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Accuracy Evaluation of Real-time Kinematic Positioning Service Based on Digital Multimedia Broadcast Network for Highway Construction Site in Korea

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The virtual reference system–real-time kinematic (VRS–RTK) method can be used for the precise position monitoring of construction equipment, thus facilitating automation in the construction industry. However, the use of the VRS–RTK method is limited to construction sites where monitoring multiple construction equipment requires constant access to long-term evolution (LTE) data communication, which poses a cost issue and limits connections in accordance with the VRS–RTK service server capacity. To address these challenges, the broadcast real-time kinematic (B'RTK) method was developed. In this study, we aim to evaluate the B'RTK method as a new network RTK positioning service for construction automation in terms of RTK positioning performance and positioning accuracy in various global navigation satellite system (GNSS) reception environments by comparing it with various RTK methods. To assess B'RTK positioning accuracy, simultaneous observation was carried out using post-kinematic, single RTK, and VRS methods for each GNSS signal reception environment, and the accuracy of B'RTK positioning was evaluated by comparing the post-kinematic positioning results with other kinematic positioning results. The B'RTK positioning accuracy in actual construction sites is similar or superior to other kinematic positioning methods, including the VRS–RKT method. Therefore, the B'RTK method may be highly useful for the real-time monitoring of construction equipment and construction automation.

1. Introduction

The adoption of smart construction technology, which combines digital and traditional construction techniques, has surged in recent times at construction sites. Smart construction technology refers to the use of technology to increase productivity, safety, and quality throughout the design, construction, and maintenance phases of construction work via digitalization, automation, and unmanned machinery. In 2018, the Ministry of Land, Infrastructure and Transport announced a smart construction technology roadmap to establish the foundation for using smart construction technology by 2025 and achieve complete construction automation by

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2030.[1] Moreover, the Ministry of Science and ICT is pursuing fundamental technologies related to various fields by releasing a 10-year strategy for unmanned mobile technology innovation and growth in 2018.[2] Automated construction technology is a key area of focus for such endeavors for ensuring stability by reducing the need for manual labor in demanding construction work through the precise automatic control of construction equipment. It is a leading smart construction technology that aims to minimize errors due to worker inexperience or mistakes, and it is actively applied primarily to large-scale civil infrastructure construction sites.

The acquisition of real-time location information for construction equipment is a critical component of construction automation technology. To accomplish this, the global navigation satellite system (GNSS) real-time kinematic (RTK) method is commonly used, which involves mounting a GNSS receiver on construction equipment and performing real-time relative positioning with a reference station. However, this method requires an expensive GNSS reference station to transmit the position correction information obtained through real-time relative positioning, limiting its practicality. The coverage of the reference station is generally limited to about 20 km owing to distance-dependent errors, whereby accuracy decreases as the distance between the reference station and the GNSS receiver increases. In the case of construction sites with long extensions, such as highways, this presents technical and cost challenges, because a large number of reference stations need to be installed, or the reference stations must be relocated in accordance with the input location of construction equipment.

To address these limitations, a network RTK positioning service is available in South Korea, allowing the use of the GNSS RTK method without the need to install a separate reference station in the target area. This is achieved by collecting location correction information from the National GNSS continuously operating reference station (CORS) network, modeling it for the entire country, and providing it through various wireless communication networks. The network RTK positioning service offers several methods, including a virtual reference system (VRS), the Flächen Korrektur parameter (FKP), and the master auxiliary concept (MAC), depending on the modeling and provision of correction information. In South Korea, the most commonly used network RTK positioning service method is VRS–RTK.

The VRS–RTK method is currently being used in South Korea to provide the real-time location information of construction equipment with a correction modeling accuracy of approximately 3 cm for the horizontal position, making it highly useful for construction automation. However, the user must constantly communicate the initial position of the receiver and the value of the position correction information to the service server, leading to limited connections due to the inadequate server capacity and increased costs associated with LTE data communication access. These limitations restrict the method's effective use in construction sites where the real-time monitoring of multiple pieces of equipment is necessary. To overcome these challenges, the Technical Information Business Team of the Technical Research Institute of Munhwa Broadcasting developed the broadcast real-time kinematic (B'RTK) method.[3] The B'RTK method applies a correction information model that uses the single DGPS technique based on the national CORS closest to the initial position of the receiver. The DMB network, which covers more than 90% of the nation, delivers data to unspecified people in one direction free of charge. Additionally, the B'RTK method provides a 24-h monitoring system through its own integrated control center to ensure user convenience and the stability of a continuous network connection. These features make the B'RTK method highly suitable for construction sites, as it overcomes the limitations of the VRS–RTK method, such as limited connections and high communication costs.

