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# A PILOT STUDY ON LEVELING NETWORK ADJUSTMENT OF MULTI-DIMENSIONAL GEODETIC CONTROL POINTS IN REPUBLIC OF KOREA


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# Outline of the Presentation

- INTRODUCTION
- DESIGN OF A PILOT LEVELING NETWORK BASED ON UCPS
- NETWORK ADJUSTMENTS AND RESULTS
- CONCLUDING REMARKS

# INTRODUCTION

# TRADITIONAL GEODETIC CONTROL POINTS IN KOREA

## Triangulation Points (TPs)

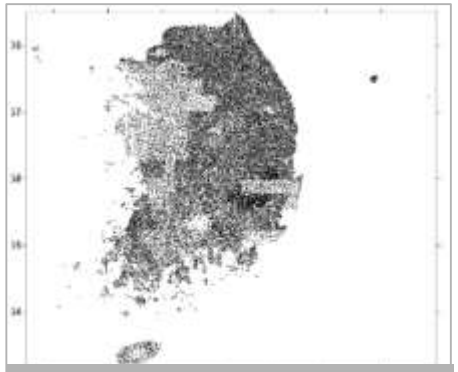
- About **16,000** points with 2.5 km gridding spaces
- **Mostly located on the hilltops for visibility of traditional surveys**
- 75% of TPs were re-surveyed by the GNSS technique
- Nationwide adjustments were performed in 2008 for densification of the new global geodetic datum (KGD2002).

## Geodetic Benchmarks (BMs)

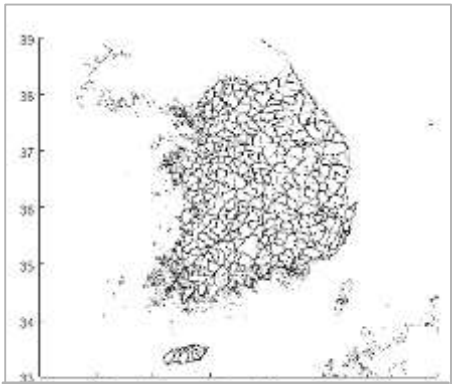
- A total of **7,296 points** (1st-order: 1,135, 2nd-order: 6,161)
- Sited **every 2km or 4km along major national and state roads**
- Nationwide adjustment were carried out from 2005 to 2006

## Limitations

- **Poor accessibility of TPs** due to their topographical locations
- **Low spatial density of BMs** because of geometrical feature of leveling loops
- **Difficulty to maintain** a huge number of the geodetic points



Triangulation Posints Survyed by GNSS



Geodetic Leveling Benchmarks

# MULTI-DIMENSIONAL GEODETIC CONTROL POINTS IN KOREA

## Unified Control Points (UCPs)

- **Multi-dimensional geodetic control points** providing *3-D geodetic coordinates, orthometric heights, and gravities*.
- **Multi-functional surveying control points** for traditional surveys, GNSS, relative gravimetry, and ***satellite photogrammetry and remote sensing***
- **Installed in the low elevation areas with a consideration of accessibility**
- **The UCP network will supersede the most traditional geodetic points.**

| GNSS | Spirit-leveling | Relative Gravimetry |
|---|---|---|
|  |  |  |
| Geodetic coordinates($\lambda, \phi, h$) | Orthoognal height($H$) | Gravity($g$) |

# STATUS OF UCPS INSTALLATION AND SURVEYING CAMPAIGN

## The 1st-phase UCPs

- **Overview**
  - ❖ **1,196 points** were installed from 2008 to 2012 at mostly **10km** gridding spaces
  - ❖ Surveyed by GNSS, **spirit-leveling (double-running & single connection)**, gravimetery
  - ❖ GNSS network adjustment was completed
  - ❖ **Simple arithmetic computation** was adopted for height determination
- **Limitations**
  - ❖ **Low density** of supporting traditional surveying techniques (e.g., spirit-leveling)
  - ❖ **Very poor reliability** of leveling network
  - ❖ **Relative low precision** of geodetic leveling

