Journal of the Korean Society for Geospatial Information Science
Vol.24 No.2 June 2016 pp.47-54
ISSN: 1598-2955 (Print)
ISSN: 2287-6693(Online)
http://dx.doi.org/10.7319/kogsis.2016.24.2.047

Research Paper

Feasibility Study of Network-RTK(VRS) Surveying Inside and Outside of Korean CORS Network

Kim, Kwang Bae*† · Du, Chenghao† · Lee, Chang Kyung*****

Abstract

This study aims to analyze the accuracy for feasibility study of Network-RTK(VRS) surveying inside and outside of Korean CORS network. The southwest coast of Korea where some part of mainland and islands are outside of CORS network is chosen as the test area. To evaluate the accuracy of VRS surveying at surveying points, several Unified Control Points (UCPs) inside and outside of Korean CORS network were selected as the points in the test area. The feasibility of VRS surveying was analyzed by investigating the errors related to the location of points inside and outside of CORS network and the difference of 3-dimensional coordinates observed on different date. As the results of this study, the orthometric height errors of points outside of CORS network based on KNGeoid14 were improved about 5.0 cm in RMSE in comparison with KNGeoid13. The height errors of VRS surveying were considered to be less relevant to the results from PDOP and number of satellites (GPS and GLONASS). However, the orthometric errors caused by the geoidal height of KNGeoid and the ellipsoidal height of VRS surveying at points located outside of CORS network need to be addressed carefully for control surveying. When a point surveyed twice on different date, the difference of the ellipsoidal height of the point outside of CORS network was larger than that of the point inside of CORS network.

Keywords : Network-RTK(VRS), Korean CORS Network, Unified Control Point, Orthometric Height, KNGeoid13, KNGeoid14

1. Introduction

Since the mid-1990s, Virtual Reference Station (VRS) system has suggested the optimal means of processing reference receiver data and then provided corrected information to users in real-time. The distance of two continuously operating reference stations (CORSs) is less than 70 km in most countries and regions, and the precision of Network-RTK would be in an acceptable range within 35 km in baseline (El-Mowafy, 2012). VRS is currently one of the widely accepted methods of Network-RTK technology.

In Korea, National Geographic Information Institute (NGII) installed CORS Network with 59 CORSs, and has serviced Network-RTK(VRS) since 2007. These CORSs cover almost whole area of Korea. As many other coastal countries, there are many islands off mainland along coastline. The current CORS network can not completely cover all parts of the coast, and so some VRS surveying along the coast may be conducted outside of the network. The positioning accuracy of VRS inside of CORS network within a baseline of 70 km was comparable to that of the RTK (Kim et al., 2008).

For the past few years, different approaches have been tested to evaluate the availability and reliability of VRS. An analysis of test data in a VRS network in southern Germany shows that a horizontal positioning accuracy in the level of ±5 cm can be achieved for baselines with a length up to 35 km (Retscher, 2002). Another study about accuracy of VRS network in Dubai gives a result of a 1 ~ 5 cm level accuracy that proves system reliability (El-Mowafy et al., 2003).

Received: 2016.05.20, revised: 2016.06.21, accepted: 2016.06.29
* Member · Ph.D., Dept. of Civil and Environmental Engineering, Sungkyunkwan University, kbkim929@gmail.com
** MSc, Dept. of Civil Engineering, Kunsan National University, duchenghao0220@163.com
*** Corresponding Author · Member · Professor, Dept. of Civil Engineering, Kunsan National University, leeck@kunsan.ac.kr
† The first two authors (Kim, Kwang Bae and Du, Chenghao) contributed equally as co-first author to this paper.

There were several studies to deal with the accuracy of VRS surveying inside of CORS network. UCPs inside of CORS network were measured with Network-RTK (VRS) system and ordinary Real-Time Kinematic (RTK), and compared with Official Coordinates Record (OCR) of the UCPs (Kim et al., 2008). The horizontal accuracy by VRS and ordinary RTK was 3.1 and 2.0 cm, respectively, implying that the accuracy of VRS surveying is comparable to that of ordinary RTK surveying. Han et al.(2010) analyzed VRS data obtained from several VRS receivers such as Trimble, Magellan, Leica and Topcon, and showed that the standard deviations of the VRS surveying were less than 3 cm. Therefore, they suggested VRS surveying could be used to public control point surveying. Lee(2013) measured 1st and 2nd benchmarks by VRS surveying to evaluate the accuracy of the height. The average errors of heights on the 1st and 2nd benchmarks were 2.15 and 1.80 cm, respectively. Network-RTK(VRS) surveying for applying to Ground Control Points (GCPs) survey to investigate long-term shoreline changes was implemented (Kim et al., 2014). The root mean squares error (RMSE) of differences between Network-RTK(VRS) and Static GNSS surveys were ±2.0 cm in plane and ±7.0 cm in height, respectively. Song(2015) assessed height accuracy of VRS survey using national geoid model developed recently in plain, mountainous, and island areas.