In previous studies, the accuracy of B'RTK and VRS positioning at integrated reference points has been compared and analyzed, and similar results have been found.(4) However, integrated reference points are typically set up on level ground with no obstructions, which does not reflect the reality of construction sites. Since construction sites often have environmental factors that can interfere with GNSS signal reception, such as soil, trees, and structures under construction, relying solely on previous studies to determine the usability of B'RTK positioning at construction sites is difficult. Therefore, in this study, we aim to evaluate the RTK positioning performance of the B'RTK method for construction automation by comparing it with various RTK methods. We will also evaluate the positioning accuracy based on the GNSS satellite signal and the environment of RTK correction information reception to ensure the stable use of the RTK method in monitoring construction equipment at actual construction sites. To accomplish this, the study site chosen was a highway construction site located in Bogae-myeon, Anseong-si, Gyeonggi-do, known to contain a large bridge and a tunnel section with various environmental factors that hinder the use of the RTK method. To evaluate the accuracy of B'RTK positioning, simultaneous observations were made using the post-kinematic, single RTK, and VRS–RTK methods for each GNSS signal reception environment. The accuracy of B'RTK positioning was compared with the other kinematic positioning results obtained by post-kinematic methods. The results of this study will provide insight into the usefulness of B'RTK positioning for construction automation, as well as its performance in challenging environments.

2. Theoretical Background

Positioning based on GNSS surveying can be performed by two methods: the static method in which data are post-processed and the RTK method in which the location is determined by processing the observation data in real time. The latter calculates the location of a mobile station in real time through a series of transmission processes by transmitting the correction value for the carrier phase from a single control point to the mobile station in real time.(5) The basic concept of RTK is to allow the user to obtain observation values with an accuracy of several centimeters in real time by using the carrier error correction value of the control point that yields a precise location.(6) In this study, to analyze the positioning accuracy of MBC B'RTK at highway construction sites, the usability of BRTK was evaluated by comparing it with the RTK method (single and VRS) already used at various construction sites. The description of the RTK methodology in this study is given below.

2.1 RTK positioning

The concept of RTK positioning is based on the use of the value of carrier phase error correction from a precisely located reference point to enable real-time observations with centimeter-level accuracy (see Fig. 1). This approach is similar to the differential global navigation satellite system (DGNSS), but the data transmitted for error correction in RTK positioning is carrier phase reception data.(7) However, because RTK positioning requires continuous carrier phase measurements for each satellite and can be more susceptible to transmission errors than DGNSS, a stable and fast data transmission system is essential.(7)

2.2 Network RTK positioning

In RTK positioning, the accuracy of the estimated position decreases as the distance between the reference and mobile stations increases owing to the degraded correlation of errors caused by ionospheric and tropospheric effects. The achievable centimeter-level accuracy is limited to a baseline length of 10–15 km. To overcome this distance-dependent error, the network RTK correction signal is developed by calculating the RTK correction signal in a network method (Fig. 2).

The network RTK correction signal is generated by collecting RTK correction signals from multiple reference stations located near the user's location and then comprehensively calculating the RTK correction signal suitable for the user's location.(8) By utilizing information calculated from multiple reference stations, it has the advantage of generating correction signals suitable for user locations over a wider area compared to conventional RTK.(8)

The National Geographic Information Institute currently provides different types of network RTK correction signals obtained by various methods such as VRS, FKP, and MAC methods, depending on the calculation method and signal structure used. VRS positioning creates a virtual reference point through network modeling and determines the precise location of a mobile station through RTK positioning between the created virtual reference point and the mobile station. Correction messages are received from reference stations already installed around the position where the virtual reference point is to be installed, and a virtual correction message suitable for the location is generated by combining these messages.(9) The installation of these virtual reference points creates the effect of operating a large number of reference stations with only a small number of actual reference stations, thereby covering a wider area.(9)

