# A Pilot Study on Levelling Network Adjustment of Multi-Dimensional Geodetic Control Points

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**Keywords**: Network Adjustment, Geodetic Control Points, Spirit-Levelling, Height

## SUMMARY

Like most other countries, triangulation points and levelling benchmarks (BMs) have traditionally played a core role as the geodetic control to support compatible data collection for the geospatial disciplines. Due to a limitation of the traditional surveying techniques, such as triangulation, trilateration and spirit-levelling, these control points have had to be separately installed and maintained. While the triangulation points are mostly located on hilltops for the visibility, the BMs are established along major national and state roads for the surveying efficiency and precision; hence accessibility of the former is restricted, and spatial density of the latter is sparsely populated. To resolve this problem in Korea, the national geographical information institute (NGII) has designed and established the so-called the unified control points (UCPs) which enable to offer multi-dimensional geodetic coordinate sets with improved accessibility and accuracy. With the advent of the global navigation satellite systems (GNSS), the horizontal control points are no longer placed on the top of hills and mountains for the line of sight, and they can be instead installed in the low elevated areas. NGII initiated the UCPs establishment projects with GNSS, spirit-levelling and gravimetric campaigns in 2007. The implementation of the 1st-phase UCPs network was completed in 2011 with the uniform spatial density about 10km, and since then, the 2nd- densification has been underway for the spatial frequency about 3km to 6km. The UCPs will, therefore, supersede the legacy geodetic points after the full implementation under schedule to be 2025. While the GNSS technology can readily implement the horizontal geodetic network, there is a technical challenge to establish the vertical network due to characteristics of the geodetic levelling. To this end, a pilot study project had been carried out to design a new version of the UCPs-based levelling network as well as to demonstrate the effectiveness regarding accuracy and reliability. An experimental network around the vertical origin was designed in this study by using 621 points, and subsequently, a series of the network adjustments was conducted. In this contribution, concept and strategy of the UCPs based levelling network are briefly given with some examples. This is followed by presenting details of the pilot network and its measurements together with the network processing procedure. Finally, results of the adjustments will be provided with emphasis on the impact of the UCPs-based network regarding accuracy, reliability and estimated heights.

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## 1. INTRODUCTION

The traditional geodetic controls, such as triangulation points (TPs) and levelling benchmarks (BMs), had played an indispensable role in supporting compatible data collection for the geospatial disciplines. To this end, the nationwide adjustments of these networks were carried out from 2005 to 2006 for densifying the Korean Geodetic Datum 2002, referenced to the international terrestrial reference frame 2000 (NGII, 2006; Lee et al., 2008). It is worth taking note that the TPs had been mostly re-surveyed by the modern satellite positioning technique (i.e., global navigation satellite systems - GNSS) before the project whereas the most recent levelling data was included to the densification. The geodetic effort, hence, led to successful modernisation of the Korean geodetic infrastructure regarding accuracy and compatibility with the international standards. Nevertheless, the location of the TPs and spatial density of the BMs still restricted usability of the controls. To remedy this problem, the national geographical information institute of Korea (NGII) has designed and established the so-called the unified control points (UCPs) that offer the multi-dimensional geodetic coordinate sets, for instance latitude, longitude, ellipsoidal and orthometric heights, geoidal undulations and gravity anomaly (Bae et al., 2011). Mostly being installed in the elevation areas, the UCPs has significantly improved usability and accessibility, which was proved by NGII (2013).

As the 1$^{st}$-phase, a total of 1,196 UCPs (i.e., the 1$^{st}$-phase UCPs) had been installed at mostly 10km gridding spaces and subsequently surveyed by GNSS, spirit-level and gravimeter for three years since 2008. The GNSS measurements were simultaneously adjusted to derive the 3-D geodetic coordinates. On the other hand, heights of the UCPs were determined by using simple arithmetic computation as they were only connected to the nearest BMs by the double-running observations, Even though the 10km gridding was dense enough to support the modern GNSS, it was far sparse for other traditional surveying techniques. To mitigate this situation, NGII commenced the 2$^{nd}$ phase implementation of UCPs (i.e., the 2$^{nd}$-phase UCPs) in 2012 to densify the 1$^{st}$-phase control points up to 3km gridding intervals via installing additional 6,000 points, e.g., see Figure 1. It is also very crucial to be noted that the geodetic levelling network will be rebuilt as part of the project by integration of all the UCPs and some of BMs loops. As a consequence, the new infrastructure will supersede the current vertical geodetic network after the full implementation (NGII, 2015). The 1$^{st}$ phase UCPs' levelling loops need to be re-surveyed to connect more than two near geodetic points for enhancing geometric strength and reliability, and of course, the same strategy is applied for the 2$^{nd}$ phase. Note that the maximum allowable misclosure of $\pm 2.5\text{mm}\sqrt{Km}$ is a standard for the field campaign.

Once the UCP-based geodetic network is established, NGII will carry out to a series of geodetic adjustments to estimate 3-D geodetic coordinates as well as heights. Since the vertical network will be changed, a pilot study had been performed to design a new UCPs-based vertical network integrated with BMs and to derive a strategy and a procedure of the levelling network adjustment. The objective was to build and adjust an experimental levelling network and demonstrate the effectiveness of the UCPs based approach. This paper presents a concept of the new levelling network design with some example cases. After then, details of the testing network is given with an adjustment procedure, and results of the adjustments are presented.