The previous researches have been performed all about accuracy and applications of VRS surveying inside of CORS network. They showed that the accuracy of VRS surveying inside of CORS network with a baseline less than 100 km is reasonable. This study deals with the accuracy for feasibility study of VRS surveying inside and outside of Korean CORS network. Especially, the southwest coast of Korea where points of some part of mainland and islands are located outside of CORS network was chosen for the test area.

To evaluate the accuracy of VRS surveying at a point, the accurate coordinates of the points are needed. NGII determined the plane coordinate and orthometric height at UCPs by Static GNSS survey and differential levelling, respectively, and is servicing the OCR of UCPs by NGII. The feasibility of VRS surveying was evaluated by investigating the errors related to the location of points inside and outside of Korean CORS network and the difference 3-dimensional coordinates observed on different date of VRS surveying.

2. Network-RTK(VRS) Surveying in Korea

NGII established CORSs that currently cover the whole South Korea and has provided Network-RTK(VRS) service since 2007. VRS service started with a total of 14 CORSs in 2007. In April 2008, 30 CORSs of Ministry of Government Administration and Home Affairs were integrated with existing 14 CORSs of NGII. In addition, 15 CORSs were added into the network by May 2016. Currently, 1000 users can simultaneously use VRS surveying.

In order to ensure the reliability of VRS surveying, repetitive measurement procedures are established by NGII (NGII, 2013b). The work regulations of VRS surveying are shown as following:

- Each point is measured three times with VRS receiver.
- Epoch rate of each session must be longer than 10 seconds.
- The PDOP of each surveying has to be controlled less than 3.
- After a measurement is completed, the VRS receiver should be re-initialized at some place where 30 m in minimum is away from the surveying point.
- The difference of plane coordinate of surveying point between the sessions should be controlled less than 5 cm.
- The difference of height of surveying point between the sessions should be controlled less than 10 cm.

3. Field Testing

3.1 Planning

The test area of this study includes a part of

Jeollabuk-do and Jeollanam-do in south-western Korea. In this area, eight CORSs (EOOH, KUSN, NONS, JUNJ, JUNG, YONK, JIND, and JAHG, denoted as black triangle in Fig. 1) compose six triangular networks as shown in Fig. 1. Since some of UCPs in the test area does not have orthometric height, 24 UCPs (denoted as black dot in Fig. 1) are chosen as test points. Among them, 20 UCPs are located inside of triangular networks and 4 UCPs (U1003, U1130, U1131, and U1132) are located outside of triangular networks.

The longest baseline between CORSs is about 186.2 km between EOCH and JIND. All baselines except the longest one are shorter than 110 km. It is roughly satisfied the requirement mentioned by El-Mowafy (2012).

Trimble R8 with TSC2 Controller and Topcon HiPer II with FC-250 Field Controller were used for VRS surveying in the test area. The Trimble R8 communicates with the control center via portable WiFi hotspot of cell phone 4G network. On the other hand, Topcon HiPer II transmits data with the control center via cellular phone technology. All of them require good cellular coverage in the test area. Since

