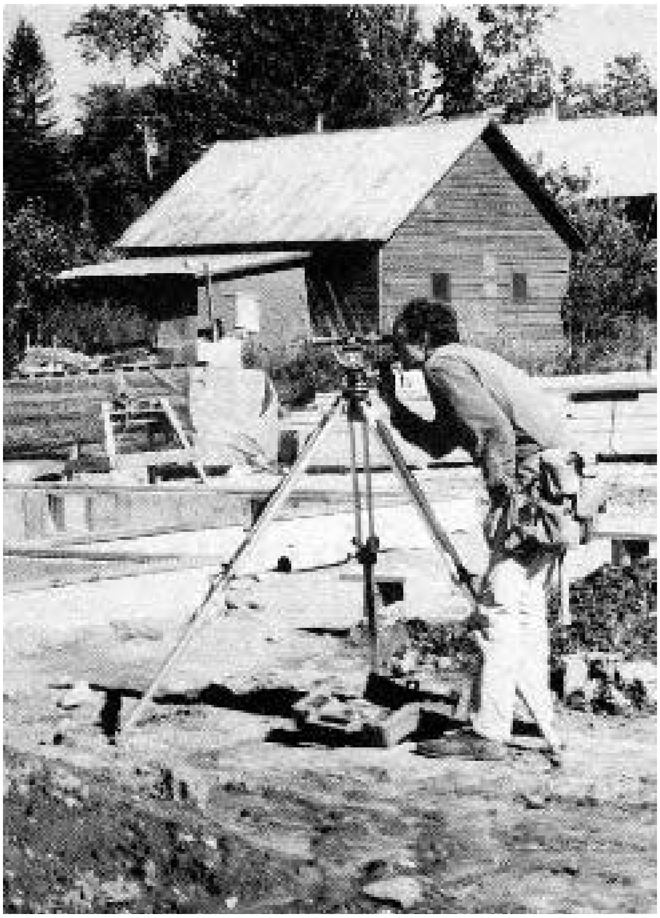
by David Carns

Foundation Layout by Transit

A few surveyor's tricks can improve the efficiency and accuracy of your site measurements



Although my formal education is in civil engineering, I've been in and out of residential construction for the last 13 years. During this time I've come to realize that while many builders own good quality transits, few take full advantage of the tool's potential.

This article is for builders who are acquainted with simple transit techniques, but are not acquainted with many of the methods a professional surveyor uses to save time and avoid errors. Some of these methods are simple setup tips and some are more complex procedures.

Get the Right Tools

For the distances and elevations that most small buildings involve, you can achieve a high degree of accuracy with a steel tape and most transits.

Transits. A transit is really two instruments in one: a leveling tool and an angle measuring tool. For foundation leveling, an optical level should be accurate to within 1/4 inch in 100 feet. Most quality builders levels and transits can achieve this (see "Shopping for Transits and Builders Levels," *JLC*, 12/90).

For foundation layout using the transit, you'll want a minimum accuracy of 3/8 inch in 100 feet on horizontal measurements (see "Foundation Layout From A Single Point," next page). This means you'll want a one-minute transit. Anything less may dictate using more time-consuming layout procedures such as the 3-4-5 triangle or two-tape method.

Tapes. If you're going to do a lot of layout it may be worth investing in a 100-foot surveyor's tape, which is calibrated in decimals of a foot rather than inches. Decimals make the calculations (and consequently the layout) simpler, and the measurements will match the site survey and foundation plans.

Choose a steel tape. Cloth or fiberglass tapes are durable and light, but because they have a tendency to stretch they're only good where accuracy is not too important.

Rods. If you find yourself doing much site or foundation work, it's worth making the investment (about $100) in a true surveyor's rod, which is calibrated in decimals of a foot. If you use a section of a carpenter's tape fastened to a wooden pole for a level rod, you'll have to convert your measurements from feet and inches to decimal portions of a foot.