2.3 DMB-based RTK positioning (B'RTK)

The VRS method requires a continuous connection between the mobile station and the VRS server, which limits its use at construction sites where multiple machines must be managed. This is due to the increase in VRS server capacity, a limit on the number of accesses, and the cost associated with using the data communication network. To address these issues, the Technical Information Business Team of the Technical Research Institute of Munhwa Broadcasting developed the B'RTK method. Unlike the VRS method, the B'RTK method transmits the

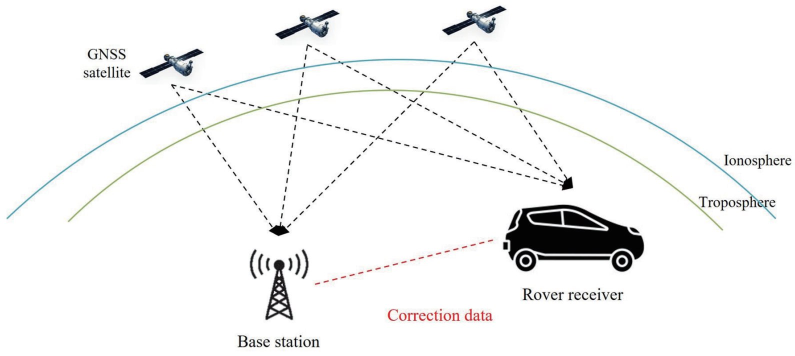

Fig. 1. (Color online) Conceptual diagram of RTK positioning.

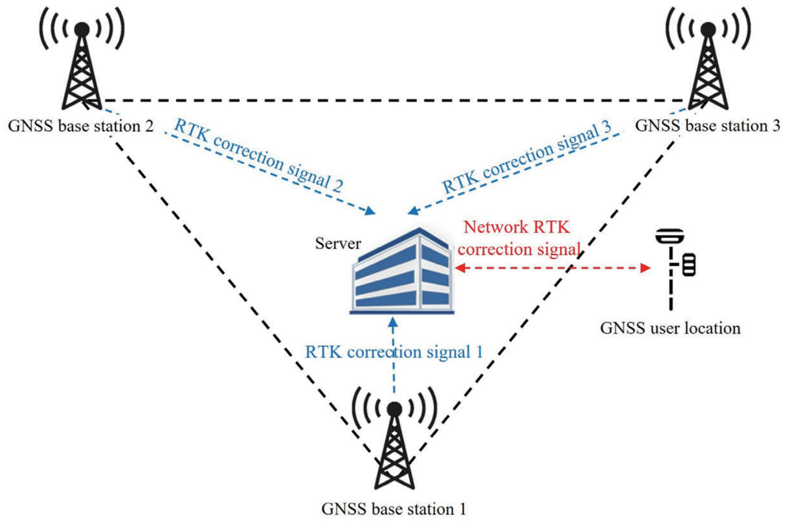

Fig. 2. (Color online) Conceptual diagram of network RTK correction signal calculation.

correction signal of the reference station free of charge through the terrestrial DMB broadcasting network. This makes it a more convenient and cost-effective option for high-precision positioning, particularly as the demand for this type of technology continues to increase. Moreover, the B'RTK method is equipped with a 24-h monitoring system through its own integrated control center, ensuring continuous network connection stability and user convenience.(3)

B'RTK is a novel network RTK positioning method that transmits the correction signal of the reference station via the terrestrial DMB broadcasting network, free of charge (Fig. 3). The service area of terrestrial DMB covers over 90% of the country, as shown in Fig. 4, making it highly convenient and widely accessible. The ability of DMB to deliver data to unspecified recipients at no cost in one direction makes it an ideal transmission medium to meet market needs; this has been rapidly increasing its demand for high-precision positioning, despite the limited number of connections and cost issues associated with the VRS method.(3) Therefore, it may be extensively used at construction sites.(10)