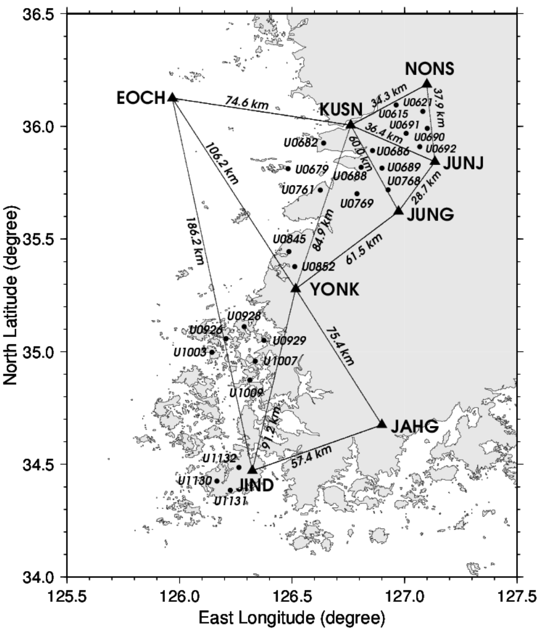

Figure 1. Location of UCPs and CORSs in the test area

the communication system in Korea is comprehensive, both communication modes give a perfect performance during the test. Trimble R8 can track satellites of GPS, GLONASS, Galileo, BeiDou (COMPASS), and Quasi-Zenith Satellite System (QZSS) (Trimble, 2014). Topcon HiPer II can receive signals from GPS, GLONASS, and Satellite-Based Augmentation System (SBAS) including Wide Area Augmentation System (WAAS), European Geostationary Navigation Overlay Service (EGNOS) and Multi-Functional Satellite Augmentation System (MSAS) (Topcon, 2012).

3.2 Observation

For field testing of VRS surveying, two items of the work regulations of VRS surveying of NGII were strengthened to get more precise observation. The modified procedures are as follows:

- Each point is measured four times with two VRS receivers.
- Epoch rate of each session is 30 seconds.

VRS receivers used in Korea are similar in functions, but different in capability, performance, and precision. In this study, two types of VRS receivers, Trimble R8 and Topcon HiPer II, were used. VRS surveying at 24 UCPs was carried out on 4 days (April 11, 12, 19, and May 2) as shown in Table 1. Four sets of 3-dimensional coordinates were determined by each VRS receiver, therefore, eight sets of 3-dimensional coordinates were prepared at each UCP. The 4th column (Time) in Table 1 indicates total measurement time for conducting 4 sessions, which includes observation time of 30 seconds in each session and re-initialization time at some place where 30 m in minimum is away from the surveying point after completing each session. VRS surveying took almost 20 minutes on average during 4 sessions at each UCP. Among them, 6 UCPs were observed two times on different date to check variations depending on observation date. Exceptionally, Topcon VRS receiver was failed to fix ambiguity integer at U1132 located outside of CORS network.

The plane coordinates and ellipsoidal height of

Table 1. Observation Campaign in 2014 at UCPs (TRM: Trimble, TPS: Topcon)

Point	Location	Date	Time	Receiver Used
U0929	Inside	Apr. 11	09:12 - 09:29	TRM, TPS
U0928	Inside		09:55 - 10:14	TRM, TPS
U0926	Inside		10:42 - 11:00	TRM, TPS
U1003	Outside	Apr. 11	11:55 - 12:15	TRM, TPS
		Apr. 19	18:40 - 19:00	
U0852	Inside	Apr. 11	15:10 - 15:25	TRM, TPS
U0845	Inside		16:00 - 16:20	TRM, TPS
U0761	Inside		17:30 - 17:52	TRM, TPS
U0679	Inside		18:22 - 18:40	TRM, TPS
U0682	Inside		19:20 - 19:30	TRM, TPS
U0686	Inside	Apr. 12	08:50 - 09:17 18:20 - 18:35	TRM TPS
		May 2	08:46 - 09:01	TRM
U0688	Inside	Apr. 12	09:42 - 10:10 17:54 - 18:04	TRM TPS
		May 2	09:19 - 09:37	TRM
U0769	Inside	Apr. 12	10:45 - 10:58	TRM, TPS
		May 2	09:59 - 10:18	TRM
U0768	Inside	Apr. 12	11:22 - 11:43	TRM, TPS
		May 2	10:30 - 10:55	TRM
U0689	Inside	Apr. 12	12:57 - 13:15	TRM, TPS
		May 2	11:30 - 11:46	TRM
U0692	Inside	Apr. 12	13:55 - 14:07	TRM, TPS
U0691	Inside		14:30 - 14:44	TRM, TPS
U0690	Inside		15:13 - 15:27	TRM, TPS
U0621	Inside		15:54 - 16:07	TRM, TPS
U0615	Inside		16:50 - 17:09	TRM, TPS
U1131	Outside	Apr. 19	10:00 - 10:20	TRM, TPS
U1130	Outside		10:40 - 11:02	TRM, TPS
U1132	Outside		11:30 - 12:20	TRM
U1009	Inside		15:30 - 15:50	TRM, TPS
U1007	Inside		16:30 - 16:55	TRM, TPS

UCPs were determined by averaging the four coordinates obtained from VRS surveying at UCPs. The plane coordinates based on Transverse Mercator (TM) coordinates and the ellipsoidal height of each UCPs were obtained from VRS surveying. The orthometric height was calculated by subtracting the geoidal height from the ellipsoidal height.

