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DETERMINATION OF LOCAL HEIGHT USING GLOBAL POSITIONING SYSTEM WITH LOW PRICE RECEIVERS

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ABSTRACT

This paper considers ability of replacing conventional method that uses leveling equipment and bar staff by using Global Positioning System (GPS) in establishing technical and IV class leveling networks in a very narrow area. These are two leveling classes that are widely used in the real projects. Surveyors can thus save time, reduce expense in production outside and still ensure the required accuracy. Methods: In this study, local heights will be calculated using 2008 Earth Gravitational Model (EGM 2008) combines with bilinear interpolation function or determined directly using GPS technique and will then be compared with local heights after adjustment using conventional geometrical leveling method. Geometrical leveling networks will be adjusted using specific software. Adjusted local heights are original heights to compare with those from other methods. The results of study are remarkable and prove that GPS technology can be applied as a major method to determine local heights and the Cm accuracy can be surely reached even using low price GPS receivers and common software in reality of works. Application: This method can be used to quickly determine local heights in reality and reduce considerably expense and time of work.

Key words: Local height, bilinear, interpolation, leveling network, Geoid Undulation, EGM

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1. INTRODUCTION

GPS technology has been widely used in Vietnam since 1996 but its major applications are for establishing plane control networks for different purposes such as building all national horizontal control networks (Class 0, I, II, III), horizontal control networks in engineering geodesy, in movement monitoring of large building or in surveying and mapping. It is obvious that GPS application in these sectors was acknowledged and detailed to “National regulation in measurement and processing GPS data in engineering geodesy” in 2012 whereas the application of GPS technology for local height determination is extremely limited. Two major causes are density of gravitational network and surveyors cannot access these data. In the real projects, leveling networks largely have two classes including IV and technical class. At the same time, they have the same position with plane control networks. This means that surveyors simultaneously have to use GPS for establishing plane networks and conventional geometrical leveling method for determination of local heights. As a result, time, expense can be doubled and consequence is a huge waste of technology.

Some researchers conducted different studies to determine local height using GPS technology with the highest accuracy. A geoidal map was established using “Satlevel” colocation method, Suffer Software, data from GNSS receivers and data of leveling network in a small part of Nigeria (Olaleye J. B et.al 2013). This geoidal map can be used to interpolate the undulation of a certain point and enhance the analysis of geological structures in the area. Three different interpolation techniques were used as a tool to model geoid in a local area. The main data are GPS/Leveling data and its role is served for practical applications in geodesy (Mahmoud El-Mewafi 2015). The Earth Gravitational Model 2008 was assessed the suitability on the entire of territory of Poland based on a network of 360 GPS/leveling sites. The results of the study indicated that this model is very accurate in comparison with existing geopotential models for the area of Poland (Z Adam Łyszkowicz 2009). A similar study but in a smaller area, EGM 2008 provides centimeter level of accuracy if it has enough gravity data (Robert Rosa et.al 2016). GPS technology was considered as a replacement of classical leveling method in some areas and different classes of leveling networks (Adam Łyszkowicz & A. Łyszkowicz 2002). In this study, author recommended GPS becoming a main method for determining normal heights in rural area. The undulation can be calculated for one point if it has both ellipsoidal and local height. The precision of this value depends on several factors including the number of the surveying points, distribution of surveying points, the used method and the accuracy of used instruments. Especially, in very small area, the Earth Gravity Model 2008 is the most precise model (Amal Mahdi Ali 2016). The difference of orthometric heights between GPS technology and conventional leveling technique is about 0.003m (Y. D. Opaluwa and Q. A. Adejare 2011). Although leveling technique has higher precision, EGM96 was highly recommended for transformation between orthometric and ellipsoidal heights.

The above studies have a common point is that they were conducted with a high density GPS/leveling network or a large number of gravitational points, and they were largely conducted in a vast area. GPS receivers are dual frequency with high accuracy, and GPS data were processed by very strong software. Therefore, results are considerable, local heights can be reached centimeter level of accuracy and meet some different purposes. However, in this study, local heights will be quickly determined by two methods and still meet required accuracy using low price, single frequency GPS receivers and very common software. At the same time, time and expense of the practical projects can be sharply reduced. In the first method, local heights will be determined by connecting directly benchmarks with leveling network. In the second measure, local heights will be determined using interpolation method and 2008 Earth Gravitational Model. In both cases, local heights gained from using directly GPS or interpolation method will be compared with local heights from conventional leveling method after adjustment.

2. MATERIALS AND METHODS

2.1. Study Areas

The data are collected from the actual projects in reality including two areas with different scale of leveling networks. In the first area, leveling network has two control points and three new points and area of this network is small. Two control points have coordinates and leveling heights in local coordinate and height system ***(Figure 1)***.

Figure 1 Location of network 1

where:

BT-03; BT-04: Control points provided by employer of project.

GPS1, GPS2, GPS3: New points

The different height and distance amongst control points and new points in this network are very small. This network aims to build a new factory in Ba Thien industrial zone in Vinh Phuc province.

