the error in the vertical in a single measurement, we must solve for the the combined error in distance and angle.

The error associated with the horizontal distance is straightforward to account for, but the error in the inclination is more difficult due to the fact that it is held within the sin function, which makes the error become **nonuniform** and a function of the angle itself.

To make this problem solvable, we will (1) **approximate** linearity over small changes in the inclination, $\delta\alpha$, and (2) approximate that any errors in the angle measurement are $\gg$ any errors in the distance measurement. From the first approximation, you can compute the average error in the sine of the angle – that is, the vertical component – as:

$$\overline{\delta(\sin\alpha)} = \left|\frac{\sin(\alpha+\delta\alpha) - \sin(\alpha-\delta\alpha)}{2}\right| \tag{2}$$

The vertical error $\delta(\Delta z)$, therefore can be calculated as:

$$\delta(\Delta z) = l\overline{\delta(\sin\alpha)} \tag{3}$$

Now, you can compute $\delta(\Delta z)$ for each step based on the data in Table 2.

4.2.2. *Combining errors from multiple steps.* After computing the error from each section of the leveling survey, you have an expected Δz, $(\Delta z)_0$, and the associated 2-σ (i.e., 2-standard-deviation) *uncertainty* (a synonym for *error*), $\delta(\Delta z)$, for each step.

The next task is to put these together. Each of these legs of the survey is **summed**. Therefore, in order to propagate error, one must use the equivalent of the distance formula, by taking the square root of the sum of the squares of the errors:

$$\delta(\Delta z)_{\text{total}} = \left(\sum_{i=1}^{n} (\delta(\Delta z)_i)^2\right)^{1/2} \tag{4}$$

Based on Equation 4, answer:

(1) What is the 2-σ propagated vertical error between the river left and river right floodplain surfaces?
(2) Considering this error, does your original statement about which side of the river might more likely flood hold? Explain your reasoning.

5. Exercise: Cross sections

While this was not necessary to be the case to measure pure vertical distance, all of your points along the river were marked along a single straight-line path that you maintained by keeping a consistent compass direction and walking a direct imaginary line connecting two prominent trees on the floodplains. The path between these two trees took you perpendicularly across the river. As such, your leveling line covers a single **cross section** of the river and its floodplain.

Within the line of the channel crossing (7.72 meters in Table 2), your partner marked out water depth every meters. Furthermore, recall from your notes that both your feet are at the water's edge. Because you already are correcting for your eye elevation, this means that the depth can be simply subtracted from the elevation along this transect to produce a cross-section that includes the river-bed topography.

Table 3. Water depths across the river; supplement to leveling data in Table 2 to help build a channel cross section.

Distance across river [m]	**Water depth [m]**	**Notes**
0	0	Water's edge, river right.
0.5	0.04	
1.5	0.14	
2.5	0.21	
3.5	0.32	
4.5	0.53	
5.5	0.71	
6.5	0.82	Thalweg
7.5	0.23	
7.72	0	Water's edge, river left

Using either graph paper or a computer program (spreadsheet, programming language, etc.), create a plot of this sample river cross section.

6. Measuring Azimuth or Horizontal Angle

Thus far, we have learned about:

- Measuring distances
- Measuring vertical angles (inclinations)

Using the two, we then were able to perform **leveling** across a river, including propagating error, to find where flood hazards may be higher. We also were able to construct a cross section across a river channel.[2]

However, while we can construct one-dimensional topographic profiles[3], it would be even more helpful if we could place these data in space on a map. This requires horizontal positioning. Because we are making these measurements from a single point, we are naturally in a polar coordinate system, and therefore will record positions in terms of *distance* and *angle*.

The first question, therefore, is how to set the coordinate system for the horizontal angle. There are two main methods:

(1) An angle that is aligned with true North, such that 0° aligns with North.
(2) An angle that is arbitrary

The first option is better overall, and required when an absolute orientation be needed. The second option can be easier to set up, and works when only relative positions between objects need to be known. The first option works by default with a compass for which the **declination** – the angle between magnetic north and true north – is known. The second works with any method of defining a horizontal angle, though such a method may be combined with additional information on position and/or orientation to create an oriented coordinate system. Both methods require additional information on positioning in order to **geolocate** the local (i.e., the survey's) coordinate system in a way that allows it to be plotted on a map (Section 7, below).

Before we proceed, there is a convention to define in 3-D projected (as in, map projection) coordinate positions:

- **Easting** (E): the x-coordinate
- **Northing** (N): the y-coordinate
- **Elevation** (z): the z-coordinate

6.1. Azimuth with a compass.

Azimuth is the horizontal angle away from north. It starts at 0° at due north, and increases counter-clockwise:

- 0°: North
- 90°: East
- 180°: South
- 270°: West

These angles can be provided by a compass whose declination is properly adjusted (see Figure 7, below).