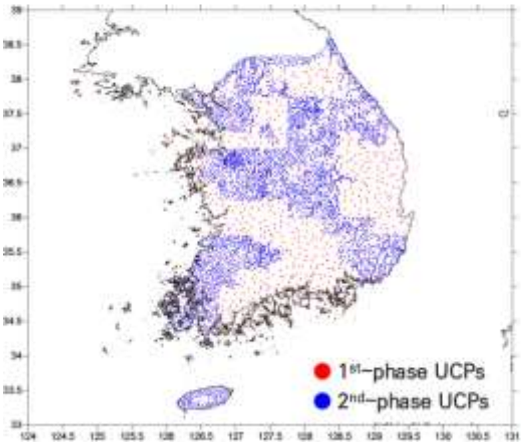


Figure 1. Distribution of the UCPs in 2017.

## 2. DESIGN OF A PILOT LEVELING NETWORK BASED ON UCPs

### 2.1 Concept and Strategy

As shown in Figure 1, UCPs installation project is underway for target spatial density of 3km×3km except for mountainous area. It ultimately aims at replacing the legacy geodetic references (e.g., TPs and the BMs) and constructing a single-layer geodetic network based on the UCPs, which leads to enhancing accuracy and reliability of the national geodetic infrastructure with much-improved usability. Note that the TPs were observed either by mostly GNSS or by EDM (Electronics Distance Measurement Unit) whereas the BM network comprises the 1$^{st}$- and the 2$^{nd}$-order with respect with surveying class and network connection. GNSS campaign at the UCPs can be readily carried out soon after their installation, but spirit-levelling generally takes much time-consuming and requires substantial laborious works. To this end, it might be efficient to include part of BMs' loops in the UCPs-based levelling network. As previously mentioned, a loop of the 1$^{st}$-phase UCP is only linked to the nearest single BM, and arithmetic calculation is made to determine its height. To estimate heights as accurate and reliable as possible, the UCPs-based vertical network should be constructed and rigorously adjusted together with the BMs' loops. For this purpose, three strategies were under consideration for the design of the levelling network: (a) substitution of BMs by UCPs; (b) designation of BMs as UCPs by GNSS survey; (c) new installation of UCPs (e.g., 2$^{nd}$-phase).

As shown in Figure 2, the 1$^{st}$-phase UCPs (i.e., solid red circles) are connected to a single BM, whereas the 2$^{nd}$-phase UPC (i.e., blue solid circles) is linked to at least two BMs. Considering 3km radius of the solid yellow circles, UCPs and their loops can replace some of BMs and thire connecting lines. For example, the BM *'01-00-00'* and *'01-00-01'* can be excluded if the loop *'01-00-02↔UCP1↔ 02-00-01'* is surveyed by using the 1st-class standard (i.e., 2.5mm$\sqrt{Km}$ ). Note that the 2nd-class standard (i.e., 5mm$\sqrt{Km}$ ) was employed for the 1st-phase UCPs' surveys; hence red solid lines in the figure will not be maintained if the UCPs-based network is implemented in the future. By adding an 'UCP2' in the network and surveying a loop '03-00-00↔UCP3↔03-00-01', the loop '02-00-02↔02-00-03' can be removed from the network. Furthermore, if it is possible to survey a line between 'UCP2' and '04-00-02', geometric strength and reliability of the network enable to be enhanced.

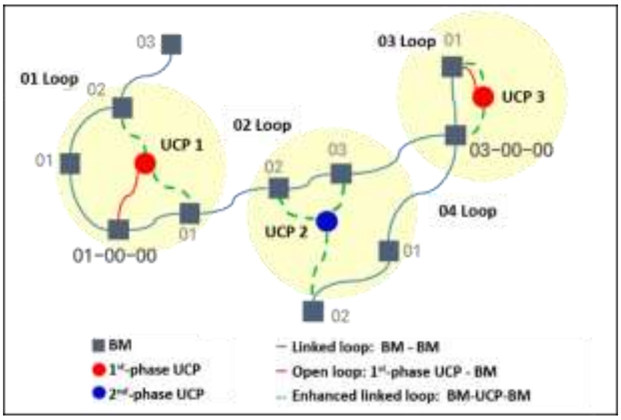



Figure 2. A strategy of substituting BMs by UCPs.

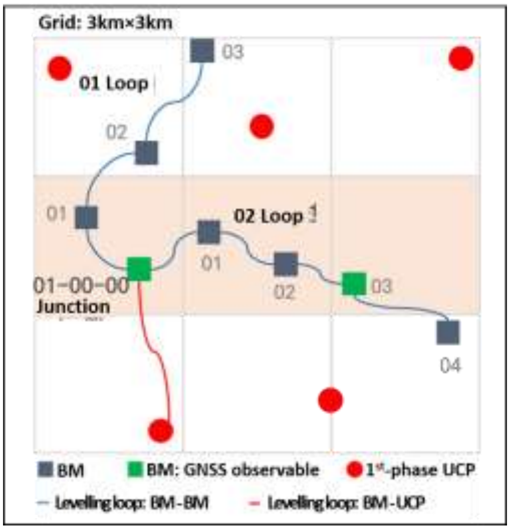



Figure 3. A strategy of designating BM as UCP.

Figure 3 and 4 represents a distribution of UCPs and BMs at 3km gridding space with the inclusion of levelling loops. If no UCP exists within the light yellow solid grids, and reconnaissance reveals benigin circumstance of GNSS observation at '01-00-00' and '01-00-03', these BMs can be designated UCPs by the GNSS survey. This is attributed to the fact that BM only differs from UCP in the aspect that the former does not provide the 3-D geodetic coordinates (e.g., latitude, longitude, and ellipsoidal height). If this is possible, it does not need to set up a UCP in the 2nd row and 1st and 3rd column of the grid system, but at least one UCP should be added in the 2nd row and 2nd column. If the 2nd row and 2nd column of the grid do not have any of a UCP or a UCP-designated BM in Figure 4, one of the 2nd-phase UCPs should be placed.