In the second area, leveling network has three benchmarks and eleven new points. Positions of these points range in a long distance and follow a route. It is approximately 52km of leveling network. This network is severed for a new road in the future in Pleiku city, GiaLai province *(Figure 2).*

Figure 2 Location of network 2

where:

472421; 484409; 873463: Three national horizontal control points of this network

GPS1, GPS2, GPS11: New points

These three control points have coordinates in the national coordinate system but do not have local heights. The local heights of eleven new points are determined by connecting this network with three other benchmarks (not show in the figure 2).

In both areas, the local heights are determined using leveling method and have class IV level of accuracy based on Vietnamese standard ($f_h = \pm 20\sqrt{L(Km)}$).

2.2. Ellipsoidal, local heights and bilinear interpolation method

The heights gained from GPS technique refer to ellipsoid surface **(H)** and local heights are calculated from mean sea level **(h)**. The distance between two surfaces is the geoid height or the undulation. In order to determine local heights using GPS technology, geoid height (N) or the undulation (ζ) or subtraction $\Delta N(\Delta\zeta)$ at observed points need to be known. It can be written by following equation

$$\Delta h_{AB} = \Delta H_{AB} - \Delta\zeta_{AB} \qquad (1)$$

The heights between two surfaces are transformed together by equation.

$$\zeta_i = H_i - h_i \qquad (2)$$

Using X, Y coordinates in local coordinate system or WGS84 system, the undulation of each point can be written as follow.

$$\zeta_i = c + a.X_i + b.Y_i \qquad (3)$$

X, Y coordinates in a local coordinate system or can be replaced by coordinates in WGS system. These coordinates gained from GPS adjusted results.

To determine three parameters a, b, c the number of GPS/leveling points is at least three points. Is case of the number of GPS/leveling points is more than three, three these parameters will be calculated using the least square method.

$$v_i = c + a.X_i + b.Y_i - \zeta_i \qquad (4)$$

2.3. Methodology

Conventional geometrical leveling is the main method for determining local heights of all levels of national leveling networks in Vietnam. Therefore, they are original heights in this study. Local heights of three new points in the first network will be calculated by using directly local heights from GPS adjusted results after fixing local heights of two control points BT2-03 and BT2-04.

On the other hand, in the second network, local heights of eleven new points will be determined from three benchmarks for the first step. In the second step, the undulations of four collected points will be used to interpolate for the rest.

3. EXPERIMENT DESIGN

The following tables are the parameters of benchmarks and measured different height values of two leveling networks which are determined by a tight geometrical technique *(Table 1, 2, 3)*.

Table 1 Local Heights of Benchmarks Of Two Geometricle Leveling Networks

Order	Point's name	h(m)	Level of accuracy
1	BT2-03	27.788	Class IV
2	BT2-04	26.515	Class IV
3	I(DN-BMT)67	729.717	Class I
4	III(IAR-PLK)10	769.581	Class III
5	I(DN-BMT)74	813.536	Class I

Table 2 Parameters of the First Network

Order	First point	End point	dh(m)	Length of route (Km)
1	BT2-03	GPS1	-7.545	0.90
2	GPS1	GPS2	-1.491	0.45
3	GPS2	GPS3	-3.113	0.21
4	GPS3	BT2-04	10.871	1.65

Table 3 Parameters of the Second Network

Order	First point	End point	dh(m)	Length of route (Km)
1	I(DN-BMT)67	GPS01	-29.092	1.99
2	GPS01	GPS02	-1.747	4.43
3	GPS02	GPS03	13.737	3.56
4	GPS03	GPS04	-21.517	4.59
5	GPS04	GPS05	3.220	4.18
6	GPS05	GPS06	6.325	3.58
7	GPS06	III(IAR-PLK)10	68.993	3.32
8	III(IAR-PLK)10	GPS07	-28.383	2.75
9	GPS07	GPS08	-37.176	3.95
10	GPS08	GPS09	38.593	3.88
11	GPS09	GPS10	13.926	3.68
12	GPS10	GPS11	13.431	4.08
13	GPS11	I(DN-BMT)74	43.622	7.96

Using above data to adjust two networks and adjusted local heights will be used as the original heights for reference of local heights from GPS technique.

4. RESULTS AND ANALYSIS

Three new points GPS1, GPS2, GPS3 are connected to two benchmarks BT2-03; BT2-04 by following network *(Figure 3)*.