4. Accuracy Analysis of VRS Surveying

4.1 Error Related to the Location of Points Inside and Outside of CORS Network

In this study, the errors were computed by subtracting the plane (N and E) coordinates, ellipsoidal height (h), and orthometric height (H) of OCR from the coordinates surveyed by VRS at each UCP. The plane coordinates and ellipsoidal heights are directly compared with the OCR of UCPs, but the ellipsoidal height were converted into orthometric height. The orthometric height is computed by subtracting geoidal height from ellipsoidal height. Here, two types of geoidal heights were used; the first is given in the OCR of UCPs and the second is derived from geoid models: KNGeoid13 (NGII, 2014a) and KNGeoid14 (NGII, 2015).

Figs. 2, 3, 4 and 5 show the errors of plane coordinates, ellipsodial heights, and orthometric heights based on geoidal heights of the OCR, KNgeoid13, and KNGeoid14 from Trimble R8 and Topcon HiPer II. The y-axis in Figs. 2 and 4 indicates the errors of plane coordinates and ellipsodial height. The y-axis in Figs. 3 and 5 shows the errors of orthometric height. The date on the x-axis in Figs. 2, 3, 4 and 5 indicates that VRS surveying was performed at UCPs.

As shown in Figs. 2 and 4, the maximum errors of the plane coordinate are 3.2 cm at U1007 located inside of CORS network in Fig. 2 and 3.5 cm at

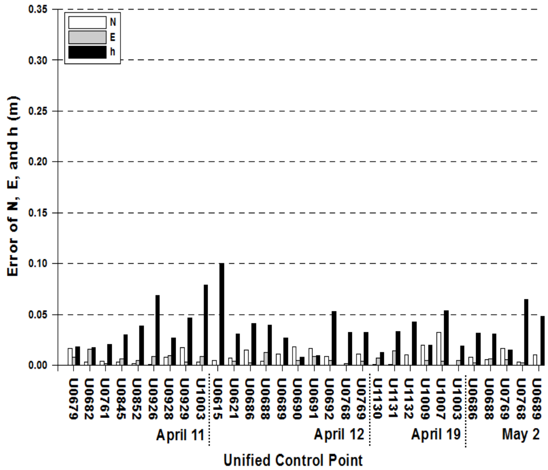

Figure 2. The errors of plane (N and E) coordinates and ellipsoidal height (h) from Trimble R8

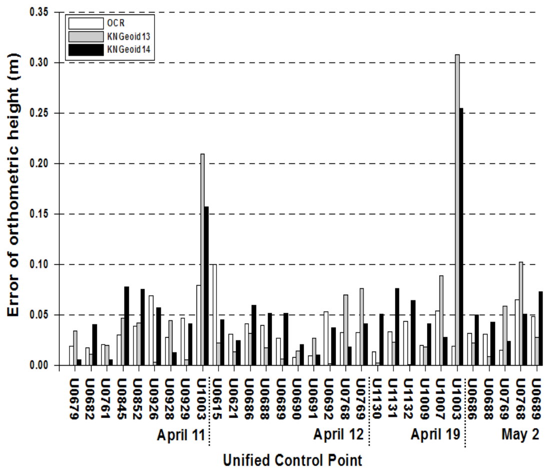

Figure 3. The errors of orthometric heights based on geoidal heights of the OCR, KNGeoid13, and KNGeoid14 from Trimble R8

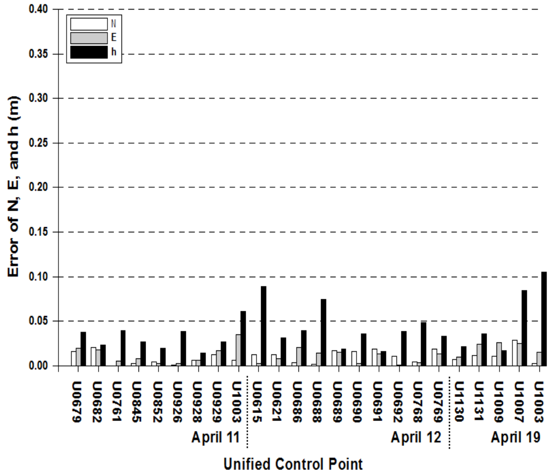

Figure 4. The errors of plane (N and E) coordinates and ellipsoidal height (h) from Topcon HiPer II

