RESEARCH APPLICATION OF GNSS RTK CORS TECHNOLOGY IN THE ESTABLISHMENT OF VERTICAL CONTROL NETWORKS

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Abstract

The paper shows the theoretical and experimental application of GNSS RTK CORS technology in the establishment of vertical control networks. Result survey data of national vertical control networks measured using the leveling method in HaiPhong has reached accuracy m_H^{γ} =±3.7cm, equivalent to the fourth order national vertical control network by levelling method.

Keywords: *GNSS RTK CORS, leveling, VNGeoNet.*

1. Introduction

Elevation is one of the two critical components required to determine the position of a point. In the construction of coastal and riverside infrastructure, accurate elevation determination ensures precise design and construction, thereby avoiding flooding impacts from tides and storms. For inland waterway transportation, precise elevation data supports the creation of accurate hydrographic charts and nautical maps, which enhance navigation safety.

Traditionally, vertical control networks are established by geometric leveling, the most accurate technique. The State's first- and third-order benchmarks, established between 2003 and 2004, have been widely used. However, due to rapid socio-economic development, many benchmarks have been destroyed, displaced, or subsided, reducing their reliability. Consequently, leveling lines often exceed regulatory length limits, leading to accumulated errors, reduced accuracy, and greater labor requirements.

Currently, the Vietnamese Surveying and Mapping sector, in collaboration with several specialized agencies and enterprises, has established a substantial number of GNSS CORS stations for diverse applications, with the Hai Phong region in particular exhibiting a notably high station density (25-50 km per site). Accordingly, to provide a rigorous scientific basis for applying GNSS RTK CORS technology in the establishment of vertical control networks, it is essential to conduct systematic surveys and accuracy assessments of the leveling network measurements to be constructed.

2. Research Methodology

2.1. CORS Technology

A Continuously Operating Reference Station (CORS) is a GNSS station that continuously records satellite signals at fixed locations. The CORS technology emerged from the convergence of satellite positioning, information technology, and network technology. The fundamental components of a CORS system include: The reference station network, the master station (central control and processing unit), and the end users. An overview diagram of the GNSS CORS system is presented in Figure 1.

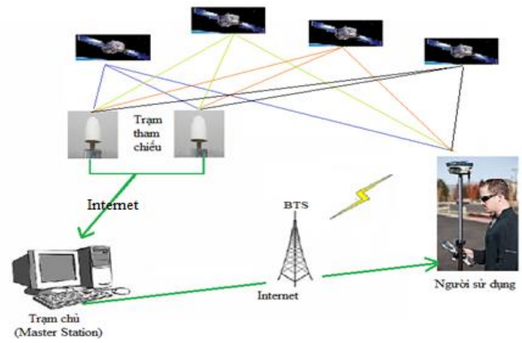

Figure 1. Schematic diagram of the GNSS CORS system

- Reference station: The reference station system consists of one or more multi-frequency GNSS receivers installed at stable and secure sites, away from potential sources of electromagnetic interference, continuously recording satellite signals and transmitting them to the master station in real time. The GNSS receivers must be capable of tracking at least 10 satellites at an elevation mask of approximately 5°, and of receiving signals at an interval of 1 second or less. The reference stations typically operate independently and are connected to the master station via the Internet. Depending on the application, the spacing between reference stations may range from 60-70 km to several hundred kilometers.

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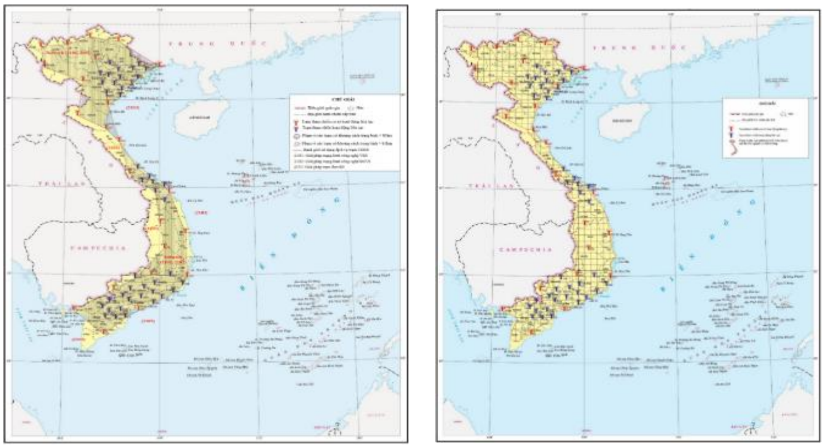