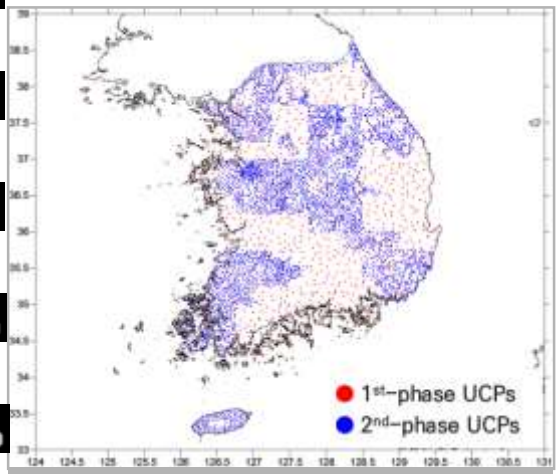
## The 2nd-phase UCPs

- **Overview**
  - ❖ Commencing the project in 2012 to the 1st-phase UCPs up to **3 km** gridding intervals by installing **additional 6,000 points**
  - ❖ Surveyed by GNSS, spirit-leveling, gravimeter
  - ❖ **But, spirit-leveling lines are connected to at least two control points (UCPs and/or BMs)**
  - ❖ Gravity observations are used for orthometric corrections and geoid modeling
- **Future Considerations**
  - ❖ Installation of remaining points & surveys
  - ❖ Design of geodetic leveling loops and circuits
  - ❖ Geodetic network adjustment

# BACKGROUND & OBJECTIVE OF THE RESEARCH

## Background

- ❖ **The UCPs will mostly supersede the traditional geodetic points (e.g., triangulation points, benchmarks) by 2025.**
- ❖ **To achieve this goal:**
  - ✓ The 1st-phase UCPs' leveling loops are re-measured by application of the 1st-class surveying specification.
  - ✓ **Geodetic leveling loops and circuits (i.e., network) are redesigned.**
  - ✓ Installation of the remaining 2nd-UPCs should be completed.
  - ✓ **The UCP network need to be re-adjusted**




Installation Status of UCP Network in 2017

## Objectives

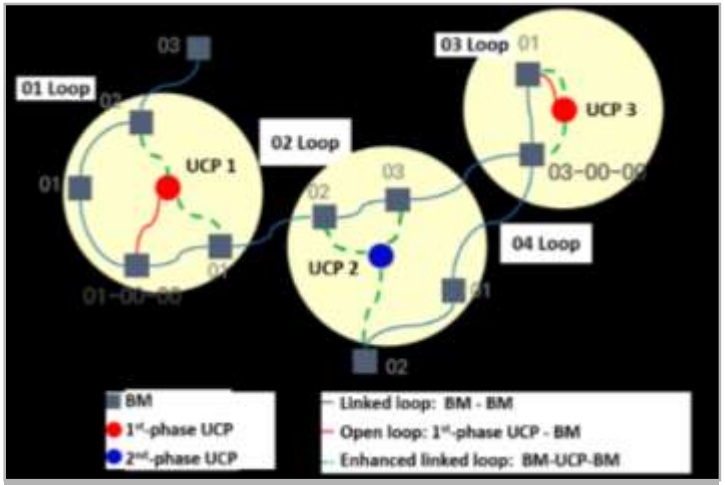
- ❖ **To develop strategies of the UCPs-based leveling network design considering with the resurveys & the new installation.**
- ❖ **To build and adjust a pilot UCPs-based leveling network to demonstrate advantages of the new approach.**

# Design of a Pilot Leveling Network Based on UCPs

# STRATEGIES OF A NEW LEVELING NETWORK DESIGN (1/3)

## Strategy#1: Substitution

- ✓ UCPs replace some BMs within 3km radius.
- ✓ Some legacy loops are removed from a new network




An example design of the strategy#1

### As IS:

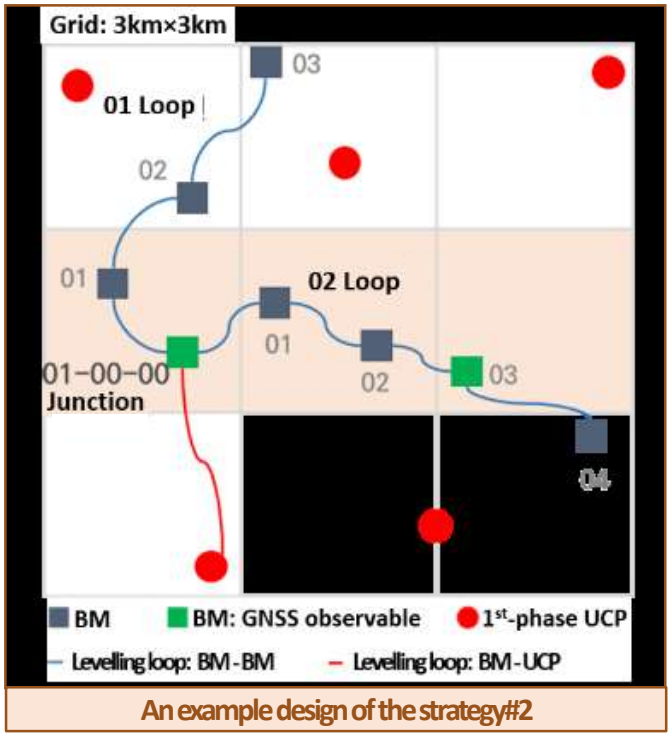
- ❖ 1st-phase UCPs are connected to a single BM.
- ❖ 2nd-phase UCPs are linked to two BMs.
- ❖ In some areas, excessive geodetic points are located as shown in Figure (4 with 3km radius).