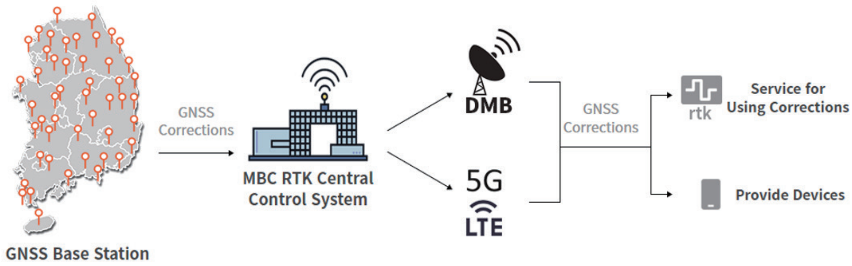

Fig. 3. (Color online) Conceptual diagram of B'RTK.

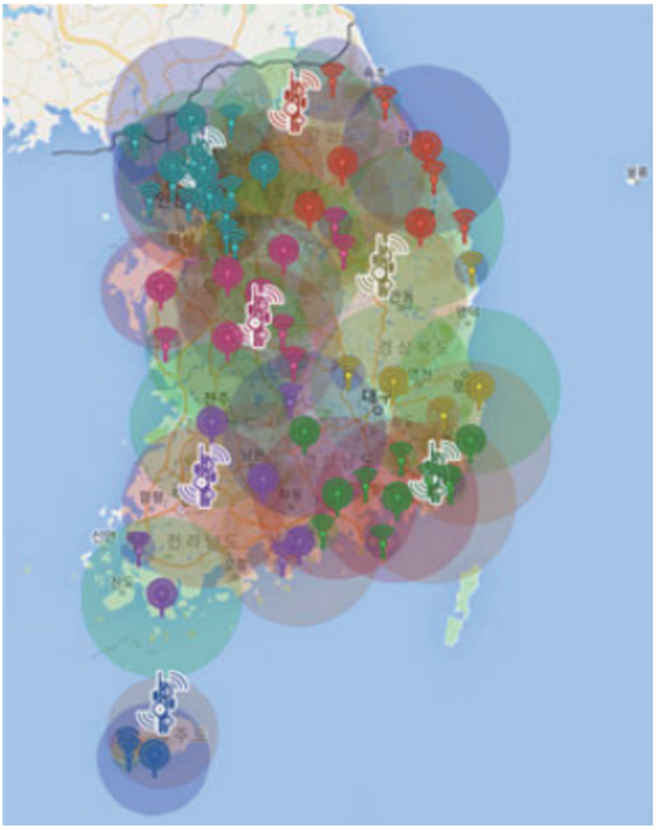

Fig. 4. (Color online) DMB service area.

3. Research Experimental Setup and Method

3.1 Research outline

The accuracy of the B'RTK method was evaluated in this study, taking into account the GNSS signal reception environment beyond the scope of previous studies. A highway construction site in Bogae-myeon, Anseong-si, Gyeonggi-do was selected as the study site, as it was expected to have various factors that could hinder GNSS signal reception. A comparative analysis was conducted using the post-kinematic method, known for its high accuracy, to calculate the length of the positioning path using the single RTK, B'RTK, and VRS methods for comparison with the specifications of the manufactured cradle. A simplified schematic of the study outline is shown in Fig. 5.

3.2 Study site

The study site for this research was a highway construction site located in Bogae-myeon, Anseong-si, Gyeonggi-do. This site was chosen because of the expected interference with GNSS signal reception therein, which would enable the evaluation of the accuracy of the B'RTK method in such an environment. The site also provided an opportunity to conduct follow-up research beyond the scope of previous studies owing to the actual highway construction occurring there (see Fig. 6).

As depicted in Fig. 6, the study site was a section of a highway interchange construction site located in the Bogae-myeon region, characterized by several structures under construction and a hilly topography, which could potentially create a challenging environment for GNSS signal reception.

3.3 B'RTK accuracy evaluation method

To evaluate the GNSS signal reception environment, the selected study site was divided into two sections: an open area (I-Section) with good GNSS signal reception and a non-open area (II-Section) with poor reception. Kinematic positioning was then performed in accordance with the planned path for each section (Fig. 7).

