Electronic Total Stations Are Levels Too

Precise Trigonometric Leveling Using Modern Total Station Instruments

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Overview

Differential leveling has been the traditional method used to establish vertical control. This method employs the use of spirit or automatic leveling instrumentation and graduated rods. Accurate results are obtained when all of the systematic errors are controlled and corrected. Short sight lengths and balanced sights are the most limiting restrictions. The absence of benchmarks at higher elevations all over the world is evidence to support the assertion that differential leveling is extremely costly and time consuming to perform in hilly and mountainous regions.

This article describes a method to extend precise vertical control efficiently and rapidly using modern electronic total station equipment. Differences in elevation are determined by measuring vertical angles and slope distances. It has been demonstrated that First Order accuracy can be obtained even when sight lengths of 100 meters are maintained during the level run. There is no requirement for balanced sight lengths and differences in elevation between backsight and foresight in one setup of 20 meters or more are not uncommon on steep terrain. Test results are presented clearly demonstrating that trigonometric leveling using modern total station equipment is the method of choice over traditional differential leveling to establish vertical control, especially in hilly terrain. Suggestions for implementation of this technique are presented, including extending vertical control in GPS networks.

Introduction

The purpose of leveling, in its simplest form, is to determine the difference in elevation between selected points. There are several methods for making this determination, involving as many types of instrumentation.

The existence of leveling dates back to ancient times. Leveling instruments were as simple as containers of water. The water surface, being aligned perpendicular to the direction of the force of gravity, forms a level surface upon which a level sight could be observed.

An example of a semi-modern level instrument is the spirit level, which employs a sensitive tubular glass vial, attached to a telescope. The vial is curved slightly upward towards its center. A fine-pitch tilting screw is turned manually to center the bubble in the vial of the spirit level. The bubble climbs to the highest point in the vial when the vial is perpendicular to the direction of the force of gravity.

Today, ‘automatic’ levels use a compensator in place of a glass vial. The compensator is a pendulous reflecting component within the optical system of the telescope that responds to the attraction of gravity to establish a horizontal line of sight.

The common controlling factor in all these devices is gravity. The accuracy of the results obtained depends on how well alignment with gravity is established and how well the resulting horizontal line of sight is defined. All other contributors to accuracy, or the lack of it, depend on influences external to the device.

In trigonometric leveling, gravity and definition of line of sight are also the controlling factors that determine the quality of the results. However, similarities between trig leveling and conventional differential leveling end there. Alignment with gravity must be established, but the line of sight is seldom perpendicular to it. Instead, the angular deviation from perpendicularity of the line of sight is measured. The accuracy of this angular measurement has the same effect on the definition of the line of sight as gravity alignment does in the spirit level or the automatic level. The use of compensators in modern total stations contributes to the accuracy that is attainable with these instruments.

Focus

Many surveyors still think of ‘low order’ accuracy when the words “Trig Leveling” are mentioned. This is due mainly to the fact that vertical angle measurements have been used for many years to reduce slope distances to the horizontal or to establish “rough” differences in elevation over long lines.

Since the existence of modern total station instruments, there have been many investigations conducted to test the feasibility of using trigonometric leveling to establish vertical control. Numerous papers have been published describing various methods and the results that can be expected using these methods. Yet, the use of trig leveling is not wide spread and is still not accepted by many surveyors. I think there are three main reasons for this.

The first reason is that FGCS specifications do not exist for trig leveling which means that the only ‘acceptable’ method to establish vertical control is conventional differential leveling for which FCGS specifications do exist. Without FGCS specifications for trigonometric leveling, the “low accuracy” perception will continue despite the fact that First Order accuracy can be obtained with relative ease.