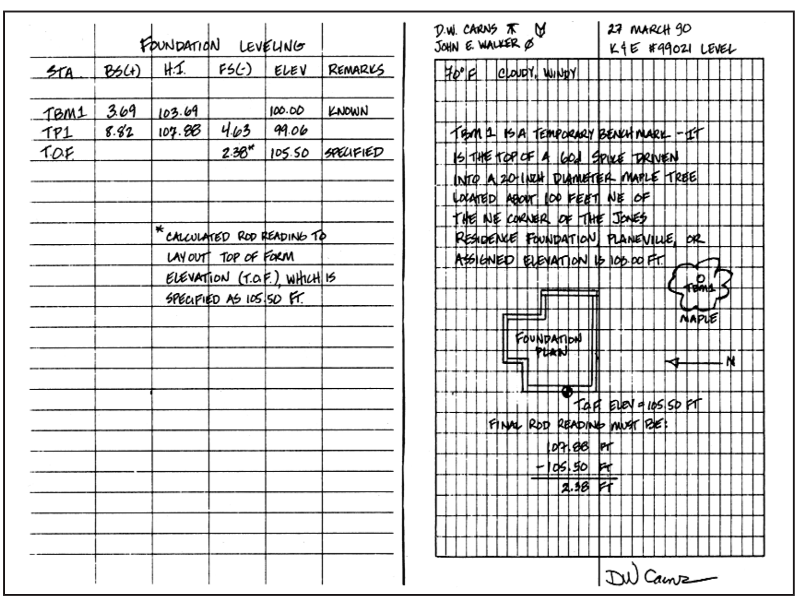
Tripods. Tripods with extendible legs are much more practical than tripods with fixed legs. I prefer wood, or plastic-coated wood, over aluminum. Wood tripods weigh a bit more, but they're less likely to blow over in a strong wind, and the legs seem to extend more easily.

A good tripod is not a minor investment (about $160), so make sure your purchase will be compatible with the instruments you now own or are considering buying. Your level may need a different tripod than your transit. Check with an engineering supply house about the compatibility before you buy.

Tips to Avoid Errors

When setting up a transit over a reference point, such as a foundation corner, concentrate first on the tripod. If the ground is sloped, put one leg on the uphill side and two on the downhill side for stability. Next, get the top of the tripod located as close as you can over the reference point by adjusting the tripod legs in and out, keeping the transit base reasonably level. Sometimes I take a pebble and drop it from just below the center of the transit to see if the transit is set up over the reference point. If so, final adjustment and leveling can be made with the leveling screws on the instrument.

When using a tilting transit as a level, keep a watchful eye on the telescope bubble, as they tend to get out of adjustment easily. There are tests you can run to determine if the level is reading correctly. One of these is described briefly in "The Two-Peg



FOUNDATION LEVELING

STA.	BS(+)	H.I.	FS(-)	ELEV	REMARKS
TBM1	3.69	103.69		100.00	KNOWN
TP1	8.82	107.88	4.63	99.06	
T.O.F.			2.38*	105.50	SPECIFIED

*CALCULATED ROD READING TO LAYOUT TOP OF FORM ELEVATION (T.O.F.), WHICH IS SPECIFIED AS 105.50 FT.

D.W. CARNS
JOHN E. WALKER Ø

27 MARCH 90
K&E #99021 LEVEL

70°F CLOUDY, WINDY

TBM 1 IS A TEMPORARY BENCHMARK - IT IS THE TOP OF A 60d SPIKE DRIVEN INTO A 20-INCH DIAMETER MAPLE TREE LOCATED ABOUT 100 FEET NE OF THE NE CORNER OF THE JONES RESIDENCE FOUNDATION, PLANEVILLE, OR. ASSIGNED ELEVATION IS 100.00 FT.