The ability to tell directions from a compass depends on the *geodynamo*, the convecting metal in Earth's outer core[4]. Mass movements within this conducting metal – which is predicted to have the viscosity of water at the temperatures and pressures of the outer core – produce a magnetic field. On average, this magnetic field is aligned with Earth's rotational axis, but it wanders significantly over time. This means that we have to be concerned about the magnetic

[2]As an important aside, I made this cross-section to be somewhat realistic for a bend of a meandering river, including a *thalweg* – the zone of deep flow along the steep and actively-eroding *cut bank*, and a point bar with active deposition on the other side of the channel.

[3]On dimensionality: These cross-sectional profiles may seem to be two-dimensional, but they are mathematically one-dimensional because they are $z(x)$, where there is only one independent variable). A two-dimensional surface would be a topographic map. A truly three-dimensional representation would include the details of the subsurface along with the map-view surface topography.

[4]iron, nickel, and a light alloying element

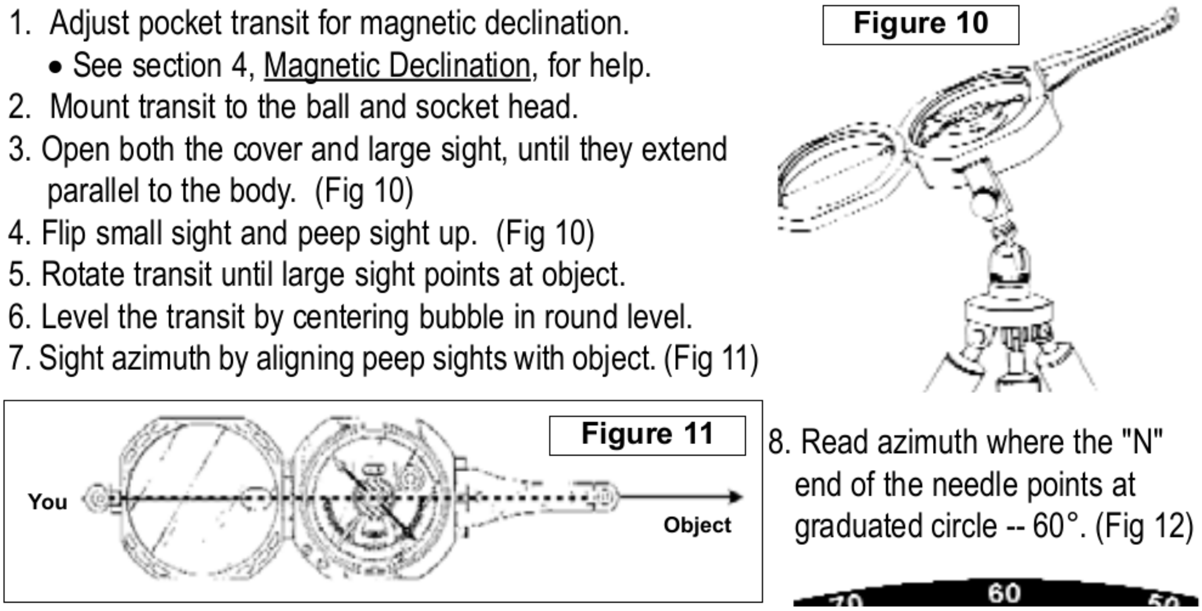


Figure 7. Finding the azimuth of an object using a Brunton pocket transit and a non-magnetic tripod. From the Brunton Pocket Transit manual. For other methods of measuring azimuth, also see the Brunton Pocket Transit manual.

declination, the angle between Magnetic North and True North, the magnetic **inclination**, the vertical angle of the magnetic field that can make a compass harder to use in some parts of the world, and how they both (and especially the declination) vary with time.

6.1.1. *Magnetic declination.* As noted above, magnetic declination must be accounted for in order to accurately use a compass. A Brunton transit has a screw that can be used to adjust the declination. Some other compasses have similar methods of changing their declinations, whereas others require that the declination adjustment to be made *post hoc*.

Declination conventions:

- Declination is **East** if **Magnetic North is east of True North**
- Declination is **West** if **Magnetic North is west of True North**