The second reason is that most of the trig leveling methods described by others in the past are difficult to execute and costly. Some of these methods require that the restrictions imposed on differential leveling be adhered to, namely, sight length and balanced sight length limitations. There are other methods that employ the use of two total stations mounted on vehicles observing simultaneous reciprocal angles, requiring numerous temperature and pressure measurements. Proponents of this method are over optimistic about the line lengths by trying to reach out to 350 meters or more. These methods yield acceptable results only after making many sets of observations and rejecting the bad ones, which makes the set up times quite long. Most surveyors are not able to justify the cost and amount of effort required by these methods, certainly not in their day to day surveying businesses.

The third reason is that most surveyors have never learned how to use their total station as a precise leveling instrument. Many surveyors take advantage of the leveling ability of their total stations for topographic surveys, but it may never have occurred to them to use their total station as a precise level. Given reason number one above, they have had no reason to do so. If there is leveling to be done, current circumstances and perceptions dictate that conventional differential leveling would have to be used. Another aspect of this third reason is that some surveyors use their total stations to measure 3 dimensional traverses thinking that they are trig leveling. They will of coarse have the perception that trig leveling is "low order" compared to conventional differential leveling. The reason for this lies in the fact that during a 3-D traverse, the height of every single instrument and target set up must be measured. These heights are usually measured somewhat crudely with a folding ruler and the accuracy of the results suffers directly from these imprecise height measurements.

Intent

The intent of this article is to widely publicize a method of trigonometric leveling that could be used in place of conventional differential leveling to establish vertical control. All surveyors equipped with modern total stations can immediately begin using this method once they learn the principles that are involved. As the method gains the attention of more surveyors, hopefully the need for FGCS specifications for trig leveling will become enough of a priority that they are actually made into a reality.

Method Described

I learned this method from it's number one proponent, Charles C. Glover, when he was a Geodetic Technician with the National Geodetic Survey working at the Instrumentation and Methodologies Branch located in Corbin, Virginia.

Try this experiment at your office. Set up 2 tripods with targets and reflectors about 100 meters apart and set up your total station in the middle, assuming that the vertical circle of your total station has an accuracy of at least 2 seconds. The distance will be shorter for vertical circles having less accuracy and can be longer for vertical circles accurate to one second or better. Measure the temperature and pressure to ensure that the correct PPM correction is entered into the instrument. This test will demonstrate the ability of your total station to precisely determine the difference in elevation between a backsite (BS) and a foresite (FS). At this point, do not be concerned with the height of the targets above the ground.

I call this test, "leveling in place". The targets will remain stationary, each taking on the role of BS and FS in succession while the total station is re-set up between turns. Any level notebook will work for this test or you may choose to use the form included here. Pick one of the targets as the starting BM and record an elevation of 100 meters in the book. Point on that target in the

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direct and measure the distance to it. In the BS column, record the Vertical Distance (VD) and be sure to note whether it is a (+) plus or a (-) minus VD. Record the slope distance to the nearest decimeter in the next column. Rotate the instrument and point on the other target and repeat the above steps recording everything in the FS column. Again, be sure to note whether the VD is positive or negative. Plunge the scope and re-point on the FS in the reverse, this time, only record the VD. Rotate the instrument to re-point on the BS in the reverse and record the VD. This completes one set of direct and reverse pointings on the BS and the FS. With the instrument still in the reverse toward the BS, re-point and measure to the BS recording the VD. Rotate the instrument and record another VD to the FS in the reverse. Plunge the scope and re-point on the FS to record another VD in the direct. Rotate the instrument and record the last VD to the BS in the direct. This completes a second set of direct and reverse pointings to the BS and FS. When you become accustomed to this procedure, it shouldn't take more than around 3 or 4 minutes to complete 2 sets of direct and reverse pointings. The advantage to the procedure is that the amount of manipulating the instrument is reduced.

Now, what to do with all these numbers? The slope distances are simply summed to give the total length of this single set-up. The lengths of all the set-ups will be summed at the end to give the grand total distance "traveled". Next, compute the means for the BS and FS readings. To prevent blunders, a precision check is performed at each set-up. The means of the first set should not differ from the means of the second set by more than a millimeter and a half (1.5mm).