FINAL ROD READING MUST BE:

107.88 FT
−105.50 FT
2.38 FT

DW Carns

Figure 1: *On the left-hand page of the author's survey book, he records the reference stations (STA), including a temporary benchmark (TBM1), a turning point (TP1) and the calculated top-of-form (TOF) elevation. The calculation is noted on the right-hand page below a sketch of the foundation plan.*

Test” on the next page. For a more detailed explanation of this and other checks, a good reference is *Surveying With Construction Applications* by Barry F. Kavanagh (Englewood Cliffs, N.J.: Prentice-Hall, 1989).

Taking notes. For even the simplest survey, keep one rule in mind: Take notes so that someone else can understand what you did, or finish your work if not completed. If you do all your calculations (diagonal measurements, etc.) ahead of time, and enter them in your notebook with a sketch of the layout, you’ll save a lot of time and aggravation in the field. Figure 1 shows an example of the format I use.

Plan on taking notes in a field-worthy book. Too often the tendency is to grab a spiral-bound notebook and a ball point pen and begin scratching out a few notes. The notebook usually slides off the pickup seat onto the floor or gets left out in the rain. For about $3.00 you can buy a *Rite-In-the-Rain* weatherproof notebook (J.L. Darling Corporation, Tacoma, WA 98421) through your local bookstore or office supply store. These little books are great. If you use a hard (4H) pencil your notes won’t smear and will virtually last forever (I still have one I used in 1972).

Double-check. Another way to avoid errors is to double-check your instrument and distance readings before you record them. For example, if you are standing at the transit reading the level rod, call out your reading to the person holding the rod and have him hold a pencil on the reading you called out. Then look through the telescope again and see if the crosshairs line up on the pencil point. This way both the instrumentman and rodman read the rod as a check on each other.

Taped distances can be measured both forward and back (opposite directions) and the average of the two measurements recorded.

A vernier scale can easily be misread (see “Reading A Transit Vernier,” right). You should double-check angles by turning the transit through the angle twice and reading the scale each time. If you make a mistake reading the vernier the first time, you can usually catch it the second time. These check procedures don’t take much time once you’re set up, and they sure can save headaches later.

Taping. Taping horizontal distances sounds incredibly simple. But it’s not. It’s one of the most difficult basic techniques to perform consistently.

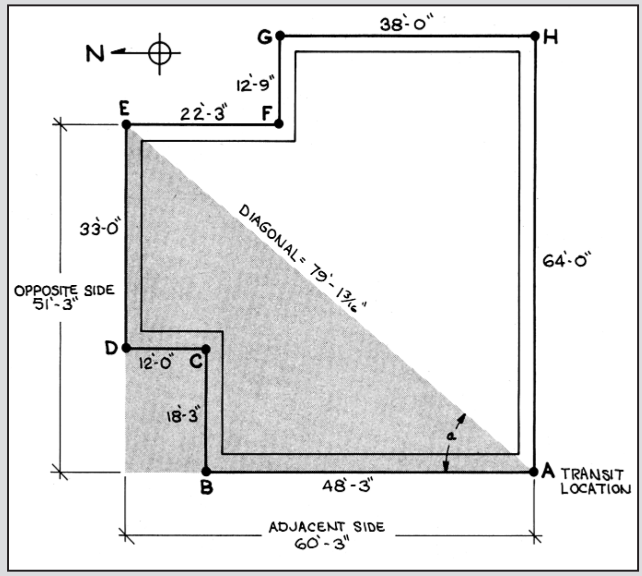
Some hints here: First, realize that all horizontal distances associated with surveys are just that, horizontal, not sloped, distances. For example, if you are laying out a building column that is to be located downhill (or uphill) from your reference points, you may have to use one or two plumb bobs, and perhaps even a hand level, to keep the tape level. Where the ground is fairly level, lay the tape so it is supported by the ground, rather than just supporting it from each end. If the ground is sloped, pull hard enough to eliminate most of the sag. This will usually take a good 15 to 20 pounds of pull for a 100 foot tape. This is where a good steel

Foundation Layout From A Single Point

The most common use for your survey skills is laying out a building foundation. If you own a one-minute transit and a calculator with trigonometric functions, you can save yourself a lot of time by staking out the entire foundation with only one steel tape and one transit setup. I’ve found that this method can cut about half the time off staking out a building foundation, compared to using two tapes and measuring out 3-4-5 triangles.