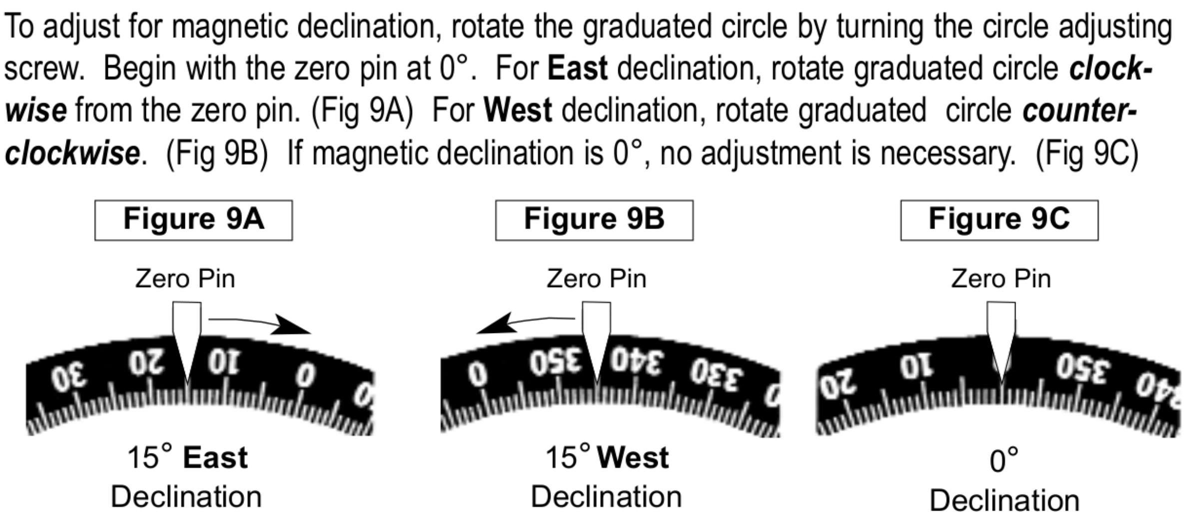


Figure 8. Brunton compass adjustments (using a screw) for declination. From the Brunton Pocket Transit manual.

Figure 9 contains declination adjustments in southern and central North America and its surroundings as of the year 2010. To obtain the most up-to-date declination adjustments and to learn more, see the resources available at `https://www.ngdc.noaa.gov/geomag/declination.shtml`.

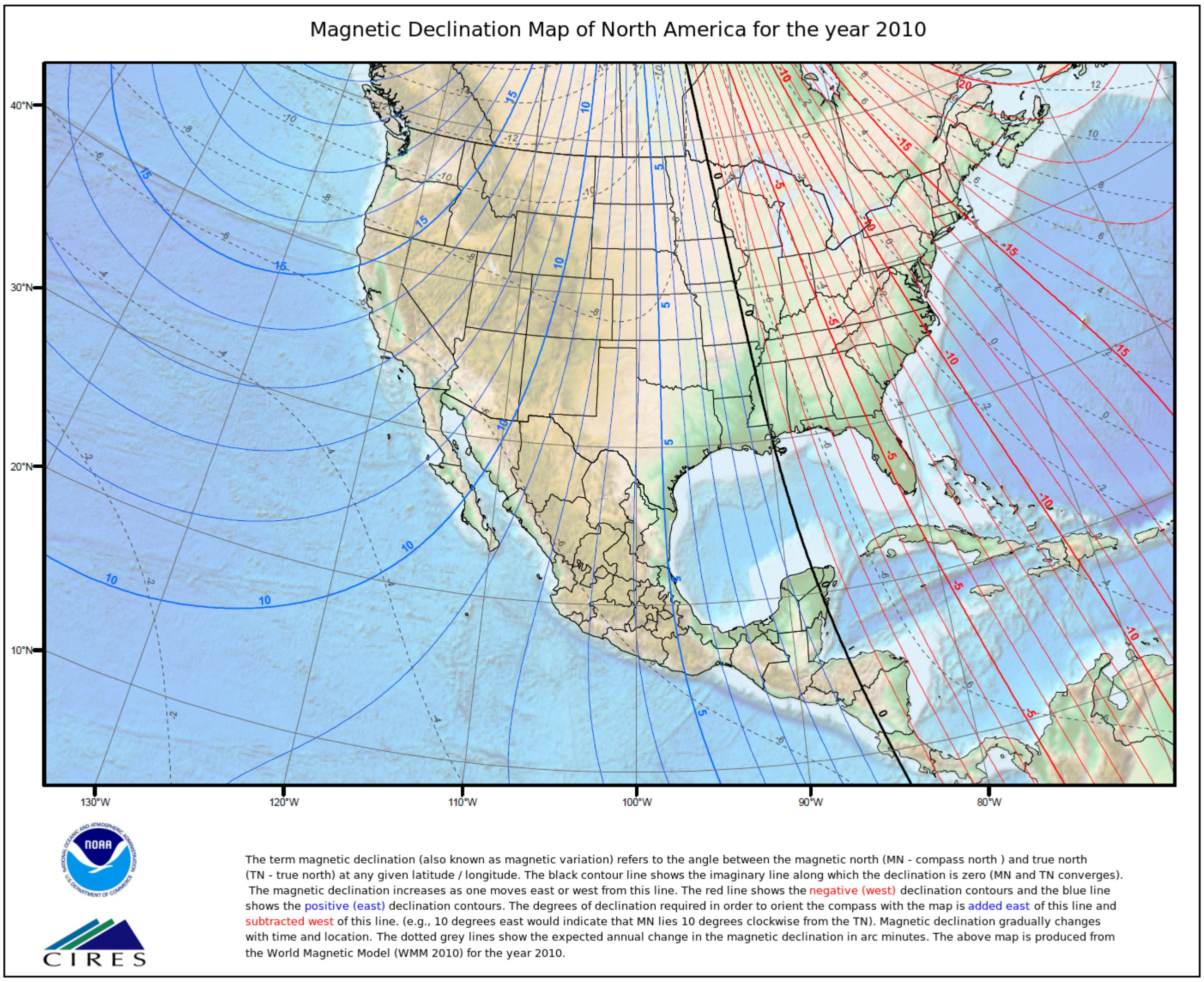


FIGURE 9. Magnetic declination in the year 2010: USA, Mexico, and environs. The black line, which travels almost perfectly through Minneapolis, St. Paul, and Duluth, is the 0-degree declination line: for now, we lucky few are so fortunate that True and Magnetic North are almost perfectly aligned.