Figure 2. Diagram of the VNGeoNet network and the coverage of RTK measurement services [4]

Table 1. Accuracy of GNSS RTK CORS-based positioning services

Methods	Absolute horizontal accuracy		Absolute vertical accuracy	
	Areas k≤80km	Areas k>80km	Plain regions	Mountainous regions
VRS, MAX, iMAX	3cm ÷ 5cm	4cm ÷ 7cm	<10cm	< 17cm
Single Base (S ≤ 25km)	< 5 cm			

- Master station: Is responsible for processing, controlling, and storing information transmitted from the reference stations through the Internet. It consists of one or more servers that receive the data from the reference stations, process the incoming data to determine correction information at the reference stations, and subsequently transmit the processed correction data to the users.

- Users: The users can employ the GNSS CORS network to perform positioning surveys using either Real-Time Kinematic (RTK) methods or Post-Processed Kinematic (PPK) methods. In the real-time mode, when the master station receives observational data from the user's receiver, it computes and transmits correction values to the nearby reference stations, which are then applied directly to the user's positioning results.

2.2. The national satellite positioning stations network (VNGeoNet)

The national satellite positioning system (VNGeoNet) comprises 65 GNSS CORS stations, including 24 Geodetic CORS stations distributed nationwide with an average spacing of 150-200 km, and 41 NRTK CORS stations located in three regions: the Red River Delta and Thanh Hoa province; the Central and Central Highlands; and the Southern region, with an average spacing of 50-80 km [1]. Data from the 65 GNSS CORS stations are transmitted directly via the Internet to the Central Control and Processing Station in Hanoi, where they are processed and provided to users in real time.

The VNGeoNet network is established within the national coordinate system VN-2000 and the national height system. Reference points used for connecting the VNGeoNet network include national zero-order coordinates and International GNSS Service (IGS) stations within the region. In addition, all GNSS CORS stations are tied to national benchmarks with accuracy equivalent to class II or class III leveling standards.

The VNGeoNet network employs a QuasiGeoid model developed specifically for the Vietnamese territory and published by the Ministry of Natural Resources and Environment, which supports the determination of orthometric heights in real-time positioning and navigation services. The service coverage of GNSS RTK measurements and the spatial extent of the QuasiGeoid model within the VNGeoNet network are illustrated in Figure 2.

The application of GNSS CORS technology in engineering surveying—such as route surveys [11] and structural displacement monitoring [7, 8, 10, 12]—has demonstrated the outstanding advantages of GNSS CORS technology.

The accuracy of GNSS RTK services provided by the VNGeoNet network in determining the coordinates and height of any given point is presented in the Table 1 [4].

2.3. GNSS Height Theory

Orthometric height is determined as follows [6, 9]:

$$H^{\gamma} = H - N \tag{1}$$

Where,

H^{γ}: Orthometric height;

H: Geodetic height (GNSS height);

N: Is the geoid undulation from the QuasiGeoid model.

Thus, when performing GNSS RTK measurements using the VNGeoNet within the coverage area of the QuasiGeoid model developed by the Ministry of Natural Resources and Environment, orthometric heights can be determined. From equation (1), according to error theory, we have:

$$m_{H^{\gamma}}^2 = m_H^2 + m_{\zeta}^2 \tag{2}$$

Based on the principle of equal influence, we obtain:

$$m_H = m_{\zeta} = \frac{m_{H^{\gamma}}}{\sqrt{2}} \tag{3}$$

If the accuracy requirement for height determination using GNSS technology is to be equivalent to that of spirit leveling, the following condition must be satisfied:

$$m_{H^{\gamma}} \le \mu\sqrt{L} \tag{4}$$

Where: μ is the mean square error (in millimeters) per kilometer of leveling, and L (in kilometers) is the leveling distance between the two considered points.

Substituting (4) into (3), we obtain:

$$m_H = m_{\zeta} \le \mu\sqrt{\frac{L}{2}} = \frac{\mu}{\sqrt{2}}\sqrt{L} = \mu_o\sqrt{L} \tag{5}$$

In the GNSS leveling method using CORS technology, L represents the distance from the CORS station to the point whose height is to be determined. For each class of spirit leveling, regulatory standards specify particular values of μ; based on equation (5), the corresponding mean square error μ_o in GNSS leveling can be derived, as presented in Table 2.

