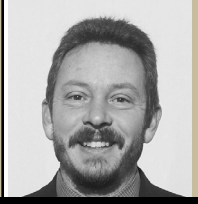

By Dan Martin

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Geodetic Leveling

Over the last 30 years, the processes and equipment we use to produce precise horizontal positions has changed dramatically. We have gone from methods requiring direct line of sight (tapes, theodolites, and eventually electronic distance measuring instruments) to less restrictive methods utilizing GPS technology. Using this technology and the processes that have been developed, geodetic quality horizontal positions can be established with relative ease over vast distances in a couple of days or less. Additionally, the accuracy of the horizontal measurements collected with GPS exceeds that of the technology it replaced. The use of GPS is also on its way to becoming the method of choice for vertical positioning, and in many common applications it can be used this way. For many applications, however, geodetic leveling is still the only method that will produce the desired results. In fact, the success of a GPS campaign designed to produce heights will rely to a great extent on our ability to observe valid benchmarks that were established by using geodetic leveling techniques.

We have always used heights in the building of our infrastructure, but today heights also play an integral role in the development of our projects. It is no longer good enough to simply know which way water flows on a project or if it is within the floodplain. In the past, it might have been good enough to set the proverbial "spike in pole," assign it an elevation of 100 feet, and go to work. Today, there is a much greater need to know on a larger scale where that water goes and who or what it impacts when it leaves our project. Heights also play a major role today in studying, predicting, and mitigating the impact of natural disasters. This means that having the ability to reference our heights to a common system is more important than ever.

What is Leveling?

Leveling means determining the difference in elevation between two or more points on the surface of the earth. As in the past, this is accomplished by making measurements to two or more points through a telescope which has been set up (leveled) with its line of sight being parallel to the local gravity field. A vertical measurement is taken to the backsight and added to its height, thereby determining the height of the center of the telescope (Height of Instrument or HI). A vertical measurement is then taken to the foresight and subtracted from the Height of Instrument, thereby determining the height of the foresight (see **Figure 1**). The instrument can then be moved ahead and the process repeated using the newly-established foresight as a backsight and establishing a new foresight. This process is commonly referred to as differential leveling.

This process is essentially the same process that has been used throughout history. Differential leveling procedures are limited by line of sight, and to a great extent, the distance between the instrument and the rod. Since the rod must be

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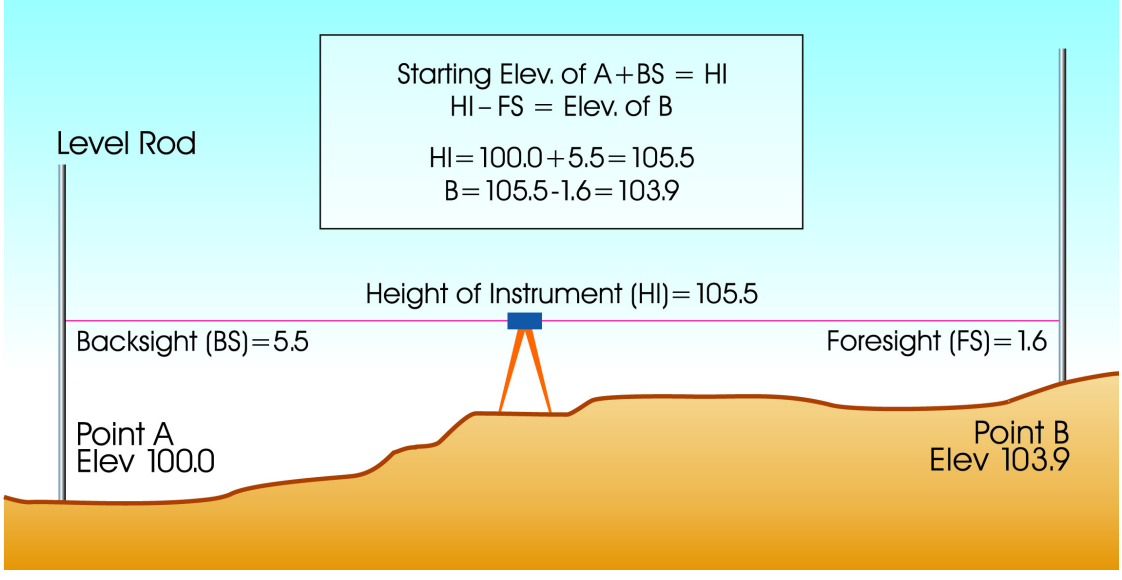

Figure 1
Differential leveling process

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read, either optically or digitally, the rod must be close enough for the observer (optical) or instrument (digital) to resolve the rod's scale in order to make an accurate measurement. Therefore, unlike GPS, the distance between marks must be physically traversed by the leveling crew (for example, 10 kilometers between marks equals 10 kilometers of walking, or 20 kilometers of walking when a level line is double run).