6.2. **Azimuth with an arbitrary angle.** Magnetic compasses are accurate, but are not always the most precise instruments. This is due to the variability of True North, the precision to which humans or machines can read the magnetic north, and potential contamination of the signal from magnetic sources in rocks and equipment. Therefore, some pieces of equipment, including **total stations**, measure horizontal angle using electronic means that are precise, but that are not referenced to any true coordinate system. Therefore, there are three different ways to use such an instrument:

(1) With an **arbitrary horizontal coordinate system**. This is quick and easy to set up, and is straightforward so long as you do not need to compare your results to those of a prior survey.
(2) Based on a **known angle**. This can be from a survey baseline with a known absolute orientation, or can be based on an arbitrary convention established in a prior survey. Such a known-angle set-up can furthermore referenced to a survey-station position that is:

- **Arbitrary**, which typically means that you set the instrument coordinates at (x, y, z) = (N, E, z) = (0, 0, 0) but set the horizontal angle based on a known direction, or
- **Known**, which typically means that you center the instrument over a known survey marker whose position has been previously recorded, and measure the height of the instrument over that marker, and use this position.

(3) Based on two points with known locations. The instrument is set over one of these points. For a total station, the user then shoots to the second known point to establish a known angle, hence establishing the horizontal coordinate system. A more "analog" approach to using two known points is using their relative positions to compute a known angle, and then using this known angle and the known first-point position to establish a coordinate system.

If the absolute position is known and the angle is non-arbitrary (i.e., is based on a surveyed geographic direction), then all surveyed points will be registered in a geographic coordinate system. Likewise, if two known geographic points are used to set up the instrument, the coordinate system will be geospatially registered.

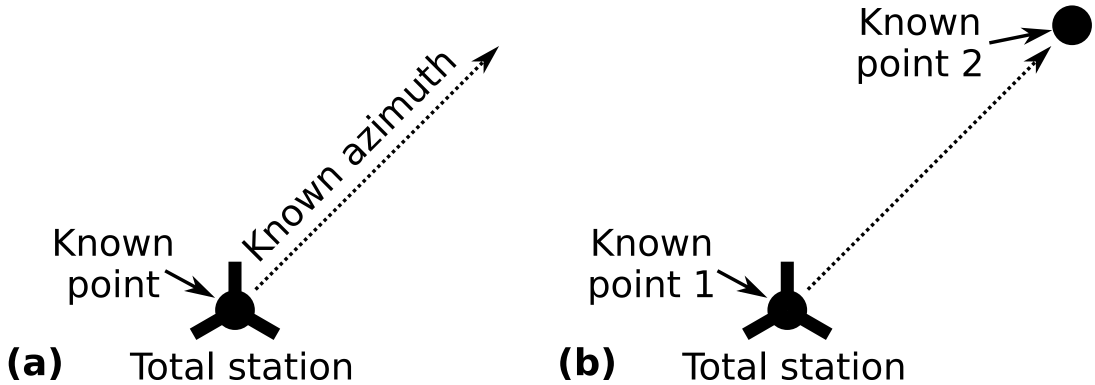


FIGURE 10. Two mechanisms to set up a total station in an absolute geospatial coordinate system. **(a)** Station at known point, using a known angle. **(b)** station at known point, shooting to another known point.

7. Absolute Positioning

Thus far, we have discussed ways to measure angles and distances, but absolute positions are incredibly valuable. **GNSS** (Global Navigation Satellite System(s)) can provide this by sending well-defined waveforms from satellites to the ground with very precise timing. Using this information from multiple satellites, a person on the ground can obtain their position to within a few meters.

Research purposes often require much higher precision positioning. This is where "differential" and "real-time kinematic" approaches come into play. In both of these approaches, a stationary GPS unit's position is compared with a "rover", which is moved with the survey team. Any changes in the apparent position of the base station are likely due to atmospheric turbulence, which alters the speed of light between the (satellite) source and (GNSS station) receiver. The GNSS-recorded position of the moving station can then be corrected for this error, reducing its location uncertainty to $\sim$1 cm.

8. Measuring angle and distance together

Three instruments can measure horizontal angle (azimuth), vertical angle (inclination), and distance together:

- A specially-equipped **laser rangefinder** that includes a digital compass
- An aptly-named **total station**

Figure 11. Two GNSS receivers mounted on rods stabilized by tripods. From Flickr user "Manop": `https://commons.wikimedia.org/wiki/File:Station_GPS_receiver.jpg`.

- A **terrestrial laser scanner** (**TLS**)

These instruments may be combined with a high-precision GNSS survey (Section 7) to add absolute coordinates to these angles and distances.