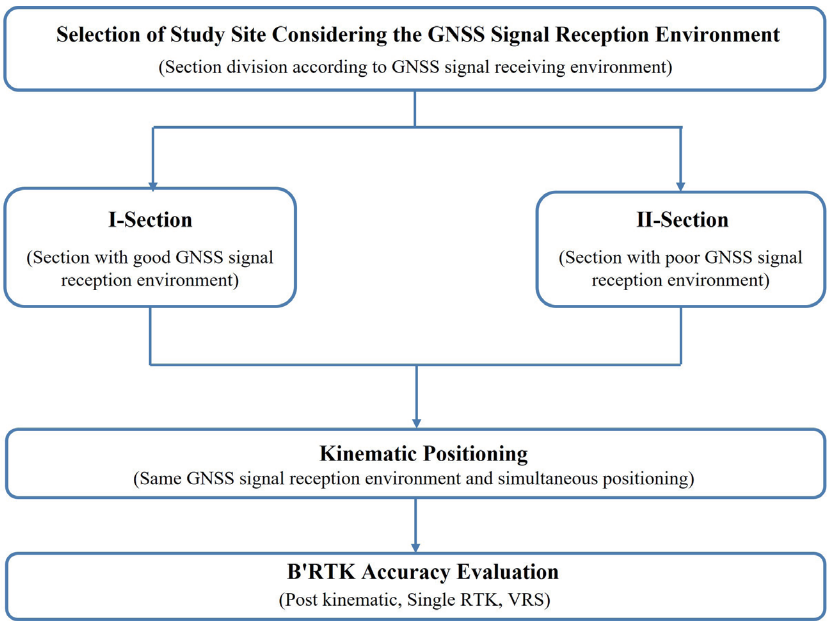

Fig. 5. Schematic of research outline.

Fig. 6. (Color online) Study site.

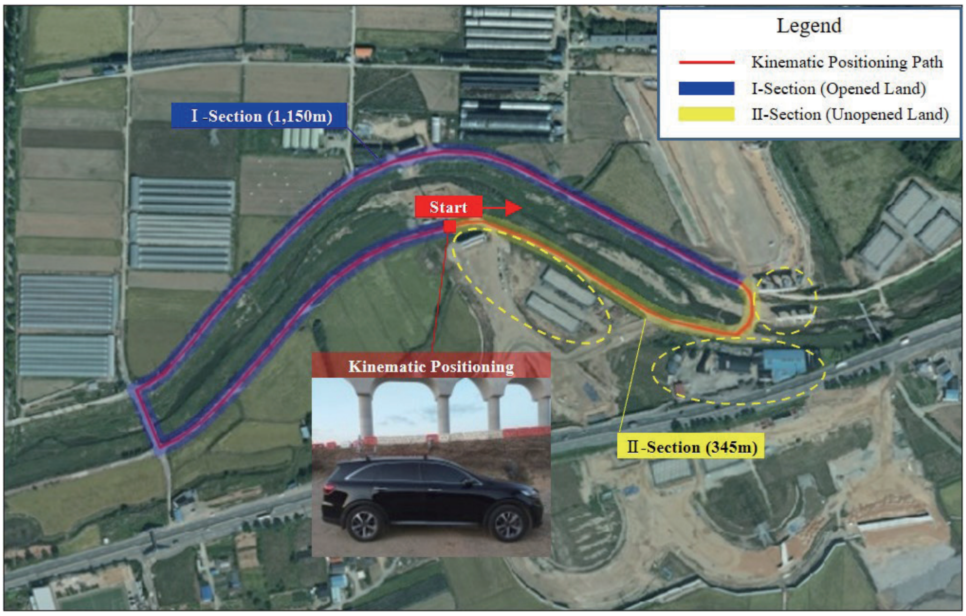

Fig. 7. (Color online) Kinematic positioning path considering the GNSS signal reception environment.

To perform a comparative analysis of the kinematic positioning methods under the same GNSS-signal-receiving environment with simultaneous observation conditions, a cradle on which four GNSS receivers can easily be attached and detached was custom-manufactured (Fig. 8).