An accurate transit, rather than just a builders level (one that doesn’t tilt), really shows its worth when laying out from a single point. With a transit, you can tilt the scope and sight the corner itself. With a builder’s level you have to use a plumb bob, and line the vertical crosshair up with the string, which may compound the likelihood of an error.

The entire building can be staked by setting up the transit over one corner, such as point A in the illustration at right. Locating the other corners involves two steps: First you need to calculate the correct angle to aim the transit for each corner. Then you need to calculate the distance from your transit to each corner, and tape it off. The calculations can be performed ahead of time at home or in the office, leaving only a minimal amount of field work.



Calculating the angle. If you remember your high school math, for any acute angle in a right triangle, the *tangent = opposite side ÷ adjacent side*. Since we know the length of the building walls (the sides of a right triangle), we can use the tangent to find the angle needed to position each corner.

For example, to find the position of corner E in the example shown, first you need to find the tangent of angle *a*. The side opposite angle *a* is made up of the two north facing walls that measure 33 feet and $18\frac{1}{4}$ feet. The side adjacent angle *a* is made up of the west facing walls measuring $48\frac{1}{4}$ and 12 feet. So, to find the tangent:

Tan $a = (33 + 18.25) \div (12 + 48.25) = 51.25 \div 60.25 = 0.8506$

Then you need to find what angle has a tangent of .8506. To do this you hit [.8506] [Inv] [Tan] on your calculator and find that the angle is 40.385 degrees.

Unless your calculator reads out in degrees, minutes, and seconds you will have to do a little converting, as the transit reads in degrees and minutes, not decimals of degrees. To convert from decimals to minutes, just take the fraction of degrees (.385) and multiply by 60 to get the minutes (23 minutes). Now you can lay out the angle with the transit to 40 degrees 23 minutes. Remember that these are horizontal angles and are unaffected by any change in elevation.

Calculating the distance. The Pythagorean theorem ($c^2 = a^2 + b^2$) is used to calculate the diagonal distances from point **A** to each corner. For example, to find the distance from **A** to **E** (the hypotenuse of a right triangle):

$c^2 = (33 + 18.25)^2 + (12 + 48.25)^2 = (51.25)^2 + (60.25)^2 = 6256.625$

$c = \sqrt{6256.625} = 79.099$ = 79 feet $1\frac{3}{16}$ inches

This procedure is repeated for points **C**, **D**, **F**, and **G**. Note that the point **H** is measured at 90 degrees. Point **B** is the zero point, or 0 degrees. The direction of the wall **BA** can be established with a compass or reference to the property lines, and taped off to the dimension specified on the prints. The transit is then set up so the horizontal angle scale is set to zero and a sight taken on point **B**.

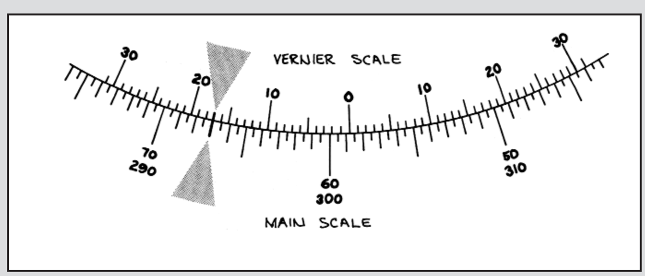
Reading A Transit Vernier

To lay out angles with a transit, you need to learn how to use a vernier. A vernier is a finely graduated moving scale such as you find on a micrometer. With a little practice, anyone can learn to read one.