### To Be:

- ❖ 1st-phase UCPs loops will be connected to two near BMs or UCPs by the 1st-class leveling
- ❖ BM 01-00-00 and -01 will be removed and the leveling loop will be no longer maintained.
- ❖ If possible, a certain UCP will be linked to three BMs and/or others UCPs for enhancement of the geometric strength.

# STRATEGIES OF A NEW LEVELING NETWORK DESIGN (2/3)

## Strategy#2: Designation




An example design of the strategy#2

✓ **BMs can be designated as UCPs by GNSS surveys.**

### As Is:

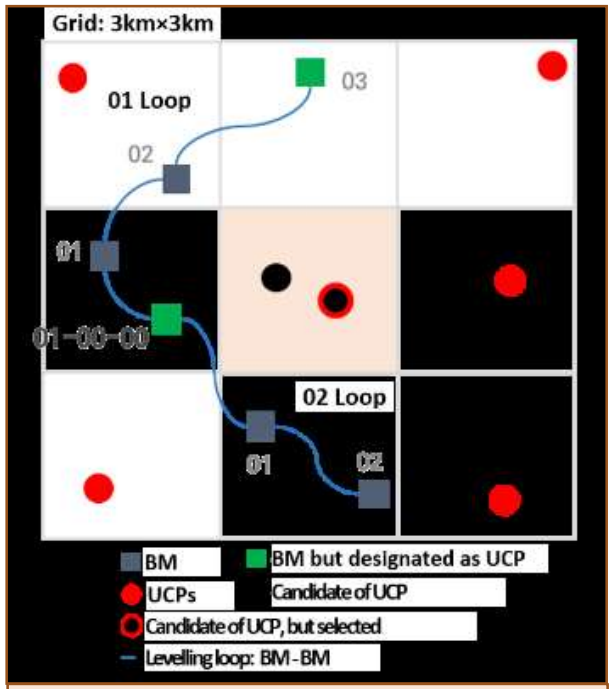
- In some area, no UCP exists at 3km gridding space
- However, GNSS surveys are possible according to reconnaissance.

### To Be:

- **Instead of installing a new 2nd-phase UCP, BM will be designated UCP by GNSS surveying.**
- For instance, BM 01-00-00 and 01-00-03 can be possible designated UCP in the future leveling network implementation.

# STRATEGIES OF A NEW LEVELING NETWORK DESIGN (3/3)

## Strategy#3: New Installation




Concept of new installation of UCPs

### As IS:

- Although the 1st-phase UCPs installation was completed in 2012, no UCP exists in some 3km grid (e.g., see, 2nd-row and 2nd-colum)
- The 2nd-phase installation project is still ongoing.

### To Be:

- Such a grid has the most high priority of new UCP installation.
- After setting up a survey mark, GNSS, spirit-leveling, gravimetry will carried out.
- By adding the new UCP, **leveling loops are rebuilt by application of the strategy 1 and 2**

# OVERVIEW OF THE PILOT LEVELING NETWORK

❖ **Circuit No. 12 of the national network**

- ✔ **The vertical origin** is included.
- ✔ The 2nd-phase UCP installation was mostly **completed**.
- ✔ The 1st-phase UCPs are **re-surveyed** to connect at least two near BMs and/or UCPs.

❖ **New installation and surveys in this study**

- ✔ **8 UCPs** were added along the west shoreline to make the leveling loops close.
- ✔ **5 leveling section** in inland were surveyed.