To find the difference in elevation between the BS and FS, subtract the mean BS from the mean FS, paying attention to the algebraic signs. To find the elevation of the FS, algebraically sum the difference in elevation with the assumed BM elevation of 100 meters. This completes the first set-up.

Next, pick up the instrument and re-set it, changing the HI. For the next set of observations, the target that was the FS is now the BS and the original BS is now the FS. Observe and record another 2 sets of D&R pointings to the BS and FS as before. Once completed, you will have an instant check on the accuracy by comparing the elevation of the FS in this second set to the assumed 100 meters since the FS in this set is the original BS on the BM in the first set.

Repeat the procedure until you have made 10 to 12 turns to simulate a level run. The whole test can take up to 60 minutes to complete. At this point you will be able to assess the accuracy of the method and your total station by noting the deviation from the assumed 100 meter BM. If the test went well, you will be eager to learn how to apply this method to your leveling projects in the future. The next section includes the details you will need to know in order to be successful using this method of trigonometric leveling.

Details for Success*

The following discussion provides guidelines for successfully performing trigonometric leveling using a total station. Necessary precautions and instrumental checks are prescribed to insure that

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the internal automatic features of the total station are operating properly. You should understand the principles of differential leveling and the particular total station being used. Differences and similarities between these two systems will be used to explain the rationale of the recommended procedures.

The National Geodetic Survey's "Geodetic Glossary" defines Trigonometric Leveling as, "Determining differences of elevation by observing vertical angles and measuring straight-line distances between points."

In the past, these two measurements were made separately, along with heights of instruments and targets. The vertical angle was measured with a theodolite and the distance with a separate EDM. The difference in heights of the angulation instrument and distance measuring instrument had to be measured. Reflector and distance measuring instrument offsets had to be known and recorded.

The temperature and atmospheric pressure had to be measured and recorded. The difference in elevation was derived by appropriate computations using these measured variables. The resultant difference of elevation was further refined by the application of corrections for the effects of refraction through the atmosphere and for earth curvature.

Modern total station Instrumentation will make the necessary measurements and computations simultaneously and directly display a difference in elevation. This difference in elevation, as a rule, is from the axis of the total station to the point intersected on the target. This is possible due to the combination of the design of the total station and proper operating procedure.

In this method, the total station and target height measurements are unnecessary. The elevation difference is transferred directly from a back sight target to a fore sight target. These two targets are constructed or adjusted so that they are the same length and the elevation difference (Delta h) mode of the total station is used. For example, a back sight of minus 2 feet and a fore sight of plus 2 feet equals a + 4 feet difference in elevation from back sight to fore sight.

In order for the difference in elevation from the axis of the total station to the reference point on the target to be correct as observed, without further computations or corrections, the following requirements must be met.

The total station measures a slope distance and a vertical angle. It computes the difference in elevation using the sine function of the vertical angle multiplied by the slope distance. In order for the computed difference in elevation to be correct, the vertical angle and the slope distance must originate and terminate at the same points.

The vertical angle originates at the horizontal axis of the total station and terminates at the where the telescope cross hairs intersect the target. However, the slope distance originates from some point located behind or in front of the horizontal axis of the total station and terminates at some point beyond the reflector.

The amount that the origination point is behind or in front of the horizontal axis is called the EDMI offset. It can be either a plus (+) or minus (-) offset. If it is in front of the axis, it is a (+), which means the measured distance must be increased by the offset distance. It is a (-) when it is behind the axis and the measured distance must be decreased by the offset distance.

If the face of a retro-reflector is in the plane of the target reference point and the EDMI measures a distance to the reflector, the distance will terminate at a point beyond the target reference point. The distance from the target reference point to the distance termination point will be equal to 1.519 multiplied by the thickness of the reflector. This excess distance is called the reflector offset. The algebraic sum of the EDMI and reflector offsets must be taken and entered in the total station. This is done via keyboard entry or by switch settings.