The main scale on a transit is typically divided into half degrees (30 minutes). The vernier is used to divide this scale into smaller increments. For example, with the aid of a magnifying glass, you can see that a one-minute transit divides the main scale into 30 equal parts.

Here’s how it’s done:

- Always measure angles in a clockwise direction.
- Start by zeroing the vernier (set the scale at 0).
- Turn the transit to the right (clockwise).
- Read the main scale (shown on bottom in the illustration) by noting the angle to the nearest 30 minutes on the main scale.
- Determine the number of minutes to add to this reading by following the scale clockwise until a mark on the vernier lines up with a mark on the main scale. Only one mark will line up perfectly.



Where the two marks line up (at the grey arrows), the vernier reads 17’. Add this to the main reading of 58°30’ for a total reading of 58°47’.

tape really proves its worth.

Tips for Leveling

Most leveling on residential and light-commercial job sites uses a basic method called *differential leveling*. The whole idea of differential leveling is to determine differences in elevation by adding *backsights* and subtracting *foresights* on the level rod. This involves setting up the level at a location where the benchmark is visible and taking a backsight.

Because a benchmark must be located where it won't be disturbed during construction, it often ends up some distance from the foundation hole and out of a direct line of sight. In this case, you have to relay elevations, using a *turning point* as a secondary reference (see "Using a Turning Point," below, left).

Even if your instrument is out of adjustment you can get an accurate reading by keeping your foresight and backsight distances equal

As the example shows, you have to set up the transit in two locations, first taking a backsight on the rod set over the benchmark, and the second time, taking a backsight on the rod set over the turning point. This process can be repeated as many times as needed. Keep track of the turning points in your notes by numbering them in order.

When you are trying to set the elevation of a slab or top of a foundation form, you will be looking for a specified foresight reading, once the height of the instrument is known. To avoid an error while reading the rod, use a rod target (a marker that slides up and down the rod), or other mark on the rod, at the final required rod reading. With the marks, the person at the transit doesn't have to read the numbers to set the slab elevation, but must only line the rod target up with the instrument crosshairs.

Even if your instrument is slightly out of adjustment, you can get an accurate reading by keeping your foresight distances approximately equal to your backsight distances. The errors will tend to cancel. In other words, try not to set the level up right next to your benchmark and take a 10-foot backsight and a 150-foot foresight. It would be much better to split the difference and set up as close to the halfway point as possible. Taking a backsight of 80 feet and a foresight of 80 feet would be ideal. ■

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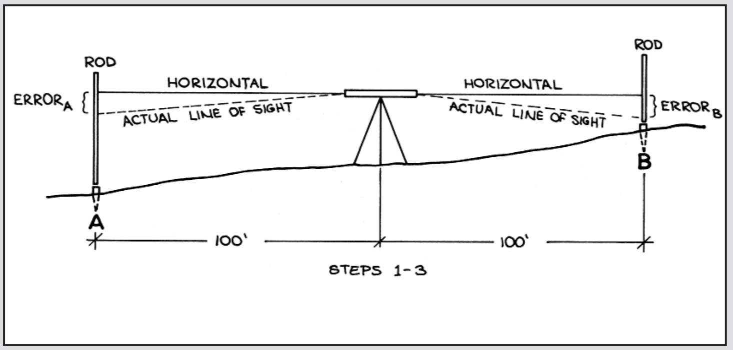
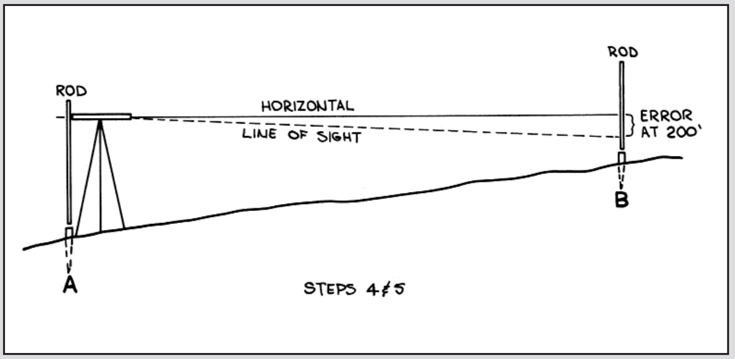
Two-Peg Test

A transit should be checked for level about every six months, or sooner if you notice a discrepancy in your readings. Here is a simple test procedure to see if the "bubble axis" of a level is parallel to the line of sight.