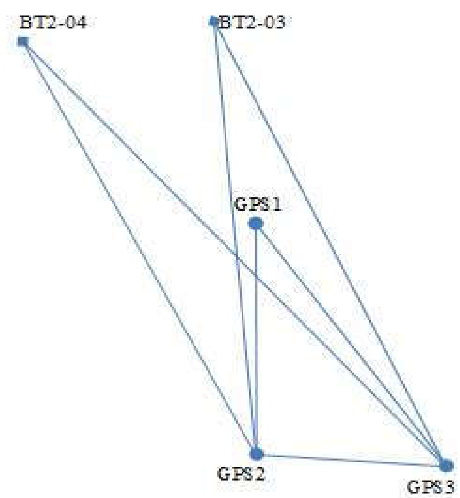

Figure 3 GPS network 1

By simultaneously fixing coordinates and local heights of two points BT2-03; BT2-04 in the process of GPS network adjustment, local heights of three points (GPS1, GPS2, GPS3) are shown in *column 3*. EGM2008 was used in the process of GPS adjustment. At the same time, using specific software to adjust conventional geometrical leveling network, adjusted heights are in *column 4 (Table 4)*.

Table 4 Local Heights from Two Methods

Order	Point's name	h_1 (m)	h_2 (m)	Deviation (m)
1	GPS1	20.244	20.244	0.000
2	GPS2	18.747	18.754	-0.007
3	GPS3	15.640	15.641	-0.001

In the second network, the eleven GPS points do not connect with any benchmarks. Their local heights are determined using geometrical leveling technique. In the other word, their coordinates and ellipsoidal heights are adjusted in WGS84 coordinate system. They are all shown in *(Table 5)*.

Table 5 WGS84 Coordinates of the Second Network

Order	Point's name	X	Y
1	GPS01	1563556.769	818559.529
2	GPS02	1560432.230	817182.011
3	GPS03	1557737.850	816665.960
4	GPS04	1554352.846	815644.245
5	GPS05	1551135.830	815536.183
6	GPS06	1548445.148	816128.111
7	GPS07	1546286.916	817016.611
8	GPS08	1543806.386	818774.989
9	GPS09	1541404.819	820549.573
10	GPS10	1538968.734	822002.193
11	GPS11	1535851.463	822441.997

Ellipsoidal, local heights and the undulations of the eleven points are in *(Table 6)*.

Table 6 The Undulations of the Eleven Points

Point's name	H	h	ζ (m)
GPS01	695.404	700.621	-5.217
GPS02	693.649	698.864	-5.215
GPS03	707.435	712.594	-5.159
GPS04	685.903	691.067	-5.164
GPS05	689.164	694.278	-5.114
GPS06	695.580	700.595	-5.015
GPS07	736.236	741.192	-4.956
GPS08	699.175	704.007	-4.832
GPS09	737.896	742.592	-4.696
GPS10	751.923	756.510	-4.587
GPS11	765.424	769.932	-4.508

Ellipsoidal and local heights of four collected points (GPS1, GPS4, GPS8, GPS11) are then used to interpolate the undulations of seven points using bilinear function. Local heights of these seven points are calculated based on their undulations. Three parameters C, a, b are calculated using the least square method and in (*Table 7)*.

Table 7 Three Paprameters C, a, b

C	a	b
-11.202173	-0.000019	0.000044

These three parameters combine with coordinates of seven points in WGS84 coordinate system to determine their undulations following equation 2. The undulations of these seven points are then compared with those from ellipsoidal and local heights *(Table 8)*.

Table 8 Deviations of the Undulations

Point's name	ζ Local undulations	ζ (interpolation)	Deviation
GPS02	-5.215	-5.217	0.002
GPS03	-5.159	-5.188	0.029
GPS05	-5.114	-5.110	-0.004
GPS06	-5.015	-5.032	0.017
GPS07	-4.956	-4.952	-0.004
GPS09	-4.696	-4.702	0.006
GPS10	-4.587	-4.590	0.003

The local heights of three GPS points (GPS1, GPS2, GPS3) which are calculated using GPS technique by fixing local heights of two benchmarks in the process of adjustment GPS network are very close to those which are determined using conventional geometrical technique combine with specific software. The deviations of the undulations of these three points are smaller than 1cm.

In term of time and expenses, GPS technique helps to save a half of working day and cut down the expenses of outside measurement geometrical leveling network and expenses of measuring equipment.

In term of level of accuracy, this leveling network has to meet class IV of accuracy and GPS technique totally gain.

In the second network, deviations of local heights between geometrical and interpolation method are from 2mm to 29mm. There are five points which have deviation are smaller than 7mm (71%) and two points which have deviations range from 17mm to 29mm. There is no specific reason for this but some factors such as accuracy of benchmarks, their distribution or even the accuracy of horizontal control points.

5. CONCLUSIONS

The experiment networks include small scale with distribution in plane surface and larger scale with distribution following a route and referring to the results of both, some outlines can be made.

GPS technique can be applied for determining local height. The gained results totally meet current geometrical leveling standards. In the process of GPS adjustment, EGM2008 should be used to transform ellipsoidal to local heights.

With the small scale network in a small area and have small different heights, local heights can be determined by connecting directly benchmarks with leveling network using GPS without geometrical technique.

One thing need to be impressed is that GPS receivers are low price and used software is very common. Local heights can be quickly calculated by surveyors in reality.

The accuracy of horizontal control points and benchmarks have not considered yet in this study. These factors and others such as distance from benchmarks to networks, the accuracy of benchmarks should be considered next study.

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