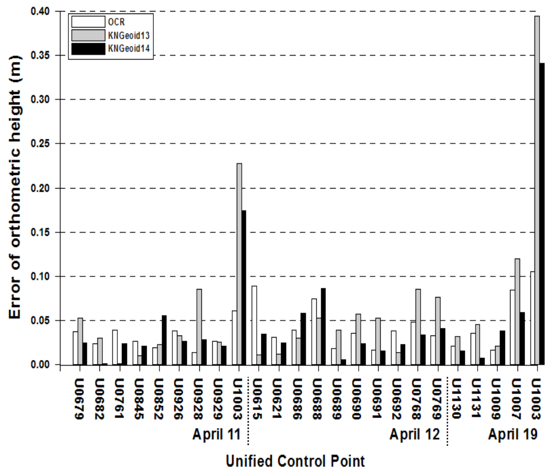

Figure 5. The errors of orthometric heights based on geoidal heights of the OCR, KNGeoid13, and KNGeoid14 from Topcon HiPer II

U1003 located outside of CORS network in Fig. 4, respectively. In other words, the errors of plane coordinates at UCPs located inside of CORS network are similar to those at UCPs outside of CORS network. The errors of the ellipsoidal height are 10.0 cm inside of CORS network and 10.5 cm outside of CORS network, respectively.

The statistics of the errors (Figs. 2, 3, 4 and 5) computed in 24 UCPs inside and outside of CORS

Table 2. The statistics of the errors of Network-RTK (Trimble R8)

Component	Min (m)		Max (m)		Mean (m)		RMSE (m)	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
N	0.000	0.000	0.032	0.011	0.010	0.003	0.012	0.004
E	0.000	0.000	0.016	0.014	0.005	0.007	0.006	0.005
h	0.008	0.013	0.100	0.079	0.036	0.037	0.041	0.023
H_{OCR}	0.008	0.013	0.100	0.079	0.036	0.037	0.041	0.023
$H_{KNGeoid13}$	0.001	0.001	0.103	0.308	0.032	0.109	0.042	0.127
$H_{KNGeoid14}$	0.005	0.005	0.078	0.255	0.039	0.120	0.044	0.077

Table 3. The statistics of the errors of Network-RTK (Topcon HiPer II)

Component	Min (m)		Max (m)		Mean (m)		RMSE (m)	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
N	0.000	0.002	0.028	0.012	0.011	0.007	0.013	0.003
E	0.001	0.009	0.026	0.035	0.011	0.021	0.014	0.010
h	0.014	0.021	0.089	0.105	0.038	0.056	0.043	0.032
H_{OCR}	0.014	0.021	0.089	0.105	0.038	0.056	0.043	0.032
$H_{KNGeoid13}$	0.001	0.032	0.120	0.394	0.041	0.175	0.051	0.148
$H_{KNGeoid14}$	0.001	0.008	0.086	0.341	0.032	0.135	0.038	0.136

network by Trimble and Topcon are summarized in Tables 2 and 3. The statistics of the error of ellipsoidal height and the error of orthometric height computed from geoidal height of OCR by NGII are same because Eq. (1) is equal to Eq. (2):

$$dh = h - h_{OCR} \quad (1)$$

$$dH_{OCR} = (h - N_{OCR}) - (h_{OCR} - N_{OCR}) \quad (2)$$

where dh is the error of ellipsoidal height; h is ellipsoidal height measured by VRS surveying; h_{OCR} is the ellipsoidal height from OCR by NGII; dH_{OCR} is the error of orthometric height computed from geoidal height based on OCR; and N_{OCR} is geoidal height from OCR by NGII.