❖ **The designed network**

- ✔ Consisted of **70 sub-circuits** composed by **621** points
- ✔ The No. of measurements is **690**, and **64%** of them was observed by the 1st-classs standard.

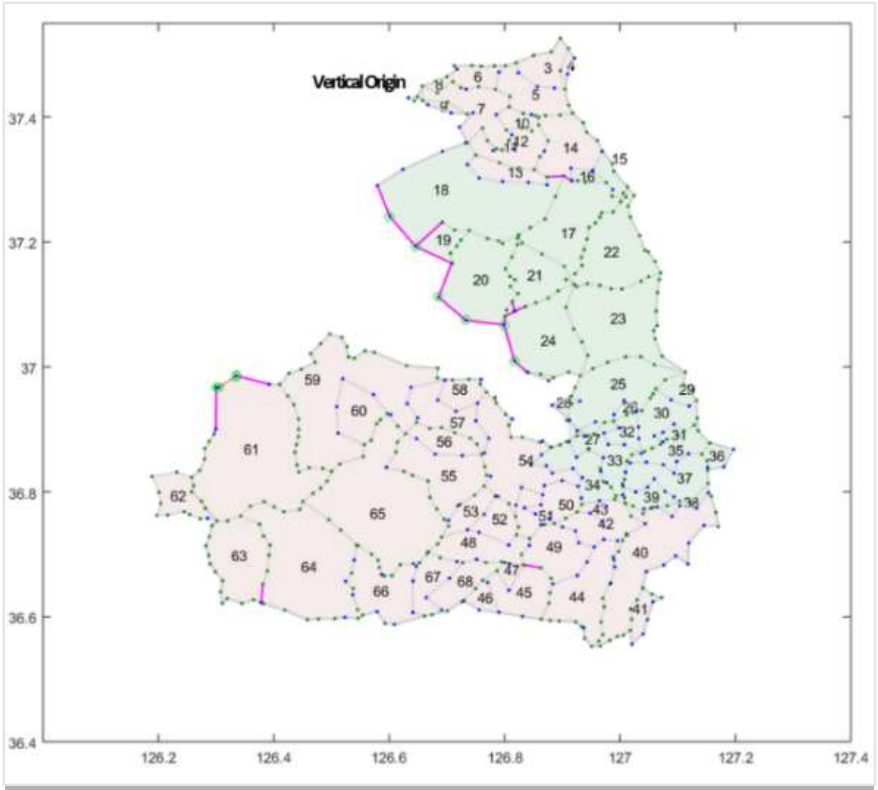
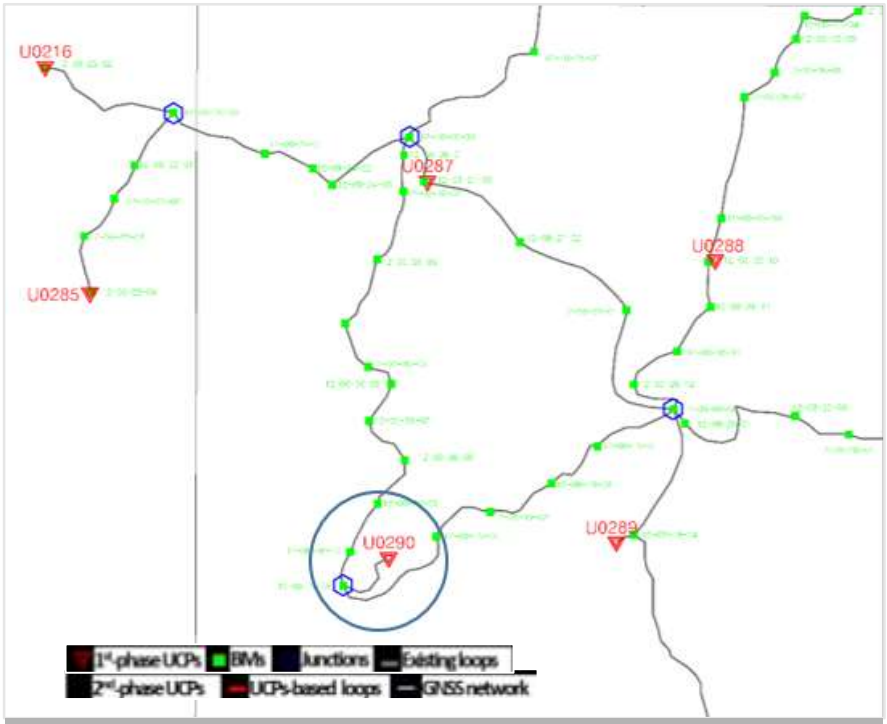
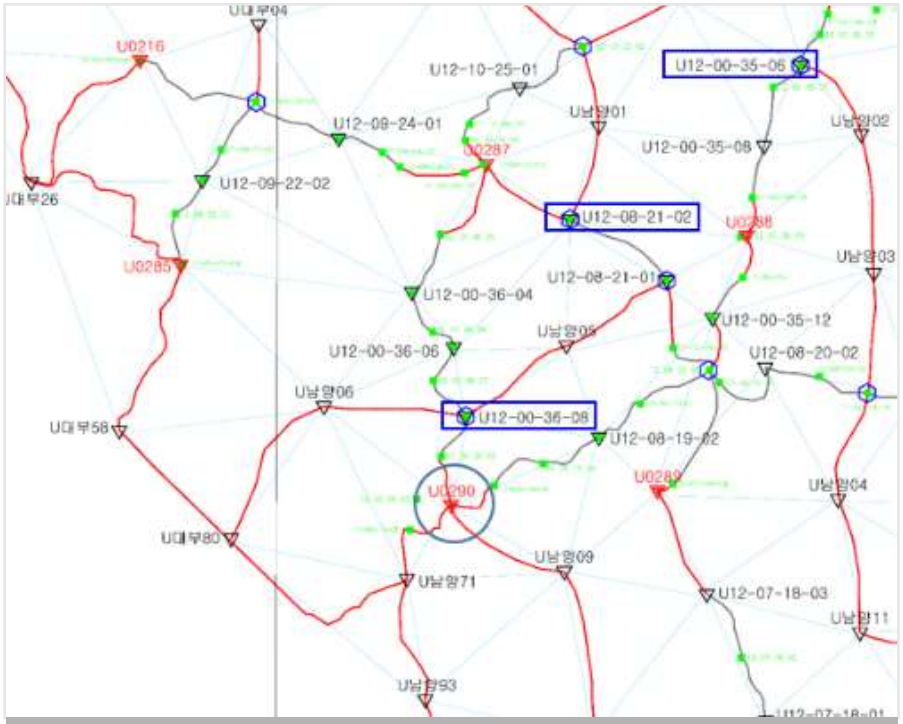