3. Results and Discussion

To evaluate the applicability of GNSS RTK CORS technology in establishing vertical control networks, the research team conducted field experiments at national leveling benchmarks in the Hai Phong area. Among the 35 national benchmarks in Hai Phong (Figure 3) surveyed and inspected by the team, only 10 benchmarks remained usable, while 25 benchmarks had been destroyed due to house construction, road building, embankment works, and similar activities. The research team employed the national satellite positioning system VNGeoNet (DSON station) to perform GNSS CORS RTK measurements at the 10 benchmarks using a CHC M5 GNSS receiver, with observation durations of 5 seconds and 60 seconds at each point and a signal logging rate of 1 second.

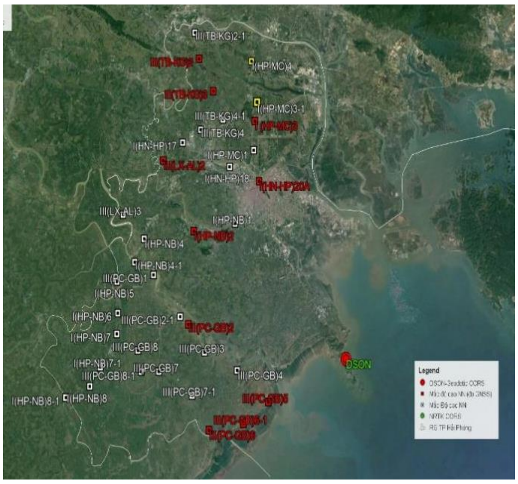

Figure 3. Diagram of national leveling benchmarks in the Hai Phong area

Measurement results are presented in Table 3;

From the results in Table 3, the coordinate and height differences between the two measurement approaches were computed:

Table 2. The mean square error per kilometer of the height

No.	Levelling Order	μ (mm)		μ₀ (mm)	
		Plain regions	Mountainous regions	Plain regions	Mountainous regions
1	Order I	2	3	1.4	2.1
2	Order II	4	5	2.8	3.5
3	Order III	10	12	7.1	8.5
4	Order IV	20	25	14.1	17.7
5	Technical	50	75	35.4	53.0

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$$\Delta N = N_1 - N_2\ ; \quad \Delta E\ E_1 - E_2\ ; \quad \Delta H^{\gamma} = H_1^{\gamma} - H_2^{\gamma} \qquad (6)$$

These results are presented in Table 4.

From the results in Table 3, the height differences were computed between GNSS RTK CORS measurements using the VNGeoNet national network and the known orthometric heights of the benchmarks. The benchmark elevations were provided by the Center for Surveying and Mapping Data Information (Department of Surveying, Mapping and Geographic Information of Vietnam) and the Department of Natural Resources and Environment of Hai Phong City. The results are presented in Table 5.

Remarks: Among the 10 points measured and verified, 8 points exhibited height differences within the permissible limits, while 2 points showed

Table 4. Comparison of the two measurement approaches

No.	Benchmark	ΔN(mm)	ΔE(mm)	ΔH^{γ}(mm)
1	I (HP-MC)3	3	4	-5
2	III(TB-KG)3	5	3	16
3	III(TB-KG)2	4	-2	15
4	III(LX-AL)2	2	3	10
5	I(HP-NB)2	-6	-7	23
6	III(PC-GB)2	3	-11	-2
7	III(PC-GB)5	5	-4	3
8	III(PC-GB)6-1	-4	0	-8
9	III(PC-GB)6	-2	-1	-2
10	I(HN-HP)20A	-6	-17	12

Table 3. GNSS RTK CORS measurement results at national benchmarks in the Hai Phong area

Benchmark	Method 1: 5-second observation						Method 2: 60-second observation					
	N_1 (m)	E_1 (m)	H_1^{γ} (m)	m_N(m)	m_E(m)	m_H(m)	N_2 (m)	E_2 (m)	H_2^{γ} (m)	m_N(m)	m_E(m)	m_H(m)
I (HP-MC)3	2314405.129	596257.473	4.606	0.003	0.005	0.012	2314405.126	596257.469	4.611	0.003	0.005	0.012
III(TB-KG)3	2317626.180	590458.073	1.031	0.003	0.003	0.011	2317626.175	590458.070	1.015	0.003	0.003	0.011
III(TB-KG)2	2321153.811	588421.454	1.656	0.005	0.003	0.010	2321153.807	588421.456	1.641	0.004	0.003	0.010
III(LX-AL)2	2310082.415	583659.653	1.640	0.003	0.004	0.008	2310082.413	583659.650	1.630	0.003	0.004	0.008
I(HP-NB)2	2302639.795	588026.918	1.765	0.007	0.005	0.019	2302639.801	588026.925	1.742	0.007	0.005	0.019
III(PC-GB)2	2292931.820	587455.365	1.372	0.003	0.003	0.008	2292931.817	587455.376	1.374	0.003	0.002	0.007
III(PC-GB)5	2285104.438	598285.110	2.324	0.003	0.002	0.010	2285104.433	598285.114	2.321	0.003	0.002	0.008
III(PC-GB)6-1	2282905.352	594986.715	4.716	0.003	0.003	0.008	2282905.356	594986.715	4.724	0.002	0.002	0.007
III(PC-GB)6	2282221.807	590416.936	4.146	0.003	0.002	0.007	2282221.809	590416.936	4.148	0.003	0.002	0.006
I(HN-HP)20A	2307950.580	596893.720	2.107	0.004	0.004	0.013	2307950.586	596893.738	2.095	0.003	0.003	0.012