The orthometric height errors of VRS surveying at 20 UCPs inside of CORS network are less than 12.0 cm. The errors of orthometric height based on geoidal height of the OCR at 4 UCPs (U1003, U1130, U1131, and U1132) outside of CORS network are less than 11.0 cm. On the other hand, the errors of orthometric height based on the geoidal height of KNGeoid13 at U1003 outside of CORS network reach to 39.4 cm as shown in Fig. 5. However, when adopting the geoidal height of KNGeoid14 at same point, the maximum error of orthometric height was decreased to 34.1 cm in Table 3. As shown in Tables 2 and 3, RMSE of 5.0 cm and 1.2 cm outside of CORS network was improved in Trimble R8 and Topcon HiPer II, respectively, when KNGeoid14 was used instead of KNGeoid13. These results may indicate that the orthometric height errors outside of CORS network based on KNGeoid14 (NGII, 2014b) generated using land and marine gravity data has better results than those based on KNGeoid13 (NGII, 2013a) yielded from only land gravity data.

Fig. 6 shows PDOP (Position Dilution of Precision) and the number of satellites (GPS and GLONASS) on average obtained from four measurements at 24 UCPs with Topcon HiPer II. The statistics of PDOP, number of GPS satellites, and number of GLONASS satellites of Fig. 6 were summarized in Table 4. According to Table 4, PDOP shows healthy geometric condition because there is ranged below 3.0 at 24 UCPs. In addition, satellites used in VRS surveying are 6.8 and 5.2 on average for GPS and GLONASS, respectively. These results may indicate that the large orthometric height errors based on KNGeoid at U1003 in Fig. 5 were considered to be less relevant to the results from PDOP and number of satellites (GPS and GLONASS) as shown in Fig. 6.

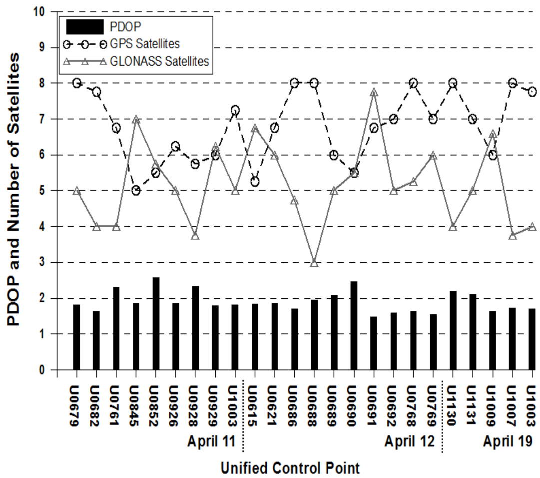

Figure 6. PDOP and the number of satellites (GPS and GLONASS) on average observed by Topcon HiPer II

Table 4. The statistics of PDOP, the number of GPS satellites, and the number of GLONASS satellites observed by Network-RTK (Topcon HiPer II) at 24 UCPs

	Min	Max	Mean
PDOP	1.5	2.6	1.9
GPS satellites	5.0	8.0	6.8
GLONASS satellites	3.0	7.8	5.2

4.2 Difference of 3-Dimensional Coordinates Observed on Different Date

Difference of plane coordinates and ellipsoidal heights observed on different date by VRS surveying was analyzed at 6 UCPs. In Fig. 7, the differences of plane coordinates(N and E) at 6 UCPs observed on different date (5 UCPs inside of CORS network: April 12 and May 2, 1 UCP outside of CORS network: April 11 and April 19) are less than 1.3 cm. The differences of ellipsoidal height at points inside of CORS network observed on different date (April 12 and May 2) are less than 3.3 cm in Fig. 7. In case of a point (U1003) outside of CORS network observed on April 11 and April 19, the difference of ellipsoidal height is 9.8 cm. The difference of the

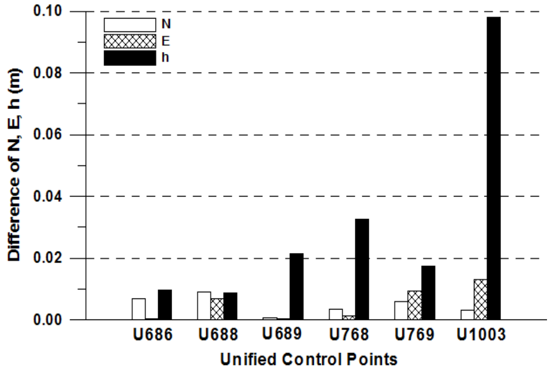

Figure 7. The differences of plane (N and E) coordinates and ellipsoidal height (h) observed on different date

ellipsoidal height of the point outside of CORS network observed on different date is about three times larger than that of the point inside of CORS network. Therefore, stable observation of ellipsoidal height by VRS surveying is necessary to keep the accuracy of orthometric height at a surveying point inside and outside of CORS network.