Diagram of leveling loops and circuits

# COMPARION OF LEGACY AND NEW LEVELING NEWORK



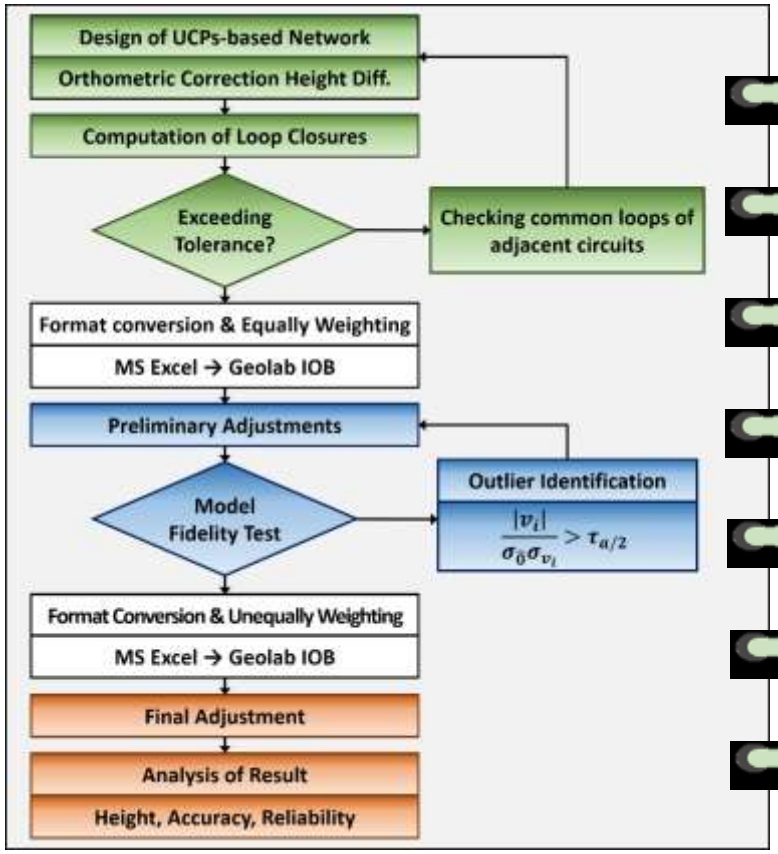

BMs-based leveling network




UCPs-based leveling network

# NETWORK ADJUSTMENT AND RESULTS

# A Procedure of Adjustment and Analysis




## Pre-analysis of measurements

- Computation of all the closures of 70 sub-circuits
- Comparison of the misclosures with the tolerance
- Removal of erroneous loops and re-definition of sub-circuits

