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The Global Positioning System (GPS), when used in a differential mode, can be used to obtain very accurate heights relative to an ellipsoid. Questions have been raised as to how accurate GPS can be used to obtain elevations based on the geoid. Several field techniques (i.e. local geoid modeling) as well as geoid modeling software have been developed in order to use GPS to obtain elevations based on the geoid. This paper will present analysis and results of testing performed by running a level loop with Differential GPS (DGPS) and conventional spirit leveling. The testing was performed in Alexandria, VA on 16&18 May 1994 by members of the Surveying Division of the Topographic Engineering Center.

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ELEVATION DETERMINATION BY USING GPS

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BIOGRAPHICAL SKETCH

Jim Garster joined the U.S. Army Topographic Engineering Center in June of 1992 as a Computer Scientist (Survey Engineer). His responsibilities include district support for Global Positioning System (GPS) and Differential GPS (DGPS) surveying projects and testing of new DGPS survey techniques. Jim received his Masters of Engineering (M.E.) in Surveying Engineering from the University of Maine in 1992. He received his B.Sc. in Mathematics with a minor in Experimental Statistics from the University of Rhode Island in 1989.

ABSTRACT

The Global Positioning System (GPS), when used in a differential mode, can be used to obtain very accurate heights relative to an ellipsoid. Questions have been raised as to how accurate GPS can be used to obtain elevations based on the geoid. Several field techniques (i.e. local geoid modeling) as well as geoid modeling software have been developed in order to use GPS to obtain elevations based on the geoid. This paper will present analysis and results of testing performed by running a level loop with Differential GPS (DGPS) and conventional spirit leveling. The testing was performed in Alexandria, VA on 16&18 May 1994 by members of the Surveying Division of the Topographic Engineering Center.

INTRODUCTION

GPS is an all-weather, 24 hour a day satellite timing and ranging system. It was developed by the Department of Defense (DOD) to provide a Precise Positioning Service (PPS) to the U.S. Military and its allies. It also supports a Standard Positioning Service (SPS) for use by civilians. GPS provides accuracies of 16 meters (SEP) for PPS and 100 meters (2 DRMS) for SPS in the absolute positioning mode (i.e. using one receiver). When used in the differential mode (i.e. using two receivers), GPS can provide 3D accuracies from several meters down to a few millimeters. These accuracies are dependent on the processing techniques used.

The DGPS processing technique used for this project was Rapid Static. This technique uses both the L1 and L2 carrier frequencies broadcast by the GPS satellites in order to measure baselines and determine positions to the centimeter (cm) level with short occupation times of 5-20 minutes per station. The length of observation time is dependent on the number of visible satellites. Loss of lock, when moving between stations, can also occur with no effect on the results since each baseline is processed independently of each other.

Conventional spirit leveling is sometimes referred to as direct leveling or differential leveling. The actual differences in elevation are measured. In this method, a horizontal line of sight is established by using a sensitive level bubble in a level vial. The instrument is leveled and the line of sight of the instrument describes a horizontal plane. The difference in elevation between a known elevation and the height of instrument is determined. Next, the difference in elevation from the height of instrument to an unknown point is derived by measuring the vertical distance with precise or semi-precise level and leveling rods.

DATA ACQUISITION

Project Area and Control

The project was conducted along a stretch of Telegraph Road in Alexandria, VA from north of the U.S. Coast Guard Station to the HEC site at the Humphrers Engineering Center (see Figure 1).