8.1. **Laser rangefinder with digital compass.** The laser rangefinder with digital compass is ideal for quick-and-dirty surveys. The top-of-the-line (as of the time of writing TruPulse 360R) is typically accurate in distance to the nearest 20 cm and precise to the nearest 10 cm. Its inclinometer is accurate to 0.25° and its digital compass is accurate to <0.5°. It has the advantage of being able to be hand-held (where the 10–20 cm accuracy and precision are often matched by the motion of the person holding it) or mounted on a tripod, and can be used to rapidly assess sites in the field – or to survey relatively large objects. Its compass means that, when paired with a decent GPS point, all recorded data will be immediately in a usable geographic coordinate system.

8.2. **Total station.** Total stations come in multiple varieties, and I will focus on three:

- Reflector-required (or "standard")
- Reflectorless
- Robotic (and these can be either of the above versions)

A "standard" total station requires that you shoot towards a prism on a rod. This specialized surveying prism focuses all light in its center to return the laser shot directly at the total station whether or not the prism is pointed directly at the total station.

A "reflectorless" total station can gather points from either a reflector or from any surface. This can be quite valuable for mapping hard-to-reach areas and/or to perform a topographic survey.

FIGURE 12. A survey prism. This would be attached to a telescoping pole.

A "robotic" total station is capable of finding and shooting the prism itself. This makes it possible for a one-person team to rapidly complete a survey. If a robotic total station is also reflectorless, it can act as a slow terrestrial laser scanner.

8.3. **Terrestrial laser scanner.** A **terrestrial laser scanner**, **terrestrial lidar**, or **TLS** is a device that takes thousands of points or more per second – distance and (often) color – to build a "point cloud" that can be used to study topography, vegetation, and more. This is an incredibly powerful survey tool. My (Wickert's) lab manages one – a Leica C10 – in collaboration with the department and the Saint Anthony Falls Laboratory (SAFL). We most likely will not use it for the course, but it is an available and powerful – though expensive and heavy – tool.

9. Moving your measurement position

Based on the above information, I would hope that you would be able to set up a piece of surveying equipment and measure the locations of a large number of points. In addition, the examples in Sections 4 and 5 show you that it is possible to move your measurement location – carefully – with basic tools such as a **clinometer** and **measuring tape or rope**. But how does one move a complicated instrument like a **total station** and maintain the same coordinate system? The answer has the following steps:

(1) Pick a good new location within sight of the new points that you would like to survey.
(2) Ideally, pound a stake + tape + nail combo into the ground to mark the location
(3) Make a "foreshot" (or "foresight") to the new location where you would like to move the station from the total station at its current location using a reflector rod. Record the location of this new point in the total station's current coordinate system.
(4) Carefully move the total station to this new location, center it, and level it.
(5) Set up the total station based on two known points.
   (a) Set the new instrument location by the point that you just measured (plus the elevation of the total station above the survey marker) for the new (N, E, z) of the instrument.
   (b) Enter the (N, E, z) of the last total-station position, plus or minus any difference between the total-station position and the height of the prism on the survey pole.
   (c) Shoot a "backshot" or "backsight" to the old position as your second "known point" to set the coordinate system.

At this point, your total station should be successfully moved. If you are concerned that something might not be right, be sure to note which points are from before or after you moved the instrument; otherwise, it may be impossible to disentangle their exact locations in post-processing! The exact directions for your total station will be unique, but will follow this general pattern.

10. Setting up a Nikon total station

This is the practical section. Maybe you just skipped to this! If so, unless you're in a huge hurry, I'd suggest you review a bit of how surveying works. Please? Nope. It may help! Okay...

The instrument-specific portions of these directions are written for the **Nikon DTM-322+ Total Station**. They will probably work on other Nikon Total Stations. Others might be sort of in the ballpark; good luck!

I am assuming that you are centering the total station on a known point. If this is not the case, you may decide not to worry about this part of the work.

For more specific instructions, please see the **Nikon DTM-322 user's manual**.

Figure 13. Nikon DTM-322, Face 1. From Nikon user's manual.