Easy Come, Easy Go

When was the last time you used a bench mark? I do not mean the "spike in pole," but a "real" bench mark? Was it near your project or did you have to conduct significant leveling observations to bring in a height? More often than not, the latter is the case. NOAA's National Geodetic Survey (NGS, formerly the U.S. Coast and Geodetic Survey), has conducted significant leveling campaigns across the country since the late 1800s. Unfortunately, many of these valuable marks have been destroyed over the years. In Vermont, we have discovered that more than 30% of the bench marks that reside in the national database have been reported as destroyed or not found, or have not been recovered since they were initially established. Additionally, some parts of the country are still undergoing uplift as a result of the removal of glacial ice from the last Ice Age, while other parts of the country are subsiding as a result of coastal loading the removal of ground water. Therefore, even if there are adequate bench marks available, the validity of their heights might be in question (especially over larger areas).

What is a Surveyor to Do?

Most surveyors are very conscientious when it comes to heights. Many will tie into vertical control whether it's a requirement or not if the control is close at hand. I believe that most would like to a tie into to vertical control all of the time for projects that have a vertical component. However, if a project does not require the use of the national vertical datum, it is difficult (if not impossible) to justify the added expense if any significant leveling is required. Bringing in a height using GPS could also be an added expense unless it is done in concert with establishing horizontal control on a project. Regardless of the method used, it is clear that valid vertical control needs to be within a certain proximity to the project.

Figure 2 Example of accumulated errors from differential leveling over long distances

Coming Full Circle

Over the last decade much has been done to enhance the horizontal network in the United States. High Accuracy Reference Networks (HARNs) have been observed in every state and Continuously Operating Reference Stations (CORS) have been established around the country; the process for submitting GPS projects to the NGS has been greatly simplified. But it is through these horizontal activities that we have found that we need to work on the vertical network. The vertical network was established and designed for use with conventional leveling equipment. Today we are accessing it on a daily basis using a technology that was not even conceived of when the vertical network was created. The primary errors associated with differential leveling are distance dependant, while the primary errors associated with GPS are not.

To illustrate this difference, **Figure 2** shows a hypothetical level line that is 100 kilometers long and observed following First-order Class Two specifications. The allowed error for this standard is 4mm *sqrt(k), where *k* is the length of the level line expressed in kilometers. Therefore, for this example the allowable error is 4 cm. You will notice that this level line begins on one side of a river, extends about 50 km north, crosses the river, and then runs about 50 km south, (note that the north and south ends of the line are only separated by 1 km). If these marks are observed with GPS, we could see up to 4 cm of misclosure between them. Prior to GPS, this would not have been a problem as these marks would never be directly connected with conventional levels.

As a direct result of these issues, NGS has now elevated (excuse the pun) geodetic leveling and leveling project submission to be counted among its top priorities.

But what can be done to improve the vertical network? Actually, the process has already begun. The last round of the HARN observations were specifically designed to improve the ellipsoid heights on the HARN stations, and NGS continues to refine the national geoid model, GEOID03 being the latest model. Though these activities are "GPS based," their purpose is to aid in the establishment of heights and allow us to use GPS to conduct rough check observations quickly and economically. Now all we need to do is to perform new leveling observations across the country.

Unlike the leveling that preceded the adjustment of the North American Vertical Datum of 1988 (NAVD 88), in which NGS had leveling parties spread across the country, this new leveling will be conducted by state, county, and local governments. The NGS role in this process will be to establish guidelines and procedures, modify and modernize the process for the submission of leveling data, conduct research into the integration of conventional leveling and GPS, and develop workshops and training tools for users. This process has already begun through the NGS National Height Modernization Program. For more information, *visit www.ngs.noaa.gov/initiatives/height_modernization.shtml.*