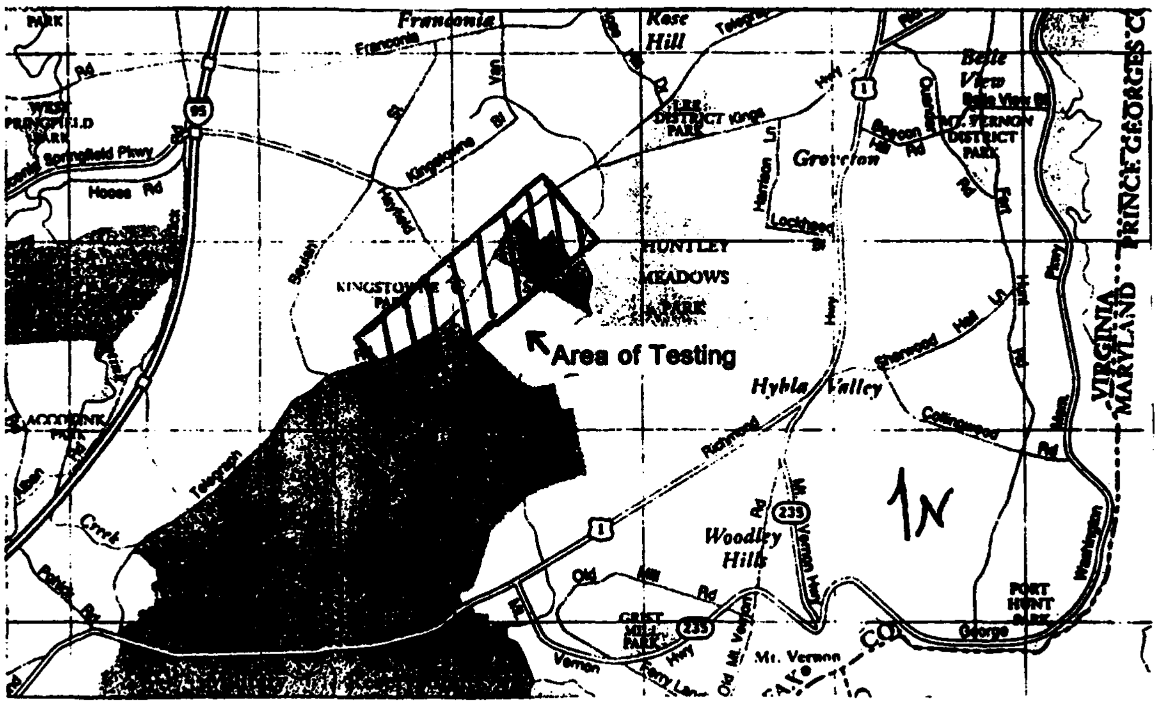

Figure 1. Area of Testing.

The level network was run from GPS37, a Fairfax County 2nd order horizontal and 3rd order vertical control point to point REMD and back. GPS37 was used as the orthometric vertical control point for the level loop. REMD was established by the National

Geodetic Survey (NGS) as part of the Virginia High Accuracy Regional Network (HARN). TEC established baselines between REMD and ETLE, which was established by NGS as part of the Federal Geodetic Control Subcommittee test course. REMD was used as the horizontal and vertical control point for the GPS Rapid Static survey.

Equipment Used

For the conventional spirit leveling, a ZEISS Ni2 level was used with 2 metric(centimeter graduations) Philadelphia leveling rods. For the DGPS survey, 2 Trimble 4000SSE GPS receivers with antennas and 2 two meter poles were used. The two meter poles were used to eliminate the need for measuring antenna heights. For the data processing, a 486 computer with Trimble's GPSurvey and geoid modeling software (GEOID90 and GEOID93) was used.

DATA COLLECTION

Conventional Spirit Leveling

The spirit leveling was performed in two loops on 16 May. The first loop was run from GPS37 to TP09 and back turning on the same turning points. The second loop was run from TP09 to REMD and back using the same method as the first. Turning points were set approximately every 200 feet. The Ni2 was set up to balance foresight and backsight distances (ie., foresights and backsights were 100 feet from level) in order to reduce atmosphere refraction and errors due to earths curvature. Certain turning points were set with rebar, so they could be reobserved during the DGPS survey. Foresights and backsights were read to the nearest 0.5 centimeter. All readings were recorded in a standard survey fieldbook.