5. Conclusion

This study analyzed the accuracy for feasibility study of VRS surveying at points inside and outside of Korean CORS network measured by two models of VRS receivers. The following conclusions are presented as the results of this study.

1. The errors of plane coordinates and ellipsoidal heights at UCPs located inside of CORS network are similar to those at UCPs outside of CORS network. When the orthometric height are calculated from the geoidal height of the OCR, the errors of orthometric height at points inside of CORS network are similar to those at points outside of CORS network. When the orthometric height are computed from the geoidal height of KNGeoid13 and KNGeoid14, the errors of orthometric height at points outside of CORS network reach to about 15.0 cm in RMSE. However, orthometric height error based on KNGeoid14 outside of CORS network was improved about 5.0 cm in RMSE in comparison with that based on KNGeoid13.

2. When implementing VRS surveying twice on

different date with same VRS receiver, the differences of plane coordinate and ellipsoidal height inside of CORS network are smaller than 1.0 cm and 3.3 cm, respectively. Stable observation of ellipsoidal height by VRS surveying is necessary to keep the accuracy of orthometric height at surveying points inside and outside of CORS network.

3. The orthometric errors caused by the geoidal height of KNGeoid and the ellipsoidal height of VRS surveying at points located outside of CORS network need to be addressed carefully for control surveying.

References

1. El−Mowafy, A., Fashir, H., Al Marzooqi, Y., Al Habbai, A. and Babiker, T., 2003, Testing of the DVRS national GPS−RTK netwrok, Proc. of the 8th ISU International Symposium, 25−28 May, Strasbourg, France.
2. El−Mowafy, A., 2012, Precise real−time positioning using network RTK, In: Jin, S. (ed.), Global navigation satellite systems − signal, theory and applications, InTech, Janeza Tradine 9, 51000 Rijeka, Croatia, pp. 161−188.
3. Han, J. H., Kwon, J. H. and Hong, C. K., 2010, Analysis of Network−RTK (VRS) positioning accuracy for surveying public control point, Journal of the Korean Society for Geospatial Information System, Vol. 18, No. 2, pp. 13−20.
4. Kim, H. I., Yu, G. S., Park, K. D. and Ha, J. H., 2008, Accuracy evaluation of VRS RTK surveys inside the GPS CORS network operated by National Geographic Information Institute, Journal of the Korean Society of Surveying, Geodesy, Photo−grammetry, and Cartography, Vol. 26, No. 2, pp. 139−147.
5. Kim, K. B., Lee, C. K. and An, S., 2014, Evaluation of the accuracy of Network−RTK(VRS) for applying to ground control points survey, Journal of the Korean Society for Geospatial Information System, Vol. 22, No. 4, pp. 127−133.
6. Lee, S. B., 2013, Accuracy evaluation of the height determined by Network−RTK VRS positioning, Journal of the Korean Society for Geospatial Information System, Vol. 21, No. 4, pp. 55−63.
7. NGII, 2013a, Development of national geoid model (2nd year), NGII Publication No. 11−1613436−000018−01, National Geographic Information Institute, Suwon.
8. NGII, 2013b, Public surveying operational regulation (revision), National Geographic Information Institute, Notification No. 2013−1887, pp. 114−129.
9. NGII, 2014a, KNGeoid13, http://www.ngii.go.kr/geoid/cons/geoid_point.do
10. NGII, 2014b, Development of national geoid model and study of vertical datum link of Asia−Pacific region, NGII Publication No. 11−1613436−000039−01, National Geographic Information Institute, Suwon.
11. NGII, 2015, KNGeoid14, http://www.ngii.go.kr/geoid/cons/geoid_point.do
12. Retscher, G., 2002, Accuracy performance of virtual reference station (VRS) networks, Journal of Global Positioning Systems, Vol. 1, No. 1, pp. 40−47.
13. Song, T. H., 2015, Accuracy assessment of VRS height survey, Master's thesis, University of Seoul, p. 59.
14. Topcon, 2012, HiPer II, http://www.topconpositioning.com/products/gnss/receivers/hiper−ii
15. Trimble, 2014, Trimble R8, http://www.trimble.com/Survey/trimbler8gnss.aspx