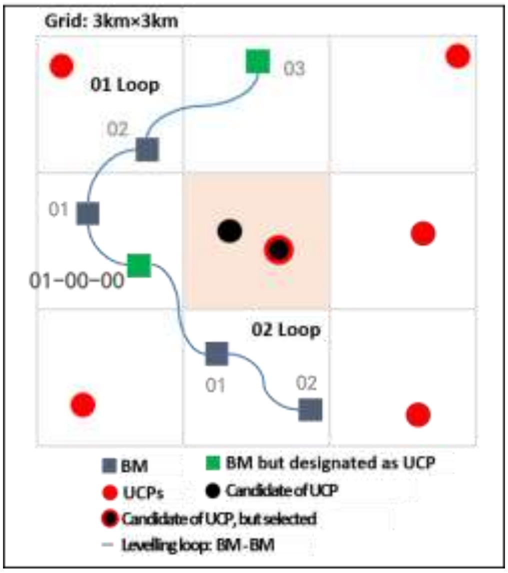


Figure 4. A strategy of installing new UCPs.

### 2.2 Design of A Pilot UPCs-based levelling Network

The 1st-order Korean geodetic levelling network consists of 20 circuits nationwide. The 12th-circuit was selected to design a pilot network as it contained the national vertical datum, and the 2nd-phase UCPs had been mostly installed and surveyed. Figure 5 depicts comparison the BMs-levelling loops with those of the UCPs-based. Looking into the left network in the picture, all the 1st-phase UCPs are only connected to a single BM, for instance, the circled U290. On the other hand, the right network shows that the number of control points becomes larger by adding the 2nd-phase UCPs, and all the UCPs are coupled to at least two near points. It is also of interest to observe the UCP290 circled in Figure 5 as it has replaced the nearest BM and roles as a junction of the network through being liked to four loops. Besides, the boxed UPCs the right diagram are the junction MBs designated as UCPs by GNSS surveys.

While Figure 6 represents the UCPs-based pilot levelling network designed in this study, Table 1 summarises the number of the geodetic points included. Although the 2nd-phase UCPs had been mostly installed according to a project plan, eight points were additionally installed by this project along the west shoreline to enhance the reliability of the network. Furthermore, five levelling sections in an inland area were surveyed, e.g., see Figure 6. As tabulated (i.e., Table 1), the pilot network is made up of 621 points, but only 34% of them is UCPs. It is, however, worth taking note that the 2nd-class BM loops will be re-surveyed about the 1st-class precision, and many of the 2nd-order BMs are going to be designated UCPs shortly. As a consequence, the total number of measurements (i.e., differential geometrical heights) included in the network is 690, and 64% of them was surveyed by the 1st-class levelling.

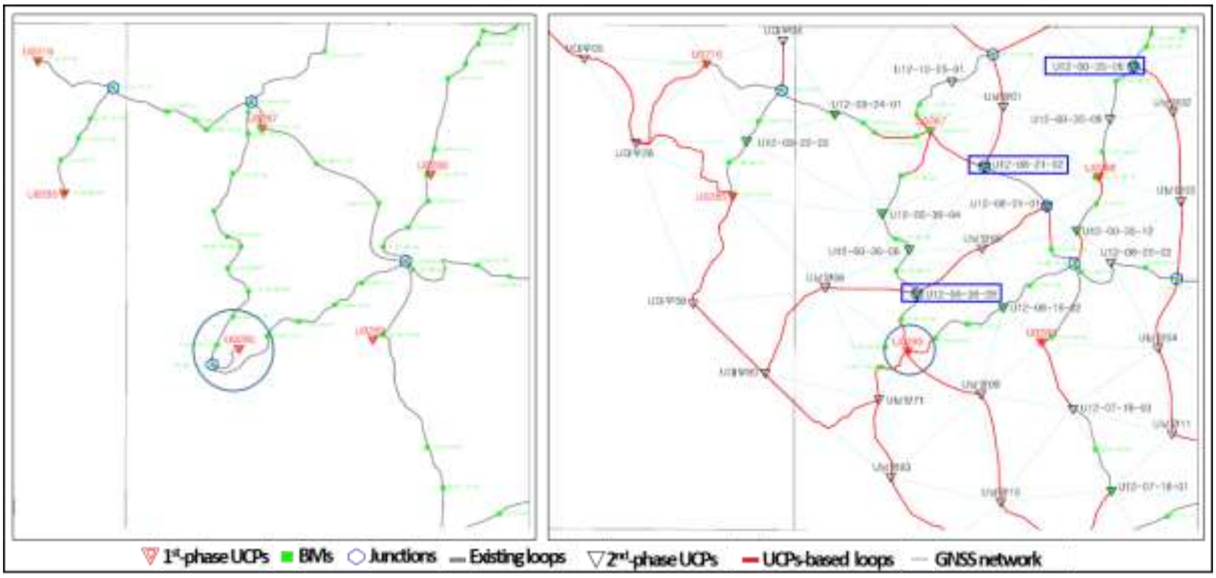



Figure 5. Comparison of BMs' loops with that UCPs-based network designed by this study.