The cradle used in this study was designed for comparing and analyzing the accuracy of various kinematic positioning methods, such as post-kinematic, single RTK, VRS, and B'RTK, under the same GNSS-signal-receiving environment with simultaneous observation conditions. The cradle could accommodate four types of GNSS receivers, and its specifications were as follows. The distance between the post-kinematic and single RTK receivers ($\overline{AB}$) was 1.500 m; the distance between the post-kinematic and B'RTK receivers ($\overline{AC}$) was 1.200 m; and the distance between the post-kinematic and VRS receivers ($\overline{AD}$) was 1.921 m.

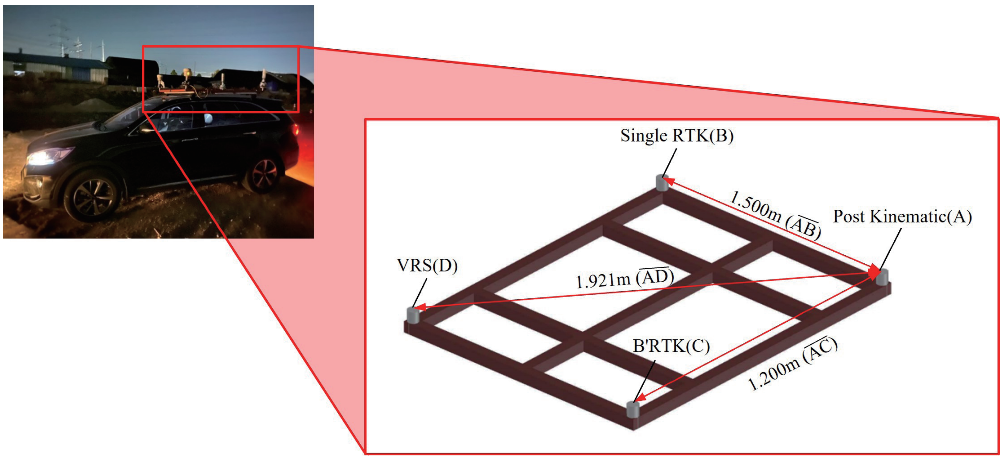

Fig. 8. (Color online) Vehicle cradle specifications.

The post-kinematic and single RTK methods used a Sokkia GCX2 receiver, whereas a Trimble R10 receiver was used for the VRS and B'RTK methods. The data acquisition interval was set to 1 s, and the cradle was mounted on the vehicle to ensure the same GNSS signal receiving environment. The data were collected while driving at a low speed (15–30 km/h), similar to the operating conditions of construction machines at highway construction sites.

To ensure simultaneous observation, the data acquisition times of each receiver were synchronized, and the GNSS signal reception environment was analyzed in I- and II-Sections, which were divided in accordance with the planned positioning path. I-Section represented an open area with good GNSS signal reception, while II-Section represented a non-open area with poor reception. The accuracy of the B'RTK method was evaluated relative to the results of the post-kinematic method, which is known to have the highest accuracy.

On the basis of the observation values acquired by positioning, the baseline variation between each method and the post-kinematic method was analyzed using the RTKLIB baseline analysis software to evaluate the positioning accuracy of the B'RTK method. This software is capable of processing not only GNSS but also GNSS data from various satellites such as GLONASS, Galileo, and BeiDou. It is widely used for research and educational purposes in the field.[11, 12] A comparative analysis was conducted between the length calculated by the single RTK, B'RTK, and VRS methods, using the specifications of the manufactured cradle as the standard.

4. Results

4.1 GNSS reception environment analysis results

Figure 9(a) illustrates the variation in the number of satellites used in I- and II-Sections for the positioning path, whereas Fig. 9(b) depicts the fluctuation in the dilution of precision (DOP) values in I- and II-Sections.