## Preliminary adjustments

- Identification of outliers w.r.t. residuals and their adoption
- Assessment of relative precision
- Determination of variances for the final adjustments

## Final adjustment

- Estimation of normal orthometric heights
- Assessment of absolute precision

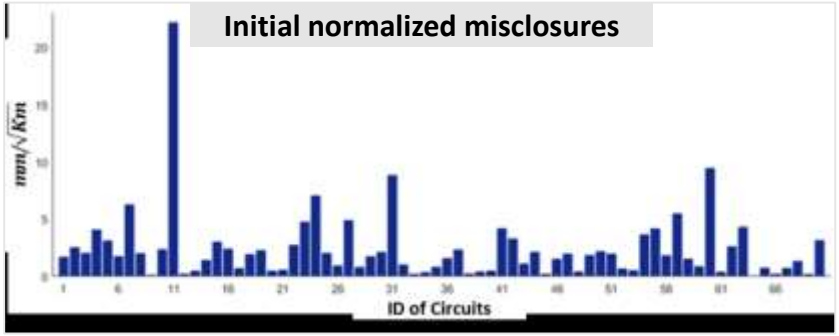
## Analysis of results

- Internal reliability (e.g., MDB)
- Comparison of the estimated heights with published ones

# PRE-ANALYSIS OF MEASUREMENTS

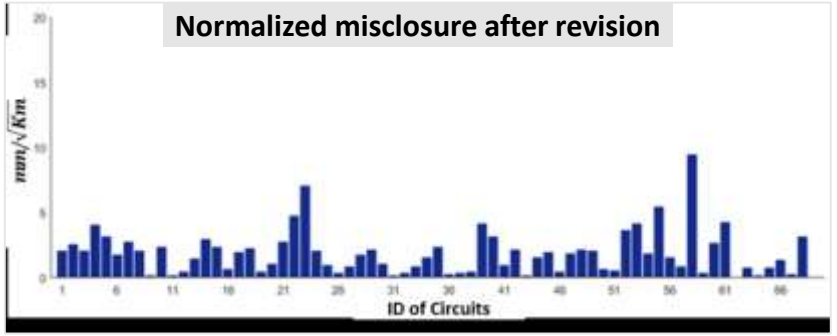
## Misclosure Computations

- Average of misclosures: $15.3mm$
- Average of normalized misclosures: $2.3mm\sqrt{km}$
- Circuits exceeding the tolerance
  - **Six circuits** had relatively larger misclosures.
  - Further analysis with adjacent circuit sharing the suspected circuits was conducted.




## Redefinition of the sub-circuits

- **Two erroneous loops** were removed and the sub-circuits were redefined.
- Average of misclosures: $13.0mm$
- Average of normalized misclosures: $1.8mm\sqrt{km}$
- ***Note that the circuits exceeding tolerance are still remained in the data.***



# PRELIMINARY ADJUSTMENTS

## Possible outlier examination

- A reference standard deviation: $\pm 2mm\sqrt{km}$
- One measurement was detected as an outlier from a local test w.r.t. normalized residuals.
- The erroneous line was removed
- The subsequent 2nd -round adjustment passed a global test

## Determination of reference variances

- **Iterative adjustments** were carried out to determine **reference variances ($\sigma_0^2$)** of the 1st and 2nd–class surveyed measurements.
- 1st-class $\sigma_0^2$: $\pm 1.7mm/\sqrt{km}$
- 2nd-class $\sigma_0^2$: $\pm 3.4mm/\sqrt{km}$
- Average relative accuracy: $\pm 3.4mm$

**Summary of the adjustments**

| Trial | No. of points | No. of Obs. | No. of unknown | Degree of freedom | A posterior variance |
|---|---|---|---|---|---|
| 1st | 618 | 684 | 617 | 67 | 1.627 (fail) |
| 2nd | | 683 | | 66 | 1.248 (pass) |
| 3rd | | | | | 0.981 (pass) |

# FINAL ADJUSTMENTS (1/4)

## Measurement Sets for the Adjustments

- Two sets of measurements were adjusted by fixing the national vertical origin

**CASE-I**

All of the stations and observations described in the section 2

**CASE-II**

The same as CASE-I, but stations & observations made by this study were excluded.