The next consideration is the refractive index correction. It is commonly referred to as the atmospheric correction and must be applied as a scale correction to the measured distance. This correction varies with air temperature and atmospheric pressure and is usually stated in parts per million (PPM). The value for this correction is usually taken from a mechanical scale or a graph or it can be computed. Some total stations require that the actual air temperature and atmospheric pressure be entered into the instrument and the correction is automatically computed and applied to the distance. Regardless of how it is handled, the correction must be entered into the total station.

Some total stations have an earth curvature and refraction correction embedded in the internal software. Some offer the option of choosing between various average values or disabling the function completely. There are some that give no options at all. Regardless of which total station is being used and what correction, if any, is being automatically applied, the value, if any, should be noted. The reason for this is so that if any future adjustments to the data are made, this already applied correction can be properly dealt with.

* *Reprinted with minor changes from "Trigonometric Workshop Notes" by Charlie C Glover and Orland W. Murray.*

Test Results

SPERRYVILLE TO LURAY VIRGINIA**

Trigonometric Leveling Test Conducted By
The National Geodetic Survey
Instrumentation and Methodologies Branch
Corbin, Virginia

The test was performed on an old second order level line that runs over the Blue Ridge Mountains from Sperryville, VA to Luray, VA. It was chosen because it provides a large change in elevation from end to end.

The purpose of this survey was to determine the accuracy, feasibility, and reliability of trigonometric leveling in mountainous terrain and from the results, recommend procedures and guidelines for other users who may wish to employ trigonometric leveling in their own work.

Specifications

No specifications were strictly adhered to while conducting this survey, since it was unknown what order of accuracy might be obtained. The observations were left somewhat free from any tolerances or rejection limits; however, a reasonable precision check was used in the data collection software to detect blunders. First Order Class II specifications were applied to closures (section, loop and ‘new minus old’ where possible) in order to provide a measure on how well the system was performing.

Instrumentation

> A Wild T2000 Electronic Theodolite having a zenith distance accuracy of 0.5 seconds and automatic indexing with a liquid compensator was used to measure direct and reverse zenith angles. A Wild DI2002 EDMI accurate to a standard deviation of 1 mm + 1 ppm in standard distance mode was used to measure the slope distances.

Targets

It was discovered during previous trig-leveling tests that earlier targets were inadequate by being too small, distorted by shadows, washed out against a skyline backdrop, and difficult to point to at short distances. The new target is larger overall and fabricated from self-illuminating translucent white plexiglass. The smaller angled wider wedge shape is easier to point on at close and long range. The targets were mounted atop hollow aluminum rods with a machined steel footplate. The rods were precisely measured to assure that they were within 0.2 millimeter of being the same length of 2.5 meters. The thermal expansion of the rods was not considered. It was assumed that they would expand equally and still remain the same height under the same conditions. A 1-inch peanut retro-reflector was built into the target 1 inch above the center of

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wedge apex.

Data Collection

Data collection was performed using a Zenith laptop IBM compatible computer with software developed at the M & I Branch of the National Geodetic Survey.

Leveling Route

The route was part of an old Second Order level line (l9485/line 112) running from Sperryville to Luray Virginia along US Highway 211. The highway is a two lane, sometimes three-lane road that winds its way over the Blue Ridge Mountains at Thornton Gap. This line had not been re-leveled for nearly forty years. The length of the line leveled was 15.7 kilometers with 9 monumented marks and two TBMs. The spacing varied from 1 to 3.43 kilometers with an average of about 1.5 kilometers.

Statistics

Section closures along the line were much better than expected. All closures met First Order Class II (4mm*SQRT Km dist.) specifications except one that missed by only 0.2 millimeter. Conventional differential leveling was run over the exact same route. The comparison of the differential leveling and the trig leveling never differed by more than a millimeter on any section.