- **Step 1:** Drive in two pegs (stakes) at A and B about 200 feet apart.
- **Step 2:** Set up and level the instrument halfway between A and B.
- **Step 3:** Read the rod over A, then over B. For each reading, sight the nearest .001 foot. The difference in rod readings is the true difference in elevation between A and B, regardless of whether or not the level is in adjustment.
- **Step 4:** Set the level right next to A and read the rod over A by looking through the wrong end of the level.
- **Step 5:** Turn the level and read the rod at B, again to the nearest .001 foot. Subtract the rod reading at B from the reading at A.

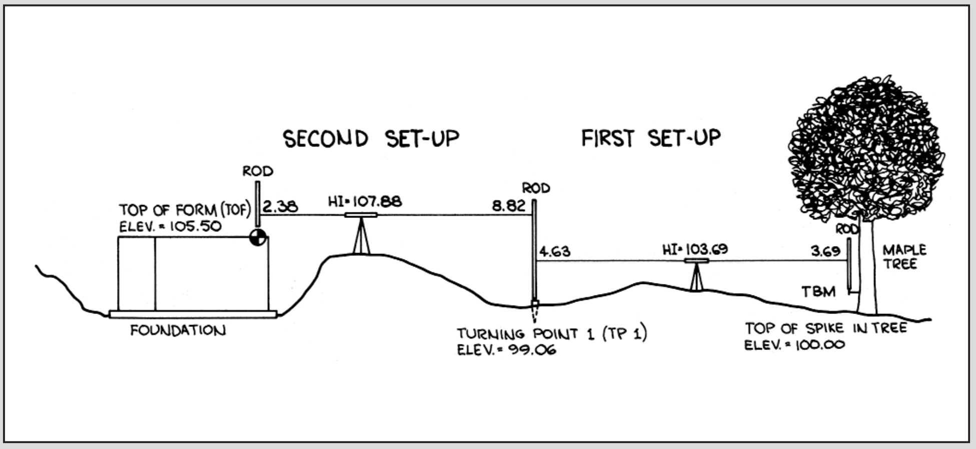
The difference in elevation obtained in Step 3 should equal the difference obtained from Step 5. If not, the instrument is out of adjustment. If this error at 200 feet is more than you can tolerate, the level can be adjusted by moving the cross hairs up or down to yield the proper rod reading on rod B, as in Step 5.





Using A Turning Point

Without a direct line of sight between the foundation and the benchmark, the transit or level must be set up twice. From the first setup, you take a backsight (BS) to establish a height-of-instrument (HI), and a foresight (FS) to find the elevation of a stake called the turning point (TP1). From the second setup, you again take a backsight to establish a second HI, and then subtract this elevation from the top of the foundation form given on the plans. This will give you a "calculated foresight" to locate on the rod when locating the top-of-form elevation. Measuring from the top-of-form, you can now accurately locate footings, sewer main, and other key elevations in your site work.



First Setup:
BS = 3.69 feet above temporary benchmark (arbitrarily set at 100 feet).
HI = 3.69 + 100.00 = 103.69 feet
FS = 4.63 above turning point (TP1)
Elevation of TP1 = HI – FS = 103.69-4.63 = 99.06 feet

Second Setup:
BS = 8.82 feet above TP1
HI = 8.82 + 99.06 = 107.88 feet
Elevation of TOF = 105.50 feet (given on plans)
Calculated FS = HI – TOF = 2.38 feet