GPS Survey

The DGPS survey was performed in one session on 18 May. One GPS receiver was set up over a known point (REMD) and collected data in the rapid static mode. The second receiver was moved to selected turning points (TP30, TP29, TP24, TP22, TP19, TP11, TP07) and GPS37 to collect data in the rapid static mode. Each station was observed for 8 to 20 minutes, depending on the number of satellites visible.

DATA ANALYSIS

Geoid Modeling

The GPS derived heights are based on the WGS84 ellipsoid (ie. ellipsoidal heights), but the heights determined with spirit leveling (ie. orthometric elevations) are base on the geoid (see Figure 3). Since the geoid and ellipsoid are not the same, there needs to be a method or model in order to compare GPS heights with spirit leveled heights. There are two models developed by NGS for this purpose, GEOID90 and GEOID93. These models were developed from gravity measurements taken at locations throughout the U.S. The stated accuracy for these models is 1-2 cm for 10 km spacing and 10 cm for a 100 km spacing.

The geoid modeling software requires a latitude and longitude as input, and returns a geoid height as output. The theory is that this geoid height can then be used in the equation listed in Figure 2, h=H+N, to determine the orthometric height.

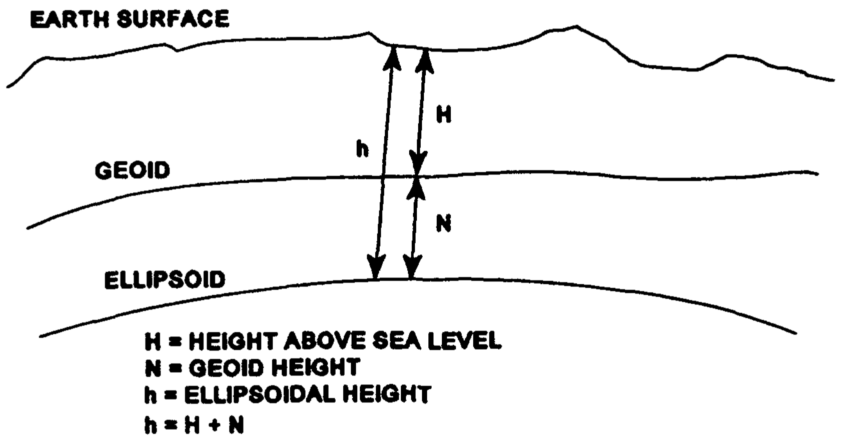

Figure 2. Geoid and Ellipsoid relationship.

Spirit Leveling

Orthometric elevations were established on 30 turning points and REMD, relative to GPS37. Since each turning point was observed twice, an average between the two values was used for comparison to the DGPS derived values. The first loop closed with a 5 millimeter error in closure. The second loop closed back on TP09 with no measurable error in closure.

GPS Survey

The GPS data was processed using Trimble's GPSurvey postprocessing software. Baselines were processed between REMD and GPS37, TP07, TP11, TP19, TP22, TP24, TP29, and TP30. The observed baselines are shown in Figure 3. While holding REMD fixed in latitude, longitude and ellipsoidal height, coordinates (lat., long., and ellp. ht) were generated for each turning point listed above and GPS37.

The GPS coordinate point values were then used as input in the geoid modeling software to determine the geoid heights for each point. These geoid heights were then subtracted from the GPS ellipsoidal heights to obtain orthometric elevations.

From the ellipsoidal heights (h), the orthometric elevations from spirit leveling (H_{level}) and the othometric elevations derived from