Total Distance Double Run	15.69 km	Max Imbalance In Any 1 Setup	110 m
Total Number of Setups	173	Average Shot Length	95 m
Average Setup Length	190 m	Longest Shot Length	205 m
Total Change In Elevation	1614.6 m	Shortest Shot Length	13 m
Ave Change In Elev Per Setup	9.3 m	Average DE Per Setup for Loop	10.2 m
Total Time to Double Run Line	29.8 hrs.	Average DE Per Section	80.0 m
Average Time Per Kilometer	53 min.	Largest DE In One Section	210 m
Average Imbalance for Loop	11.2 m	Largest DE In One Setup	19.5 m
Max Imbalance In Any 1 Section	150 m		

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Advantages of Trigonometric Leveling***

1. No restrictions on sight length due to change in elevation.

2. No need to balance backsight and foresight shot length. This makes the location choice for instrument and rod more convenient.

3. Line of sight height above ground can be maintained at maximum because the observation is always to the top of the rod. This prevents the affect of heat shimmer close to the ground.

4. Temperature gradients (layers of air of different temperatures) tend to run parallel to the ground. These layers of air are warmer near the ground and get cooler as the height above the ground increases. However, the rate of change is greater near the ground and decreases as the height above the ground increases. The density of air changes as its temperature changes. When light passes from air of one density to air of a different density, the light is refracted (bent). The greater the difference in the two densities, the greater the light will be refracted. In spirit leveling, where elevation changes significantly from backsight to foresight, the horizontal line of sight cuts through these gradients of different densities. If the backsight is high on the rod, the foresight will be low on the rod. The backsight line of sight is passing through air that is changing temperature at a slower rate than the foresight. This causes the line of sight to be refracted more on one shot than the other. In trigonometric leveling, the line of sight can be maintained reasonably parallel to the ground, preventing the line of sight from passing through these temperature gradients.

5. The height of the trig leveling target can be changed to overcome situations where obstructions to line of sight would interfere with spirit leveling.

6. The only calibration necessary for the rods is that they are the same length or any difference in their lengths is a known amount. To eliminate the accumulation of rod length error when using 2 rods, the rod used on the first backsight also must be used on the last foresight and there must be an even number of setups with the rods alternated between backsight and foresight. If only one rod is used, there is no need for any of these requirements.

7. There is no need to precisely level the total station if it has a compensator allowing for fast setups using only the circular level.

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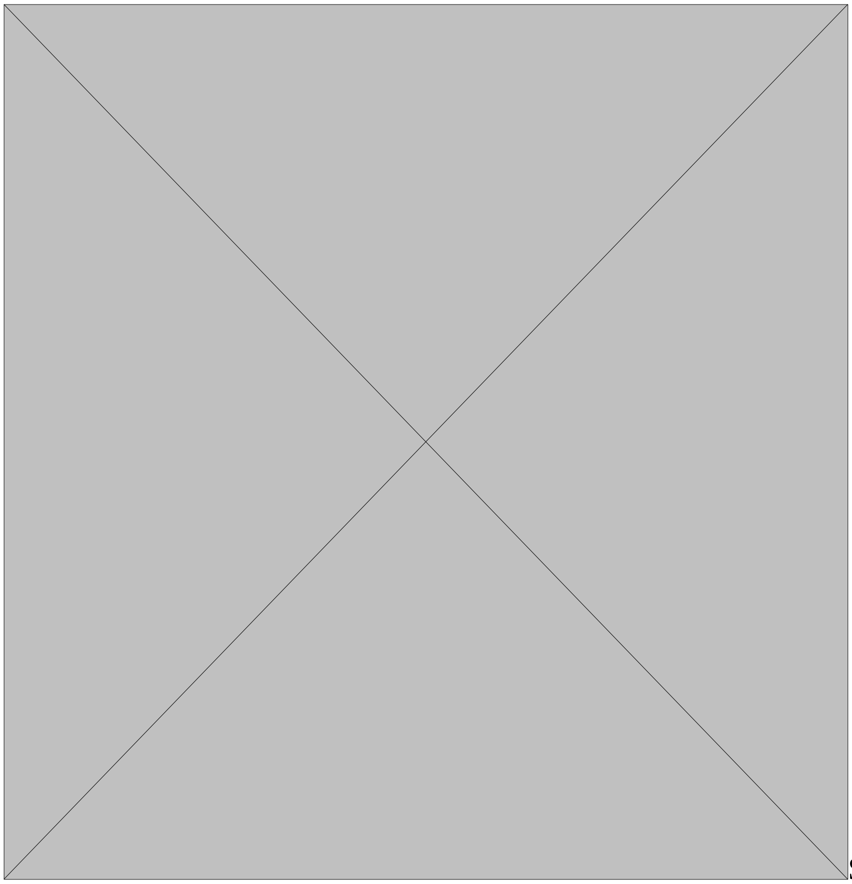
Supplier of Trigonometric Leveling Targets

