Inclusion of Leveling with GNSS Observations in a Single, 3-D Geodetic Survey Network Adjustment

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SUMMARY

The current vertical datum of the United States National Spatial Reference System, known as the North American Vertical Datum of 1988 (NAVD 88), was realized by hundreds of thousands of kilometers of differential leveling between a continent-wide network of passive marks. Maintaining this large network is challenging, time-consuming, and costly, and over 25 years has passed since the completion of NAVD 88. Passive marks can be destroyed and their heights may change over time due to crustal motion, earthquakes, subsidence, and human activities such as construction and vandalism. As a result, there is a perpetual need to update and publish new heights on marks, but re-leveling is a tedious process that requires significant time and effort. To address this problem, the National Geodetic Survey (NGS) has implemented a plan to replace NAVD 88 with a new geopotential reference frame in the year 2022. This reference frame will be based on a purely gravimetric high-resolution geoid model developed from a combination of terrestrial, satellite, and recent airborne gravity measurements. As a result of this new reference frame, GNSS observations combined with the geoid model will become the primary means for deriving orthometric heights on marks. However, questions remain on what to do with the historic leveling data, as well as future leveling data collected by surveyors. Differential geodetic leveling remains much more precise than GNSS for measuring height differences between marks within a short distance of each other (e.g., less than about 10 km). This paper presents a case study on the inclusion of historic leveling observations with recent GNSS vectors and geoid slopes from a gravimetric geoid model to derive orthometric heights on marks in a 6,400 square kilometer study area in western Oregon. A scheme was developed for weighting the leveling observations, GNSS vectors, and relative geoid height differences. The weights for the leveling data varied according to the age of the observation as well as its survey order and class per NGS survey standards. To weight the geoid height differences, a method was developed for estimating the relative accuracy of the geoid model over distances ranging from zero to about five kilometers. Afterwards, the network of observations was combined

and adjusted by least squares within a 3-D geodetic model to produce the most probable geodetic coordinates on the survey marks. Combining appropriately weighted GNSS, leveling, and geoid slope observations allows GNSS and leveling observations to mitigate weaknesses in one another. For example, GNSS adds redundancy to the leveling network and helps control the increase in error when leveling over long distances. And leveling provides greater vertical precision over short distances than can be achieved with GNSS alone. The combined approach was useful for identifying marks with published leveled heights that were inaccurate or outdated, and it helped refine estimates of the most probable heights on the marks, as well as their uncertainties.