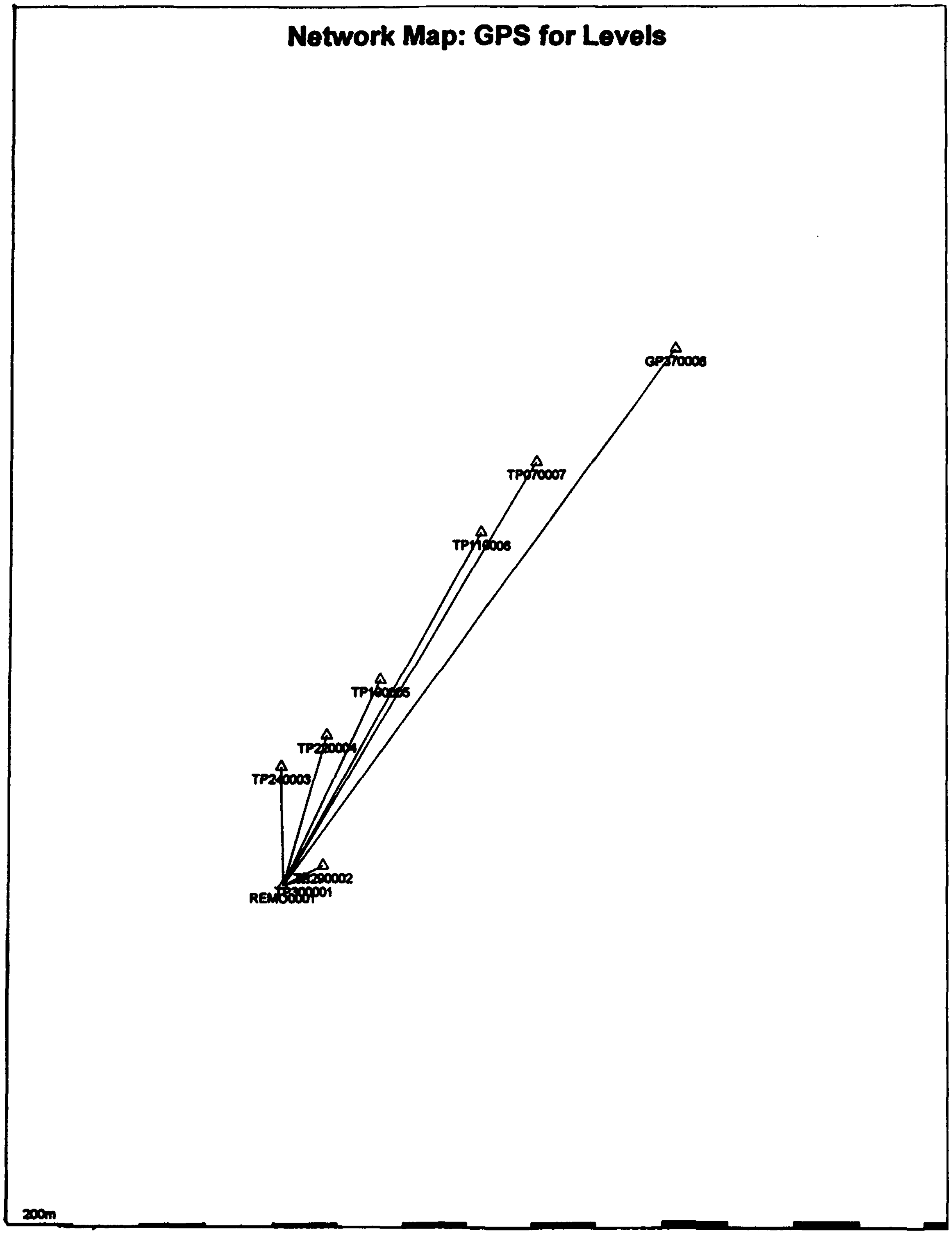

Figure 3. Network Map: GPS for Levels.

the geoid modeling (H_{model})(for both GEOID90 and GEOID93), Δh, ΔH_{level}, and ΔH_{model} were computed between REMD and GPS37, TP07, TP11, TP19, TP22, TP24, TP29, and TP30. The differences between ΔH_{level} and ΔH_{model} for each geoid model and between Δh and ΔH_{level} were also computed.

RESULTS

The results of the testing are shown in Table #1, Table #2, and Table #3. Table #1 shows the orthometric elevations from spirit leveling and the orthometric elevations determined using GEOID90 and GEOID93 with the ellipsoidal heights from GPS. Table #2 shows the differences in ellipsoidal heights and the differences in orthometric elevations from spirit leveling for each baseline. Table #3 shows the differences in orthometric elevations along each one of the baselines for both GEOID90 and GEOID93. This table also shows the difference between ΔH_{model} and ΔH_{level} for GEOID90 and GEOID93.