These targets were designed by Charlie C. Glover when he was with the National Geodetic

Survey, Instrumentation and Methodologies Branch at Corbin, Virginia.

The original target was turned over to the California Transportation Department, District 11 (CALTRANS). They retained SECO Manufacturing to duplicate and produce the target. The target and support pole is now a commercial item available from:



SECO Manufacturing
4155 Oasis Road
Redding, California 93003

Contact: Mike Copeland
Phone: 916-225-8155
Toll Free 1-800-824-4744

Expected Accuracy

The following 3 charts display the expected accuracy ("Sigma HGT in mm") for various zenith angles at varying sight lengths for instruments having different levels of accuracy in the EDM and the Vertical Circle. It will be obvious that the accuracy remains high on longer sight lengths for instruments having higher vertical circle and EDM accuracy.

<u>1 mm EDM and Half Second Vertical Circle Accuracy</u>

Zenith Angle

Sight Length	89	88	87	86	85	84	83	82	81	80	79	78	77	76	75
10	0.03	0.04	0.06	0.07	0.09	0.11	0.12	0.14	0.16	0.18	0.19	0.21	0.23	0.24	0.26
20	0.05	0.06	0.07	0.08	0.10	0.12	0.13	0.15	0.16	0.18	0.20	0.21	0.23	0.25	0.26
30	0.07	0.08	0.09	0.10	0.11	0.13	0.14	0.16	0.17	0.19	0.20	0.22	0.24	0.25	0.27
40	0.10	0.10	0.11	0.12	0.13	0.14	0.16	0.17	0.18	0.20	0.21	0.23	0.24	0.26	0.28
50	0.12	0.13	0.13	0.14	0.15	0.16	0.17	0.18	0.20	0.21	0.22	0.24	0.25	0.27	0.28
60	0.15	0.15	0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.23	0.24	0.25	0.27	0.28	0.29
70	0.17	0.17	0.18	0.18	0.19	0.20	0.21	0.22	0.23	0.24	0.25	0.27	0.28	0.29	0.31
80	0.19	0.20	0.20	0.21	0.21	0.22	0.23	0.24	0.25	0.26	0.27	0.28	0.29	0.31	0.32
90	0.22	0.22	0.22	0.23	0.23	0.24	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.32	0.33
100	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.28	0.29	0.30	0.31	0.32	0.33	0.34	0.35
110	0.27	0.27	0.27	0.27	0.28	0.29	0.29	0.30	0.31	0.31	0.32	0.33	0.34	0.35	0.37
120	0.29	0.29	0.30	0.30	0.30	0.31	0.31	0.32	0.33	0.33	0.34	0.35	0.36	0.37	0.38
130	0.32	0.32	0.32	0.32	0.33	0.33	0.34	0.34	0.35	0.36	0.36	0.37	0.38	0.39	0.40
140	0.34	0.34	0.34	0.35	0.35	0.35	0.36	0.36	0.37	0.38	0.38	0.39	0.40	0.41	0.42
150	0.36	0.37	0.37	0.37	0.37	0.38	0.38	0.39	0.39	0.40	0.40	0.41	0.42	0.43	0.44
160	0.39	0.39	0.39	0.39	0.40	0.40	0.40	0.41	0.41	0.42	0.43	0.43	0.44	0.45	0.46
170	0.41	0.41	0.41	0.42	0.42	0.42	0.43	0.43	0.44	0.44	0.45	0.45	0.46	0.47	0.47
180	0.44	0.44	0.44	0.44	0.44	0.45	0.45	0.45	0.46	0.46	0.47	0.47	0.48	0.49	0.49
190	0.46	0.46	0.46	0.46	0.47	0.47	0.47	0.48	0.48	0.49	0.49	0.50	0.50	0.51	0.51
200	0.49	0.49	0.49	0.49	0.49	0.49	0.50	0.50	0.50	0.51	0.51	0.52	0.52	0.53	0.54