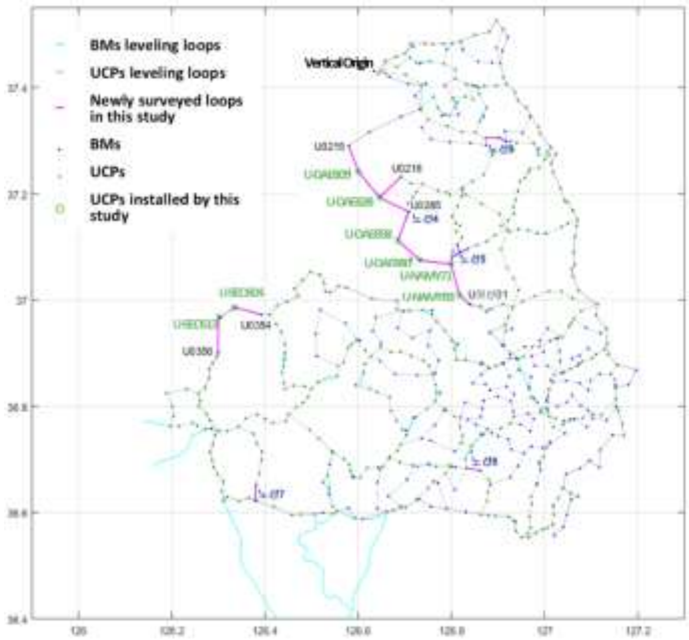



Figure 6. A pilot UCPs-based network to be adjusted.

Table 1. The number of geodetic control points included in the pilot network.

| BMs | | UCPs | | UCPs installed by this project | Total |
|---|---|---|---|---|---|
| 1st-order | 2nd-order | 1st-phase | 2nd-phase | | |
| 105 | 307 | 17 | 182 | 10 | 621 |

## 3. Geodetic Adjustment of UCPs-based Levelling Network

### 3.1 Procedure

The pilot levelling network has been adjusted by a procedure illustrated in Figure 7. Although NGII had endeavoured to carry out gravimetric campaign throughout BMs and UCPs, it was not completed yet at the time of this adjustment; hence the normal gravity was corrected to observations (Bomford, 1962). This means that the normal orthometric height system is a datum of the following reductions. Note that the future UCPs-based network will adopt the so-called orthometric height system once gravimetric surveys are completed.

Pre-analysis of measurements is exceptionally critical for a spirit-levelling network to examine possible outliers because the degree of freedom (DoF) is generally limited. As a first step, circuit loop closures were computed and compared to NGII guideline whether they are acceptable for the order of accuracy. Since GeolabPX5 software by BitWise Idea Inc. was used in this study, MS-excel formatted observations were converted to Geolab's text file (i.e., IOB) (Steeves, 2015). Subsequently, a series of preliminary adjustments were carried out by fixing the vertical origin to further identify blunders based on τ-test as well as to determine standard deviations for stochastic modelling (Cross 1994; Ghilani, 2010). After applying the reference deviation to measurements depending on assigned surveying classes, final adjustments were conducted twice by using different data sets: (a) the one described in section 2.2 (i.e., CASE-I); (b) the other that the measurements obtained by this study were excluded from the CASE-I data set (i.e., CASE-II). Finally, analysis of the outcomes of the adjustments was performed to assess accuracy, reliability and estimated height via a comparison of the two cases.

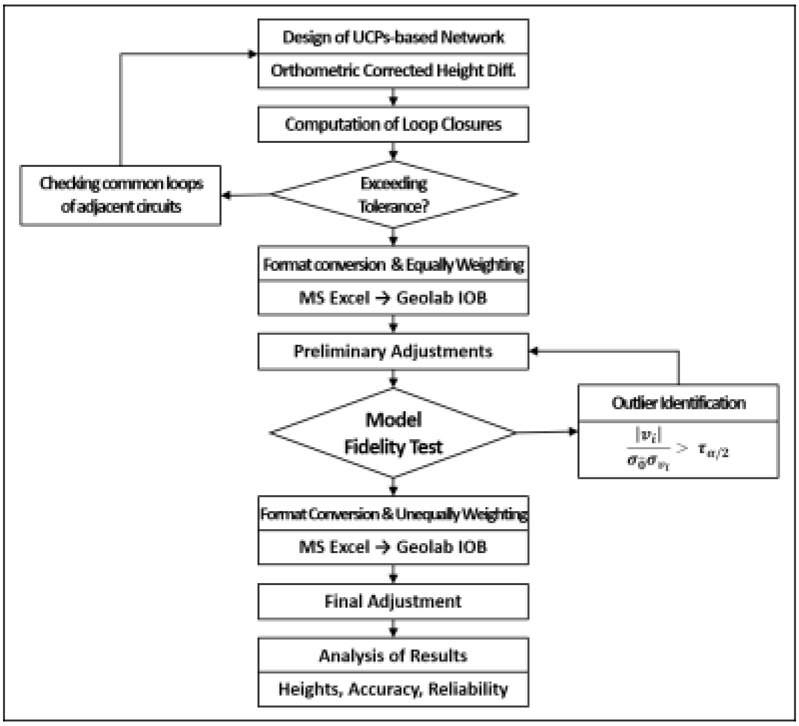



Figure 7. A procedure of UCPs-based levelling network adjustments.