Table 5. Results of height comparison between GNSS CORS RTK technology and spirit leveling

No	Benchmark	Levelling Order	National height H (m)	Measured height (m)		Height difference		Distance	Limited error (mm)		
				H_1^{γ}	H_2^{γ}	DH_1^{g} (mm)	DH_2^{g} (mm)	L(km)	Order III	Order IV	Technical
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1	I (HP-MC)3	Order I	4.616	4.606	4.611	10	5	28.837	38.1	75.7	190.1
2	III(TB-KG)3	Order III	0.985	1.031	1.015	-46	-30	34.519	41.7	82.8	208.0
3	III(TB-KG)2	Order III	1.612	1.656	1.641	-44	-29	37.587	43.5	86.4	217.0
4	III(LX-AL)2	Order III	1.596	1.640	1.630	-44	-34	33.397	41.0	81.5	204.6
5	I(HP-NB)2	Order I	1.71	1.765	1.742	-55	-32	25.473	35.8	71.2	178.7
6	III(PC-GB)2	Order III	2.169	1.372	1.374	797	795	22.486	33.7	66.9	167.9
7	III(PC-GB)5	Order III	2.428	2.324	2.321	104	107	15.564	28.0	55.6	139.7
8	III(PC-GB)6-1	Order III	4.748	4.716	4.724	32	24	18.175	30.3	60.1	150.9
9	III(PC-GB)6	Order III	4.168	4.146	4.148	22	20	20.637	32.3	64.1	160.8
10	I(HN-HP)20A	Order I	2.083	2.107	2.095	-24	-12	22.889	34.0	67.5	169.4

significantly larger discrepancies compared with the official national heights, namely: point III(PC-GB)2 with a deviation of 79.5cm, and point III(PC-GB)5 with a deviation of 10.7cm. The primary reason is that point III(PC-GB)2 is located on weak ground outside the dyke, approximately 70m from the dyke and 100m from the Van Uc River, in an area surrounded by sand and stone construction material yards. Meanwhile, point III(PC-GB)5 is situated on the edge of a narrow 2m wide dirt road adjacent to the riverbank, causing both points to suffer from subsidence. After eliminating points III(PC-GB)2 and III(PC-GB)5 from the dataset, and considering the national benchmark heights as the reference, the accuracy of height determination was evaluated using the formula for the mean square error of the actual error according to Gauss.

$$m_{H_1^Y} = \pm\sqrt{\frac{[\Delta H_1^Y.\Delta H_1^Y]}{n}} = \pm\sqrt{\frac{11197}{8}} = \pm 37(mm)$$

$$m_{H_2^Y} = \pm\sqrt{\frac{[\Delta H_2^Y.\Delta H_2^Y]}{n}} = \pm\sqrt{\frac{5066}{8}} = \pm 25(mm)$$

Based on the accuracy evaluation results above, compared with the allowable leveling errors corresponding to columns (10), (11), and (12) in Table 5, it can be seen that GNSS CORS RTK leveling meets the accuracy requirements for establishing Class IV vertical control networks and technical spirit leveling. The differences in coordinates and orthometric heights between GNSS CORS RTK measurements with 5-second and 60-second observation times are minimal. However, the orthometric height accuracy achieved with a 60-second observation time is higher than that with a 5-second observation time.

3. Conclusion

It is entirely feasible to establish Class IV vertical control networks using GNSS CORS RTK technology as a replacement for conventional spirit leveling. For network measurements, the recommended configuration is a logging rate of 1 Hz with a 60-second observation time. The experimental results presented in this paper satisfy the accuracy requirements of Class IV networks. To obtain more objective and comprehensive conclusions, further investigations should be conducted over a wider area or in additional provinces.

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