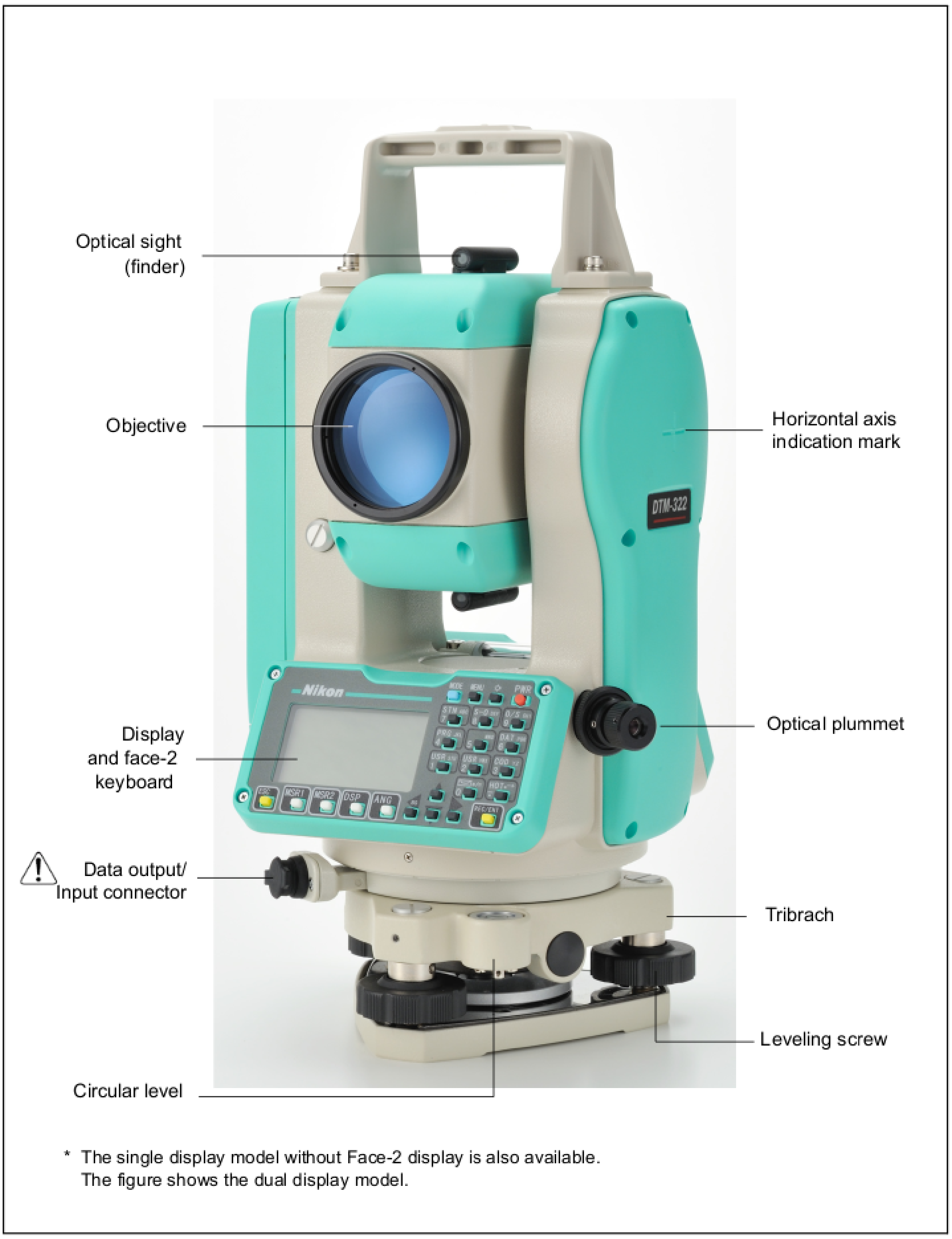


FIGURE 14. Nikon DTM-322, Face 2. From Nikon user's manual.

10.1. **Preparing your field book and taking notes.** While surveying, it is imperative to keep good notes. You will need to record both your survey stations – the points at which you place the instrument – and your survey points, which are the points of interest in the survey. You may also want to establish particular points, especially if they are easily visible and immobile landmarks, as survey monuments that you can use to establish relative locations even if you move the instrument to a new position.

Your notes should include the following information, at minimum, before you start taking points:

- Name of the current survey station
- Location of the current survey station

- How you have defined your 0-degree azimuth ("north", though this need not be north if you have decided to rotate the coordinate system after the survey – more on this to come)
- What the height of the total station is, typically measured from the top of the survey marker over which you have centered the instrument to the pivot on the scope of the total station (commonly marked with a "+"). If you are performing a survey of relative positions and do not intend to repeat it or move the instrument, then this becomes unnecessary, though still recommended (in case you later change your mind)
- Height of the prism rod, both (a) in reality, and (b) as is set inside the total station. (Note: Verify stadia rod height with a measuring tape the first time you use it!)

Once you start taking points, your notes should include:

- Point name
- Northing – Easting – Elevation (z)
- Prism rod height (in case it changes)