### 3.2 Examination of Loop Closures

A total of 70 levelling circuits was composed as shown in Figure 8, and their loop closures were computed. As tabulated (e.g., Table 2), the mean and the standard deviation of the closures is

15.3mm and ±16.4mm, respectively. Such large values could be induced by the loop lengths ranging from 7.7 km to 560km; the longer surveying distance, the larger misclosure expected in spirit-levelling. On the other hand, statistics of the normalised misclosures scaled by the distances becomes smaller as shown in the table. As illustrated in Figure 9, the circuits having the slightly larger loop closures are suspected to be contaminated by blunders, leading to making a comparison of them with the tolerances of the 2nd-class standard (i.e., $5.0\text{mm}/\sqrt{Km}$). The results uncovered that six circuits exceeded the maximum allowance. After further analysis with the adjacent circuits sharing the suspected loops, some of the inner circuits were revised by eliminating erroneous observations: no. 11 was merged with no. 7; and no. 29 was integrated with no. 25. This revision reduces the number of the circuits exceeding the 2nd-class tolerance by half (i.e., three). Furthermore, average misclosure and normalised misclosures become reduced, which is 13.0mm and $1.8\text{mm}/\sqrt{Km}$ , respectively. Note that the circuits of which misclosures exceed the tolerance still remain in the network, which will be further investigated at following steps.

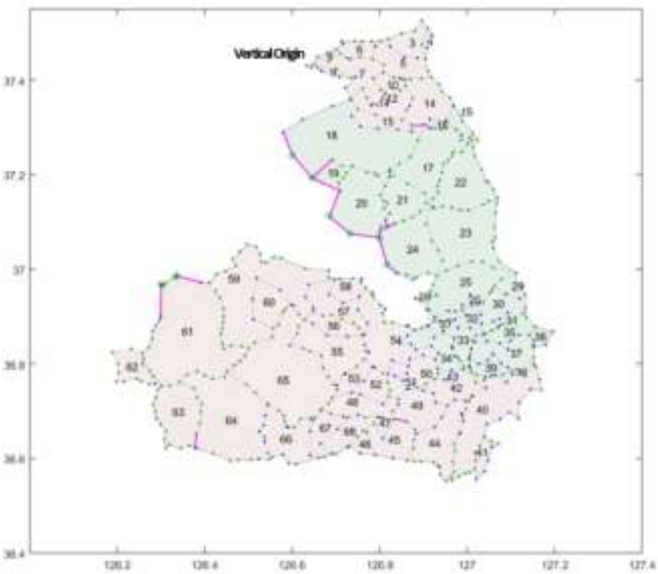
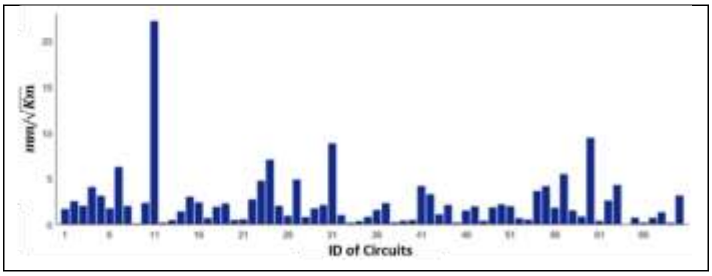


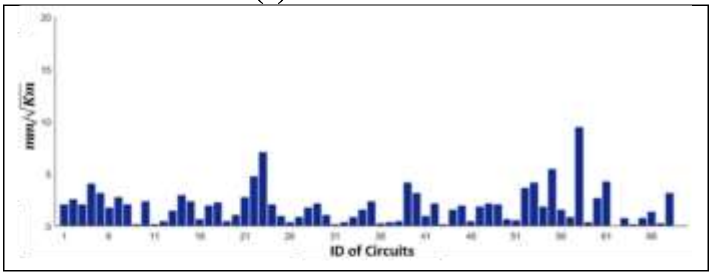

Figure 8. Inner levelling circuit of the experimental network.

Table 2. Statistical summary of the circuit loop closures.

| Items | Max. | Min. | Mean | Standard Dev. |
|---|---|---|---|---|
| Misclosures (mm) | 76.3 | 0.1 | 15.3 | 16.4 |
| Normalised misclosures ($\text{mm}/\sqrt{Km}$) | 22.1 | 0.0 | 2.3 | 3.1 |




(a) Initial circuits




(b) Revised circuits

Figure 9. Standardised misclosures of the circuit loop closures.

### 3.3 Preliminary Adjustments

A series of adjustments were carried out to identify possible blunders and determine reference standard deviations for stochastic modelling based on a distance. Note that the national vertical origin was held fixed for these adjustments. By referring to NGII (2014), a referenced standard deviation, $\pm 2\text{mm}/\sqrt{Km}$, was initially assigned to a processing to identify possible outliers. Although this assumption was in actual unrealistic as the observations were made by two different surveying precisions, this strategy was still employed for practical purposes. As given in Table 3, the 1$^{st}$ -round adjustment resulted in a rejection of the null hypothesis of the model fidelity via a $\chi^2$-test (e.g., global test) against a posterior variance. To this end, a τ-test (e.g., local test) with respect to the largest normalised residual identified 'U-ASAN06 ↔BM-12-00-27-18' as a blunder. After removing it, the 2$^{nd}$-round adjustment was conducted, failing to reject the null hypothesis of the global test. Hence, after this stage of the adjustments, it is assumed that the observations are free from outliers.