From the results in Table #1, it looks as if the orthometric elevations computed from GPS and GEOID90 will meet 3rd order leveling procedures. Results from using GEOID93, which is suppose to be a better geoid model, do not show any improvement. In fact, the orthometric elevations computed using GEIOD93 are further away from the orthometric elevations derived from spirit leveling than those computed from GEOID90.

In Table #2, the values of ΔH_{level}-Δh are not consistent and range from less than a cm to over 5 cm. The greatest differences between the ellipsoidal and orthometric values do occur at the longer baselines.

In Table #3, notice that the ΔH_{model}-ΔH_{level} values, for each geoid model (excluding baseline REMD-TP07), are almost the same. Comparing these values to the ΔH_{level}-Δh values from Table #2, the geoid modeled differences are less over the longer baselines.

Table #1. Geoid modeling results.(all measurements in meters)

Pt Name	h Ellip. Height	N GEOID90	N GEOID93	H_{model} GEOID90	H_{model} GEOID93	H_{level}
GPS37	0.249	-32.452	-32.565	32.701	32.813	32.700
TP07	3.697	-32.456	-32.566	36.153	36.363	36.170
TP11	1.457	-32.460	-32.572	33.917	34.029	33.902
TP19	-6.211	-32.468	-32.580	26.257	26.369	26.270
TP22	-5.749	-32.470	-32.583	26.721	26.834	26.735
TP24	-5.943	-32.471	-32.584	26.528	26.641	26.552
TP29	-10.580	-32.481	-32.594	21.903	22.016	21.912
TP30	-7.964	-32.481	-32.594	24.517	24.630	24.522
REMD	-5.536	-32.481	-32.594	26.945	27.058	26.965

Table #2. Differences between ellipsoid heights and leveled elevations for each baseline. (all measurements in meters)

Baseline	Δh	ΔH_{level}	$\Delta h - \Delta H_{level}$	Distance
REMD-TP30	2.428	2.443	0.015	69.19
REMD-TP29	5.042	5.053	0.011	145.06
REMD-TP24	0.407	0.413	0.006	468.02
REMD-TP22	0.213	0.230	0.017	607.19
REMD-TP19	0.675	0.695	0.020	866.48
REMD-TP11	6.993	6.937	0.056	1519.56
REMD-TP07	9.233	9.205	0.028	1846.34
REMD-GPS37	5.785	5.735	0.050	2437.29

Table #3. Differences between Geoid modeled elevations and leveled elevations for each baseline. (all measurements in meters)

Baseline	GEOID90 ΔH_{model}	GEOID90 $\Delta H_{model}-\Delta H_{level}$	GEOID93 ΔH_{model}	GEOID93 $\Delta H_{model}-\Delta H_{level}$
REMD-TP30	2.428	0.015	2.428	0.015
REMD-TP29	5.042	0.011	5.042	0.011
REMD-TP24	0.417	0.004	0.417	0.004
REMD-TP22	0.224	0.006	0.224	0.006
REMD-TP19	0.688	0.007	0.689	0.006
REMD-TP11	6.972	0.035	6.971	0.034
REMD-TP07	9.208	0.003	9.305	0.100
REMD-GPS37	5.756	0.021	5.755	0.020

SUMMARY AND CONCLUSIONS

The geoid modeled differences in the orthometric elevations do show an improvement over using the straight GPS ellipsoidal differences for the longer baselines. These differences are still up above 3 cm, which does not come close to third order leveling. However, if the orthometric elevations derived using GEOID90 were used for the level loop, third order leveling would be met. Using GEOID93 to determine orthometric elevations for leveling, would not meet the third order standard.

There is still more research that needs to be done in order to determine the best procedures for using GPS for determining orthometric elevations. The Surveying and Mapping work unit, Using GPS for Elevation Determination, will look into procedures and develop a guideline for this process during FY95.

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