10.2. **Setting up the survey monument (stake).**

(1) Place the stake in the ground (if one is not already there), ideally with a nail and tape, or at least with some kind of target dot.
(2) Enter the location of the stake and/or take a point using a high-precision differential or RTK GNSS system
(3) Remove the cover on the top plate of the total-station tripod
(4) Open the tripod and place it over the stake.
(5) Using the plumb bob, check that your position is directly over the stake.
(6) Push the legs of the tripod into the ground (by stepping on their "shoes").
(7) Check that the tripod is still directly over the stake and that its surface for the total station is level. If not, move the tripod and repeat the above two steps.
(8) Place and secure (via the screw) the tribrach and total station onto the tripod. Always keep a hand on the total station until both it and the tripod are secure.
(9) Using the optical plummet to guide you, position the total station directly over the stake. (It can move around on the top of the total station.
(10) Lock the total station in place.
(11) Level the total station. To adjust its the level of the tribrach, follow the directions in Figure 15. If more intense leveling is needed, you may need to adjust the height of the tripod by either stepping on the shoes or adjusting the leg heights (be CAREFUL with the expensive total station on it!) Doing the latter may require that you re-center the whole tripod and go back to the beginning.
    (a) First, level based on the bubble level on the side
    (b) Then, rotate the total station and use its horizontal level – always perpendicular to one of the screws on the tribrach so you can adjust the level with the back two (per Figure 15).
    (c) Optional: use the digital level to even more precisely level the instrument. It is the button with the icon that looks like a bubble level. This requires turning the total station on, and is also mentioned in the following section.
(12) After leveling the total station, ensure that it is still directly over the survey point. move it horizontally if necessary, using the optical plummet.
(13) After this final adjustment, measure the height of the total station from the "+" Horizontal axis indication mark (Figure 14

10.3. **Operating the Total Station.**

(1) Turn it on.
(2) Level with digital bubble level
(3) Check the measurement and prism settings by pressing and holding down MSR1 and/or MSR2.
(4) Prepare your notebook, if you haven't already.

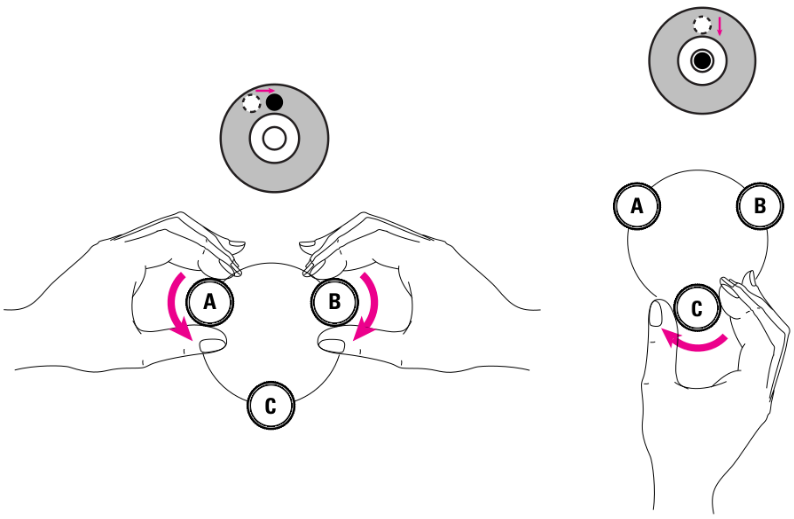


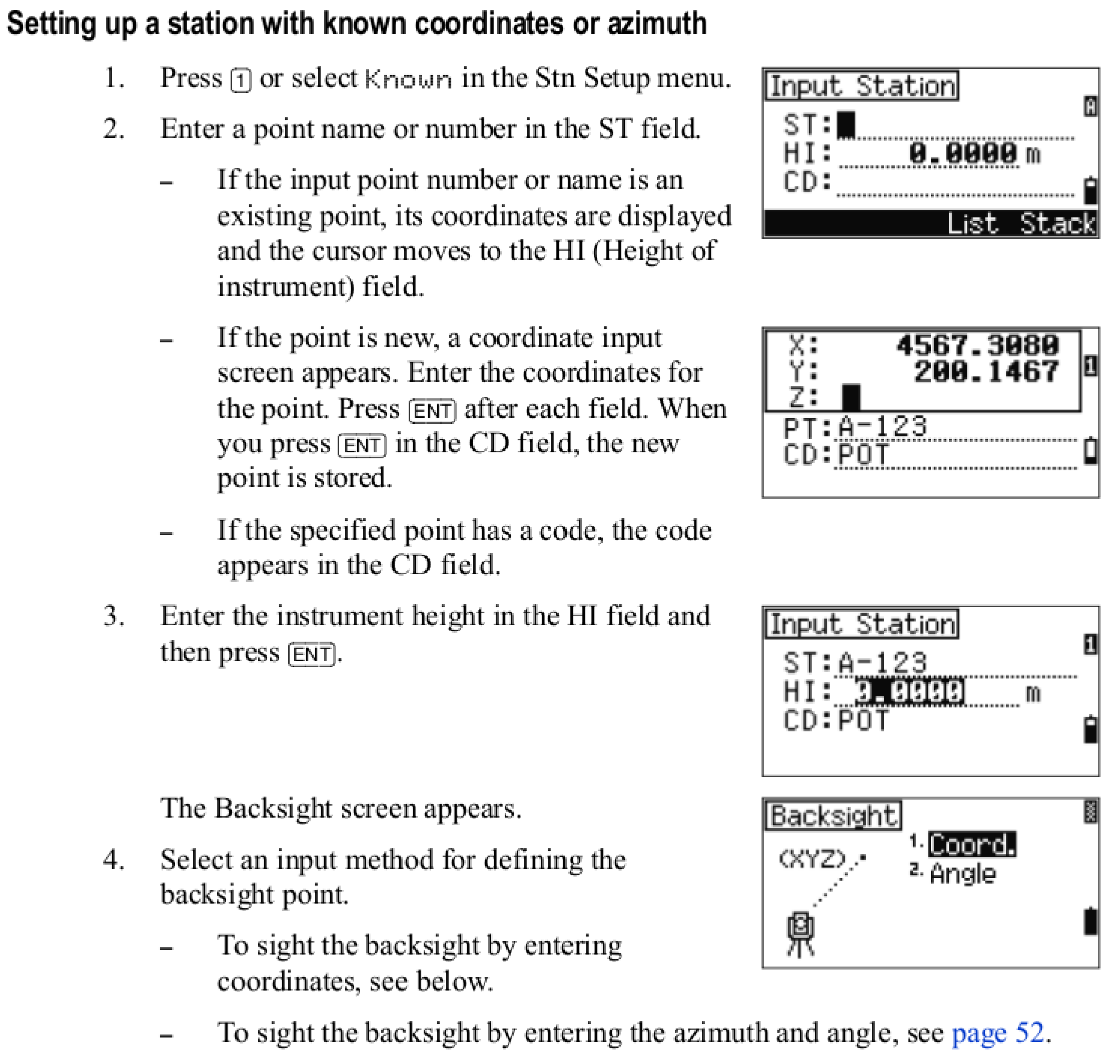
FIGURE 15. Pictorial guide to leveling a tribrach (for a total station). From Leica.