Table 3. Summary of the network adjustment to identify outliers.

| Trial | No. of points | No. of Obs. | No. of unknown | Degree of freedom | A posterior variance |
|---|---|---|---|---|---|
| 1$^{st}$ | 618 | 684 | 617 | 67 | 1.627 (fail) |
| 2$^{nd}$ | | 683 | | 66 | 1.248 (pass) |

Although the goal of the UCPs-based levelling network is to establish a signal layer network with an application of the 1$^{st}$ class surveying precision, this pilot network partly consists of 247 measurements of the 2$^{nd}$ class (i.e., $5.0\ \text{mm}/\sqrt{Km}$) as re-survey campaign is still underway. In order to realistically present the accuracy of adjusted heights, it is necessary to assign an appropriate precision of the measurements with a consideration of the surveying class applied. Hence, an empirical method was employed here to derivation of reference standard deviation for each of the surveying classes (e.g., stochastic modelling). That was, an iterative adjustments by varying the deviations until a hypothesis test against a posterior variance was passed. To begin with, half of the 2nd class standard deviation was assign to the 1st class according to the NGII standard. After several attempts, $\pm 1.7\ \mathrm{mm}/\sqrt{Km}$ and $\pm 3.4\ \mathrm{mm}/\sqrt{Km}$ were determined for the 1st and the 2nd class measurements. When these values were applied to an adjustment, a posterior variance was resulted in 0.981, passing the global test. Figure 10 depicts the relative accuracy of adjusted measurements. While the blue coloured boxes represent the accuracy of results from $\pm 2.2\ \mathrm{mm}/\sqrt{Km}$ without classifying the precision, the red coloured circles indicate those that the two classified deviations were assigned. Note that the averages of the accuracy from the two adjustments are somewhat similar (e.g., 3.4mm and 3.3mm), but the distinctive standard deviations are seen (e.g., ±1.4mm and ±0.9mm). These results are reasonable as the stochastic model with the precision classification more realistically represents the accuracy through reflection of the actual measurement quality.

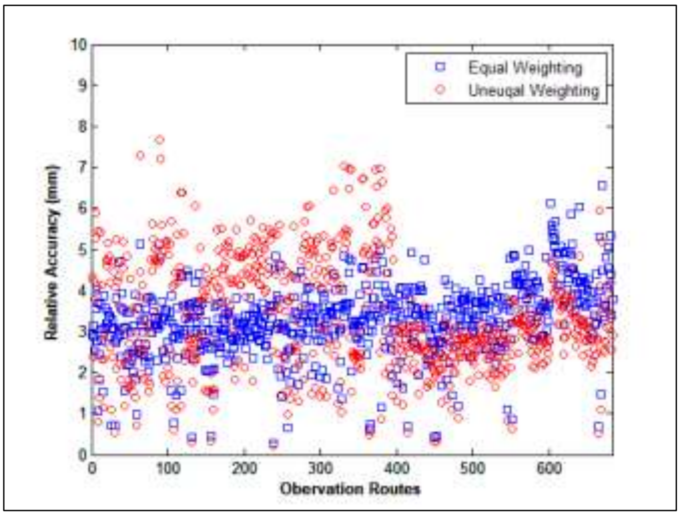



Figure 10. Relative accuracy of the levelling routes.

### 3.4 Final Adjustments

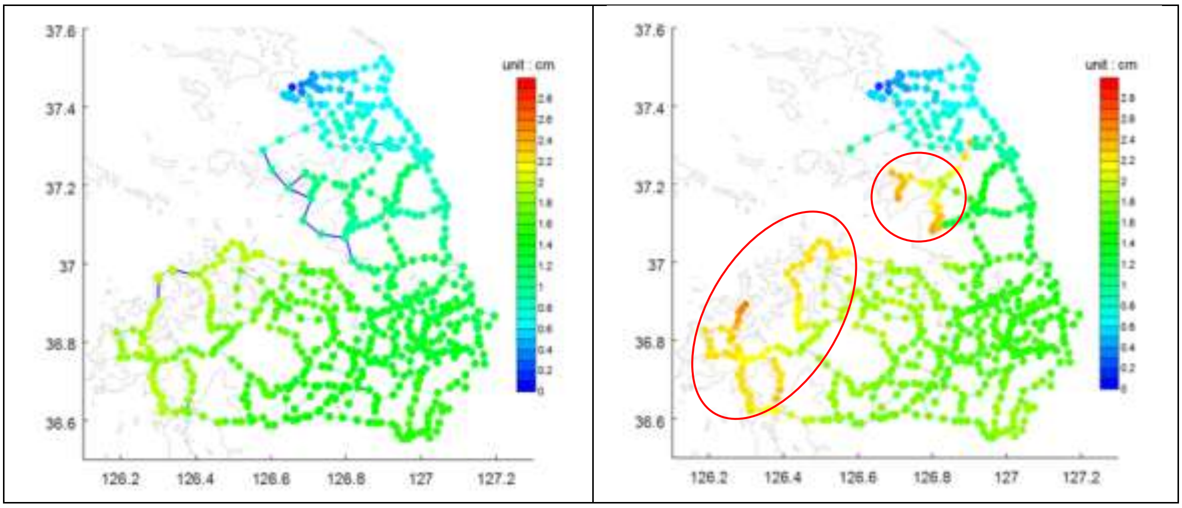
Final adjustments were carried out twice to somewhat different data sets: (a) the observations described in section 3.3, denoted by CASE-I; (b) those same as CASE-I except for the fact that the measurements surveyed by this study were excluded (i.e., CASE-II). The main reason for this approach was to investigate the impact of the new measurement into the accuracy and reliability of the final adjustment.

#### 3.4.1 Absolute Accuracy

As shown in Table 4, both rounds of the adjustments pass the model fidelity tests about a posterior variance. It is of interest to see that CASE-I's degree of freedom is larger than that of CASE-II although the number of unknowns of the latter is reduced. This is mainly because as shown in Figure 6, BMs-based levelling loops along the west coastline and in inland were connected by this study to improve geometric strength as well as reliability. While Figure 11 illustrates the absolute accuracy of the estimated heights, Table 5 summarises its statistics. These results indicate that the new network design overall enhances the accuracy. As circled in the right map in the figure, the accuracy of these areas is relatively weak as the loops are mostly open, and hence residual errors cannot be distributed over the network. By making these loops closed, the accuracy, of course, gets increased. In addition, results of the CASE-I show a clear trend that the accuracy is deteriorated as the control points are becoming away from the datum origin, which can be considered as an outstanding feature of the single origin height system.