DOP is a dimensionless parameter that represents the error caused by the relative geometry of the satellites in the same epoch. A lower DOP indicates a higher GNSS data quality, and a

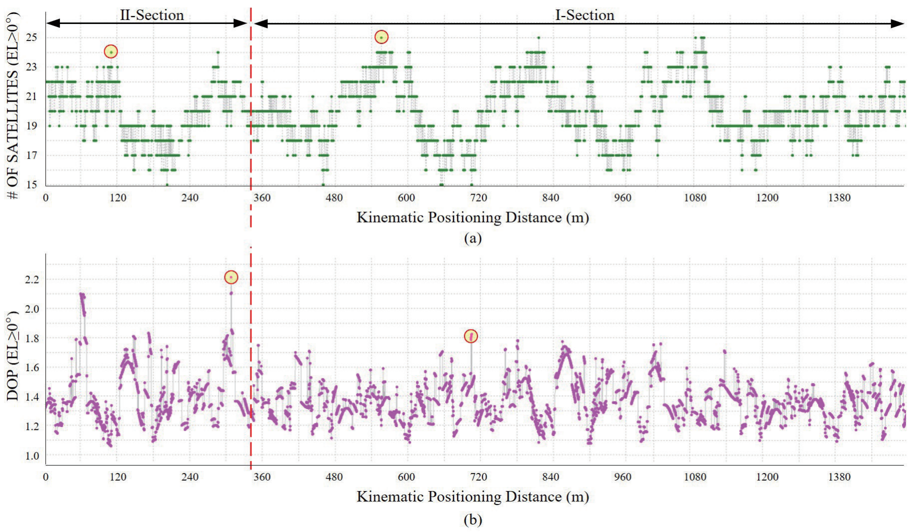

Fig. 9. (Color online) Results of GNSS signal reception environment analysis: (a) number of satellites used in accordance with kinematic positioning path and (b) change in DOP in accordance with kinematic positioning path.

DOP of 6 or higher generally indicates a low GNSS data quality.(13) In I-Section, the number of satellites used ranged from 15 to 25, and the DOP ranged from 1.0 to 1.9, with a time series distribution. In II-Section, the number of satellites used ranged from 15 to 24, and the DOP ranged from 1.0 to 2.3, with a time series distribution. No significant difference in the number of satellites used in the two sections was observed. The maximum DOP was 1.8 or higher in I-Section, indicating a better GNSS signal reception environment than in II-Section, where the maximum DOP was 2.2 or higher. However, both values were below 3.0, confirming that the GNSS signal reception environment was good in both I- and II-Sections.

4.2 B'RTK positioning accuracy analysis results

The RTKLib baseline analysis program was used to analyze the data obtained by the post-kinematic, single RTK, MBC B'RTK, and VRS methods, which were used to perform GNSS RTK movement positioning within the study area. The deviation between the calculated length and the length of the cradle was analyzed on the basis of the data acquired for the distances between the post-kinematic and single RTK receivers ($\overline{AB}$), post-kinematic and B'RTK receivers ($\overline{AC}$), and post-kinematic and VRS receivers ($\overline{AD}$), using the post-kinematic method as the reference because of its known high accuracy. The results are presented in Tables 1 to 3 and Fig. 10.

The accuracies of the GNSS RTK methods used in I-Section were compared, and the results showed that the single RTK method had the highest accuracy, with a standard deviation of $\overline{AB}$ of ±0.02967 m. This was followed by the VRS method with a standard deviation of $\overline{AD}$ of ±0.05867 m and the B'RTK method with a standard deviation of $\overline{AC}$ of ±0.07500 m. In II-Section, the B'RTK method showed the highest accuracy, with a standard deviation of $\overline{AC}$ of

Table 1.
GNSS RTK positioning data analysis results for I-Section.

I-Section	Cradle specifications		
	$\overline{AB}$ (1.500 m)	$\overline{AC}$ (1.200 m)	$\overline{AD}$ (1.921 m)
Calculated length	1.63128	1.25667	2.04003
Maximum deviation	−0.00136	0.16430	0.07685
Minimum deviation	−0.18428	−0.25278	−0.24671
Mean deviation	−0.13128	−0.05667	−0.11909
Standard deviation	±0.02967	±0.07500	±0.05867

Table 2.
GNSS RTK positioning data analysis results for II-Section.

II-Section	Cradle specifications		
	$\overline{AB}$ (1.500 m)	$\overline{AC}$ (1.200 m)	$\overline{AD}$ (1.921 m)
Calculated length	1.49311	1.20780	1.89778
Maximum deviation	0.05679	0.02155	0.06846
Minimum deviation	−0.05405	−0.05988	−0.03624
Mean deviation	0.00689	−0.00780	0.02316
Standard deviation	±0.01801	±0.01565	±0.01665

Table 3.
GNSS RTK positioning data analysis results for Total Section.