(5) Note that the horizontal angle is arbitrary, and is set to 0 when you turn the station on. We will establish our coordinate system below.
(6) Set up the point at which you are surveying. This point should be (0,0,0) if the position is arbitrary, or a real set of coordinates if the position is not arbitrary. After this, follow the directions given in Figure 16
   - **"Known"** requires a known angle or point (see Figure 10).
   - **"Resection"** uses multiple known points to find the station point. It can be useful, though I do not cover it above.
   - **"Quick"** means that you just start surveying from your current position without any setup, and with your station location left at its default position of (0, 0, 0).
(7) Measure the locations of all desired points.
   (a) Face the side of the total station that does not have the objective (i.e., that with the telescope eyepiece: Figure 13).
   (b) Unclamp the total station so it can swivel freely in both yaw (horizontal angle) and pitch (vertical angle). Clamps are shown in Figure 13.
   (c) Find the target with your eyes and rotate the total station towards it
   (d) Use the optical sight (finder) (Figure 14) to make sure that you are aiming at the target. Then clamp the total station. I typically clamp the yaw first, and then the pitch.
   (e) Looking through the telescope eyepiece, and with any focus-adjustment needed. try to find the prism and move the crosshairs (hard to see) over it.
   (f) Tell your partner to hold the pole especially steady, and take your shot.
(8) If you must move the station, first take a measurement to the new point. Then repeat these steps, and then set up a new station, using the measured input station X,Y,Z for your "known station" and performing a backsight using the X,Y,Z of your original station. See Section 9 for more details.

10.4. **Taking down the Total Station.** [This is not needed if you are moving the total station over short distances and smooth terrain and have steady hands and confidence.]

This should be common sense. In case of doubts:

- Double-check that you have recorded all required information.
- Turn off the total station.
- Carefully remove the total station and pack it away in its box. Close the box SECURELY. Never leave a total-station box closed and not latched... that's asking for disaster.



Setting up a station with known coordinates or azimuth

1. Press [1] or select Known in the Stn Setup menu.
2. Enter a point name or number in the ST field.
   - If the input point number or name is an existing point, its coordinates are displayed and the cursor moves to the HI (Height of instrument) field.
   - If the point is new, a coordinate input screen appears. Enter the coordinates for the point. Press [ENT] after each field. When you press [ENT] in the CD field, the new point is stored.
   - If the specified point has a code, the code appears in the CD field.
3. Enter the instrument height in the HI field and then press [ENT].

   The Backsight screen appears.
4. Select an input method for defining the backsight point.
   - To sight the backsight by entering coordinates, see below.
   - To sight the backsight by entering the azimuth and angle, see page 52.

FIGURE 16. Nikon setup guide, using either an angle or a known point (see Figure 10).

- Remove your carefully-leveled tripod from the ground (noooo), clean its shoes, close it, and telescope it until it is at its minimum size. Use its clips (typically provided) to hold it shut.
- Remove the prism and place it in its bag. Give it its protective cover, if it has one.
- Telescope the prism pole to its minimum length. Put it in its bag, if you have one.
- Return all gear safely to the lab.

11. Plotting the data

The data can be entered into the computer in CSV format from your notebook or downloaded via the "Communications" menu on the total station (also in CSV format). After this, they may be imported into a GIS of your choice. I suggest QGIS for point-and-click visualizations and GRASS GIS for heavy computation. A wealth of information about QGIS and GRASS GIS may be found at:

- QGIS tutorials: `https://www.qgistutorials.com`
- GRASS GIS quick start: `https://grass.osgeo.org/grass76/manuals/helptext.html`