Expected Accuracy (mm)

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1 mm EDM and One Second Vertical Circle Accuracy

Zenith Angle

Sight Length	89	88	87	86	85	84	83	82	81	80	79	78	77	76	75
10	0.05	0.06	0.07	0.08	0.10	0.12	0.13	0.15	0.16	0.18	0.20	0.21	0.23	0.25	0.26
20	0.10	0.10	0.11	0.12	0.13	0.14	0.16	0.17	0.18	0.20	0.21	0.23	0.24	0.26	0.28
30	0.15	0.15	0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.23	0.24	0.25	0.27	0.28	0.29
40	0.19	0.20	0.20	0.21	0.21	0.22	0.23	0.24	0.25	0.26	0.27	0.28	0.29	0.31	0.32
50	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.28	0.29	0.30	0.31	0.32	0.33	0.34	0.35
60	0.29	0.29	0.30	0.30	0.30	0.31	0.31	0.32	0.33	0.33	0.34	0.35	0.36	0.37	0.38
70	0.34	0.34	0.34	0.35	0.35	0.35	0.36	0.36	0.37	0.38	0.38	0.39	0.40	0.41	0.42
80	0.39	0.39	0.39	0.39	0.40	0.40	0.40	0.41	0.41	0.42	0.43	0.43	0.44	0.45	0.46
90	0.44	0.44	0.44	0.44	0.44	0.45	0.45	0.45	0.46	0.46	0.47	0.47	0.48	0.49	0.49
100	0.49	0.49	0.49	0.49	0.49	0.49	0.50	0.50	0.50	0.51	0.51	0.52	0.52	0.53	0.54
110	0.53	0.53	0.54	0.54	0.54	0.54	0.54	0.55	0.55	0.55	0.56	0.56	0.57	0.57	0.58
120	0.58	0.58	0.58	0.58	0.59	0.59	0.59	0.59	0.60	0.60	0.60	0.61	0.61	0.61	0.62
130	0.63	0.63	0.63	0.63	0.63	0.64	0.64	0.64	0.64	0.64	0.65	0.65	0.65	0.66	0.66
140	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.69	0.69	0.69	0.69	0.70	0.70	0.70	0.70
150	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.74	0.74	0.74	0.74	0.74	0.75	0.75
160	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.79	0.79	0.79	0.79
170	0.82	0.82	0.82	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.84	0.84
180	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
190	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.93	0.93	0.93
200	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97

Expected Accuracy (mm)