Total-Section	Cradle specifications		
	$\overline{AB}$ (1.500 m)	$\overline{AC}$ (1.200 m)	$\overline{AD}$ (1.921 m)
Calculated length	1.52178	1.21829	1.92729
Maximum deviation	0.05679	0.16430	0.07685
Minimum deviation	−0.18428	−0.25278	−0.24671
Mean deviation	−0.02178	−0.01829	−0.00636
Standard deviation	±0.05988	±0.04219	±0.06529

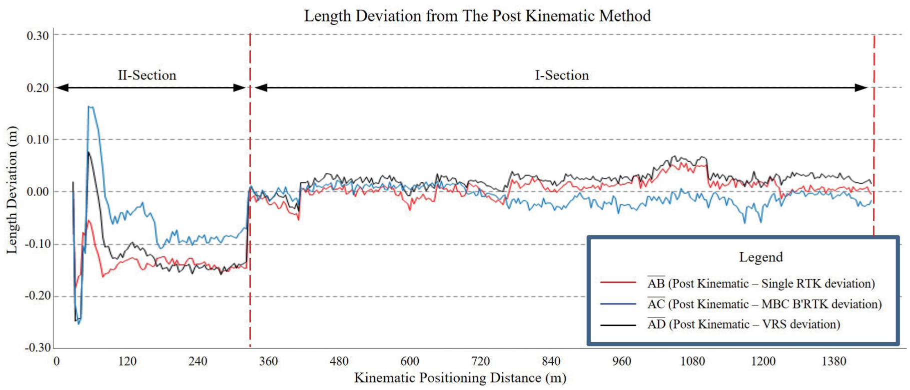

Fig. 10. (Color online) Diagram of length deviation from that of the post-kinematic method.

±0.01565 m, followed by the VRS method with a standard deviation of $\overline{AD}$ of ±0.01665 m and the single RTK method with a standard deviation of $\overline{AB}$ of ±0.01801 m. While considering the Total Section, the B'RTK method again showed the highest accuracy, with a standard deviation of $\overline{AC}$ of ±0.04219 m. This was followed by the single RTK method with a standard deviation of $\overline{AB}$ of ±0.05988 m and the VRS method with a standard deviation of $\overline{AD}$ of ±0.06529 m. Compared with the post-kinematic method, no significant difference in the standard deviation of the lengths of the three methods (single RTK, VRS, and MBC B'RTK) was observed, suggesting that excellent accuracy was achieved.

5. Conclusions

To evaluate the accuracy of the DMB-based network RTK service at a highway construction site, we selected a site in Bogae-myeon, Anseong-si, Gyeonggi-do, and divided it into two sections: an open area (I-Section) with good GNSS signal reception and a non-open area (II-Section) with poor reception. We compared and analyzed other kinematic positioning methods, including post-kinematic, single RTK, and VRS, under the same GNSS-signal-reception environment with simultaneous observation conditions. The following are the key findings.

(1) The number of visible satellites in I-Section ranged from 15 to 24, with a DOP ranging from 1.0 to 2.3, whereas the number of visible satellites in II-Section ranged from 15 to 25, with a DOP ranging from 1.0 to 1.9. Despite the better GNSS reception in I-Section, both open and non-open areas secured good GNSS signal reception.

(2) In I-Section, the single RTK method showed the highest positioning accuracy, followed by the VRS and B'RTK methods.

(3) In II-Section, the B'RTK method showed the highest positioning accuracy, followed by the VRS and single RTK methods.

(4) In Total Section, the B'RTK method showed the highest positioning accuracy, followed by the single RTK and VRS methods.

The results of this study suggest that the B'RTK method produces accurate results in actual construction sites, similar or superior to other kinematic positioning methods, including the VRS-RKT method. Moreover, the B'RTK method offers stable positioning results even in poor GNSS reception environments. This feature makes it highly useful for the real-time monitoring of construction equipment and construction automation. The B'RTK method provides high-accuracy real-time location information and eliminates connection failures and reduces communication costs when using multiple pieces of construction equipment.

Acknowledgments

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