Table 4. Results of the final adjustments.

| Case | No. of Control Points | No. of Observations | No. of Unknowns | Degree of Freedom | A posterior Variance |
|---|---|---|---|---|---|
| I | 619 | 684 | 618 | 66 | 0.981 (pass) |
| II | 605 | 657 | 604 | 53 | 1.009 (pass) |




(a) CASE-I (b) CASE-II

Figure 11. Absolute accuracy of the adjusted heights.

Table 5. Statistical summary of the absolute accuracy (1σ, unit: mm).

| Case | Maximum | Minimum | Average | Standard Deviation |
|---|---|---|---|---|
| I | 19.7 | 1.5 | 13.3 | ±3.8 |
| II | 25.6 | 1.6 | 16.1 | ±4.7 |

### 3.4.2 Reliability

Reliability refers to the controllability of observations, namely the ability to detect outliers and to estimate the effects that undetected may have on a solution (Leick, 2004). To evaluate the reliability of the final adjustments, redundancy number and marginally detectable biases (MDB) were computed from variances of the adjusted residuals and the observations. The redundancy numbers which should range between 0 and 1 provide an insight into geometric strength of a network, indicating that the lower, the less sufficient the blunders are isolated (Ghilani, 2010). On the other hand, the MDBs are the biases that can only just be detected as outliers with a certain probability at a specific significance level (Caspary, 2000; Harvey, 2006).

Figure 12 represents the results of the redundancy numbers and the MDB of the final adjustments whereas Table 6 tabulates their statistics. Since CASE-I's DoF is higher than that of CASE-II as given in Table 4, the redundancy numbers of the former are slightly larger. Furthermore, CASE-I's MDBs are overall more elevated than those of CASE-II. Although these results indicate that the reliability of the CASE-I is increased by the newly installed UCPs as well as the measurements via this project, the geometric strength is still too low to sufficiently check blenders as the redundancy numbers about 0.5 are generally required for a surveying network (Ghilani, 2010). However, this is an indispensable drawback of the spirit levelling loops because its field works generally take much time-consuming and costly. It is remarkable to realise that the number of observations whose redundancy number is zero; that of CASE-I is much smaller compared to CASE-II. Note that if the redundancy number is zero, computed residual goes infinity, indicating the lack of measurement self-checking.

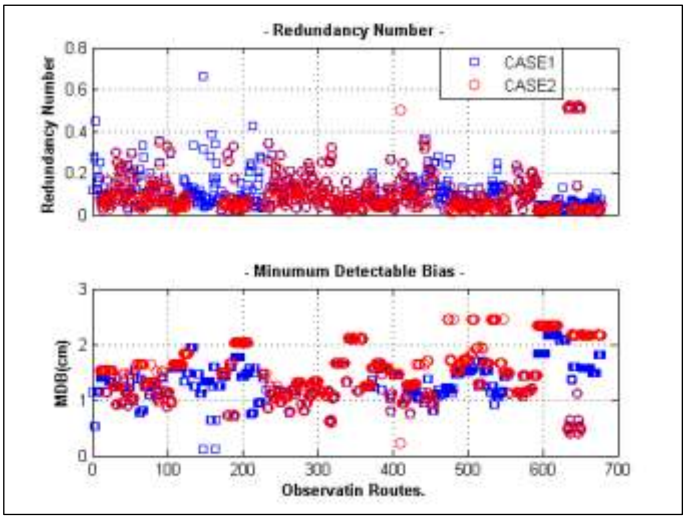


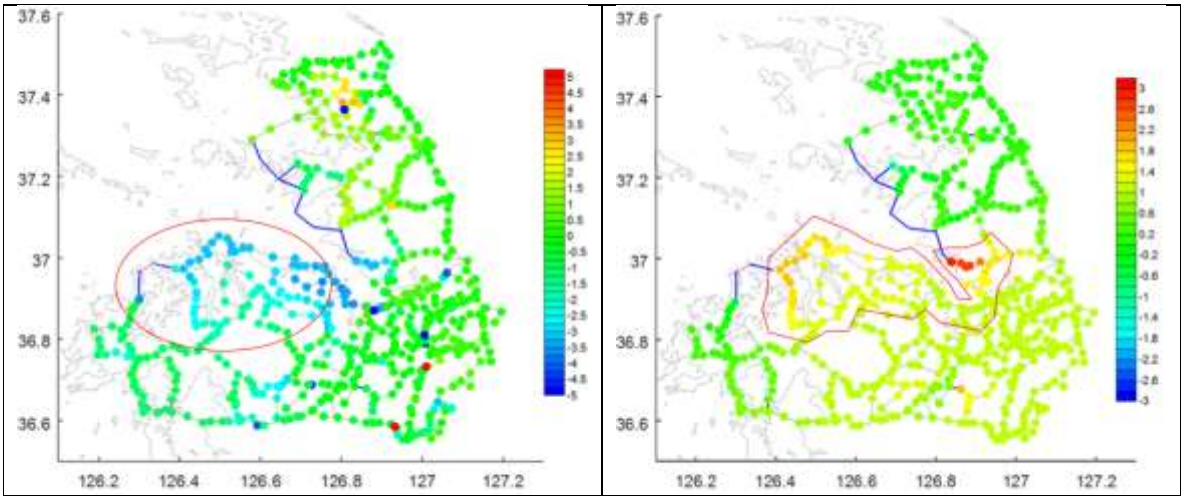

Figure 12. Reliability comparison of the final adjustments.