Expected Accuracy (mm) **Sight Length**

	89	88	87	86	85	84	83	82	81	80	79	78	77	76	75
10	0.15	0.16	0.18	0.20	0.23	0.25	0.28	0.31	0.34	0.38	0.41	0.44	0.47	0.50	0.54
20	0.29	0.30	0.31	0.32	0.34	0.36	0.38	0.40	0.42	0.45	0.48	0.50	0.53	0.56	0.59
30	0.44	0.44	0.45	0.46	0.47	0.48	0.50	0.51	0.53	0.55	0.57	0.60	0.62	0.64	0.67
40	0.58	0.59	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.67	0.69	0.70	0.72	0.74	0.76
50	0.73	0.73	0.73	0.74	0.75	0.75	0.76	0.77	0.78	0.80	0.81	0.82	0.84	0.86	0.87
60	0.87	0.87	0.88	0.88	0.89	0.89	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.98	0.99
70	1.02	1.02	1.02	1.03	1.03	1.03	1.04	1.05	1.05	1.06	1.07	1.08	1.09	1.10	1.11
80	1.16	1.16	1.17	1.17	1.17	1.18	1.18	1.19	1.19	1.20	1.20	1.21	1.22	1.23	1.24
90	1.31	1.31	1.31	1.31	1.32	1.32	1.32	1.33	1.33	1.34	1.34	1.35	1.35	1.36	1.37
100	1.45	1.46	1.46	1.46	1.46	1.46	1.46	1.47	1.47	1.47	1.48	1.48	1.49	1.49	1.50
110	1.60	1.60	1.60	1.60	1.60	1.60	1.61	1.61	1.61	1.61	1.62	1.62	1.62	1.63	1.63
120	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.76	1.76	1.76	1.76	1.76
130	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.90	1.90	1.90	1.90
140	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.03	2.03	2.03	2.03	2.03
150	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.17	2.17	2.17	2.17
160	2.33	2.33	2.33	2.33	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.31	2.31	2.31	2.31
170	2.47	2.47	2.47	2.47	2.47	2.47	2.47	2.46	2.46	2.46	2.46	2.45	2.45	2.45	2.44
180	2.62	2.62	2.62	2.62	2.61	2.61	2.61	2.61	2.60	2.60	2.60	2.59	2.59	2.59	2.58
190	2.76	2.76	2.76	2.76	2.76	2.76	2.75	2.75	2.75	2.74	2.74	2.73	2.73	2.72	2.72
200	2.91	2.91	2.91	2.91	2.90	2.90	2.90	2.89	2.89	2.89	2.88	2.88	2.87	2.86	2.86

2 mm

EDM and 3 Second Vertical Circle Accuracy

Zenith Angle

Suggestions

1. FGCS Specifications for trig leveling should be published as soon as is realistically and practically possible to do so. All surveyors interested in seeing this done should do whatever they can to promote this activity.

2. More testing needs to be done of this method and also other methods available to establish vertical control by trigonometric methods.

3. Instrument manufacturers might consider assisting however they can to help promote the use of trig leveling and also calling for the publication of FGCS specifications for trig leveling.

4.Currently, there are very few data collection and reduction programs available for trig leveling. There is a need for easy to use data collection software designed strictly for recording and reducing trig leveling observations.

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5. Users of GPS may benefit greatly by using trig leveling to densify vertical control in their networks, especially in mountainous regions.

Acknowledgments:

Charlie C. Glover – What can I say? You have to know him. He was supposed to be here to help present this paper, but he went and retired from NGS today, on 3 March, 1998. I am very glad to know him and appreciate the opportunity to learn from him.

Orland (Audie) W. Murray – Audie prefers simultaneous reciprocal observations. I can't blame him – they are the best observations you can make through this invisible stuff we call atmosphere. Audie created all of the diagrams in AutoCad to scale. These were imported into MS Power Point as DXF files and then re-worked.

CALTRANS –
Tim Dickey provided lots of background documentation describing the great success they are having using trig leveling on a routine basis. They balance their sight lengths and keep them pretty short. They might try experimenting with loosening the restrictions to see what happens.

North Carolina Geodetic Survey –
Gary Thompson
Philip Cort
Mark Boothe

We ran trig levels up to Max Patch in North Carolina - around 4 miles double run. We would have had First Order results to report in this paper, but we barely made Second Order because we didn't have the correct EDM and reflector offset in the instrument. Shame on us. The things that you learn the hard way are hard to forget. After the snow thaws up there, we will complete this test. Look for this Preliminary Draft as an article in Professional Surveyor Magazine once this test has been completed. There will also be a comparison with the differential leveling that NCGS ran over the same marks.

Appendix

The following pages include the printed slides, note forms and the field notes from a trig leveling test performed on 13 May, 1997 over 3 first order bench marks located near Harpers Ferry, West Virginia.

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