Table 6. Statistical summary of redundancy numbers and MDB of the final adjustments.

| Case | Redundancy Number | | MDB (unit: cm) | | No. of obs. whose redundancy number is zero |
|---|---|---|---|---|---|
| | Average | Std. Dev. | Average | Std. Dev. | |
| I | 0.096 | ±0.082 | 3.7 | ±1.4 | 22 (3.6%) |
| 2 | 0.081 | ±0.080 | 4.0 | ±1.8 | 82 (13.6%) |

### 3.4.3 Adjusted Heights

Adjusted heights of CASE-I have been compared to those published by NGII, and results are illustrated in the left map in Figure 13 to deliver the impact of the UCPs-based network composition into the adjusted heights. It can be seen from them that the heights of the north area become somewhat high whereas those of the south are low (e.g., biased about 3.5cm), see, e.g., the circled area in the left map of the figure. This might be attributed to the establishment of the additional loops along the west coastline. With consideration of the accuracy enhancement around that area (e.g., Figure 11), these biases seems to be a positive impact on the height estimation. It should be, moreover, mentioned here that four points of the height differences are abnormally large as over 9cm as shown in the map. These points are all the 2nd-order BMs which have been re-surveyed for linking them to the 2nd-phase UCPs from 2014 to 2015. Note that the published heights are outcomes from the surveying campaigns in the mid-2000s. With this concern, it is doubtable if the surveying monuments are displaced; therefore further verification is highly required by reconnaissance. Comparing the estimated heights of CASE-I with the published ones, Table 7 reveals that the differences of the 1st-phase UCPs are relatively large as all the original loops are all changed by linking at least two near points according to the new design strategy. On the other hand, the smallest height changes are observed in the 1st-order BMs because their loops are mostly kept in the new network design.



(a) CASE-I and Published heights (b) CASE-I and II

Figure 13. Comparison of the adjusted heights.

The right map in Figure 13 depicts the height differences between CASE-I and -II, and the lower part of Table 7 summarises their statistics. The more considerable differences are observed around the areas (e.g., the solid lines) like the left map, but magnitudes of these differences are limited. This means that the new network itself has more impacted on the height estimation, compared to the additional installation and survey. On the other hand, it should be noted that the height deviations of the 2st-phase UCPs and the 2nd-order BMs are more remarkable than the others. This is probably attributed to the fact that these control points are closely located to the newly surveyed areas.

Table 7. Statistical summary of the adjusted height comparison.

| Compared Data Sets | Type of Points | | No. of Points | Max. | Average | Std. Dev. |
|---|---|---|---|---|---|---|
| CASE-I & Published | Total | | 597 | 11.5 | 1.2 | ±1.2 |
| | BMs | 1st-order | 103 | 4.2 | 0.5 | ±0.7 |
| | | 2nd-order | 295 | 11.5 | 1.5 | ±1.3 |
| | UCPs | 1st-phase | 17 | 5.6 | 1.6 | ±1.4 |
| | | 2nd-phase | 182 | 3.6 | 0.9 | ±0.9 |
| CASE-I & II | Total | | 603 | 2.7 | 0.7 | ±0.5 |
| | BMs | 1st-order | 108 | 0.9 | 0.4 | ±0.4 |
| | | 2nd-order | 300 | 2.5 | 0.7 | ±0.5 |
| | UCPs | 1st-phase | 13 | 0.9 | 0.5 | ±0.4 |
| | | 2nd-phase | 182 | 2.7 | 0.8 | ±0.4 |

## 4. CONCLUDING REMARKS

This paper has introduced a UCPs-based geodetic network currently under materialisation in Korea for 3km gridding spaces with about 7,000. Full implementation of the new geodetic controls will mostly supersede the legacy networks that consists of triangulation points and benchmarks, delivering multi-dimensional geodetic coordinate sets. Apart from GNSS infrastructure (e.g., CORS – continuously operating reference stations), the UCPs network will be only the monument-typed geodetic points (e.g., passive controls) in the nation in the future. Even though the horizontal geodetic system enables to be readily implemented by GNSS technology, there is a technical challenge to establish the vertical one which leads to this study.

After addressing drawback of the current UCPs as vertical controls, a concept and strategy of the UCPs-based levelling network have been discussed with a view to enhancing accuracy, reliability and accessibility. Depending on technical circumstances which can be encountered, three schemes were proposed to design the UCPs network, such as substitution, designation, installation. A pilot network was composed with 621 points throughout the northwest region of South Korea. After examination of loop closures, a series of preliminary adjustments were made to identify a blunder and determine a stochastic model; one measurement was removed, and $\pm 1.7$ mm and $\pm 3.4\ \mathrm{mm}/\sqrt{Km}$ were defined to reference standard deviations. Final adjustments have been performed twice, and the results can be summarised: (a) the new 2nd-phase UCPs and observations achieved by this study indeed improve the accuracy of the estimated heights but marginally enhanced the reliability; (b) the UCPs-based levelling control enables to change the published heights to about 3cm at maximum, which should be a positive impact with consideration of the geometric enhancement.

NGII is the process of the project that nationwide installs the 2nd-phase UCPs as well as carries out GNSS and spirit levelling campaigns as well as gravimetric surveys. Although the normal orthometric height system was adopted to the pilot network, the orthometric system will be introduced as a national standard if the project is completed.

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