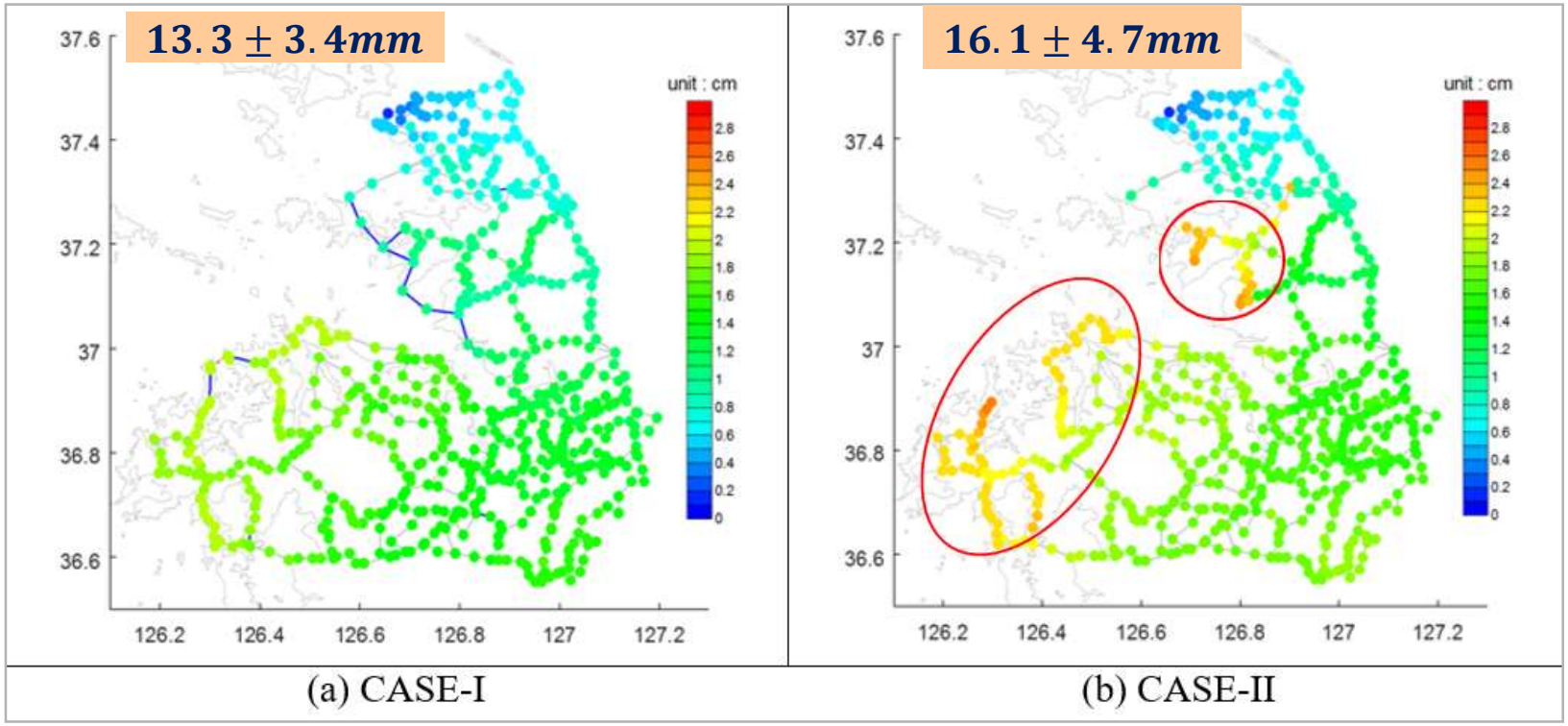
## Overall Results of the Adjustments

- Global tests of adjustments were passed.
- DoF of CASE II is smaller than that of CASE I in spite of its small number of stations.
- The new installation and surveying campaign enhance overall reliability of the leveling network.
- NGII continues performing field campaigns for improvement of geometric strength.

| 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) |

# FINAL ADJUSTMENT (2/4)

## Absolute accuracy

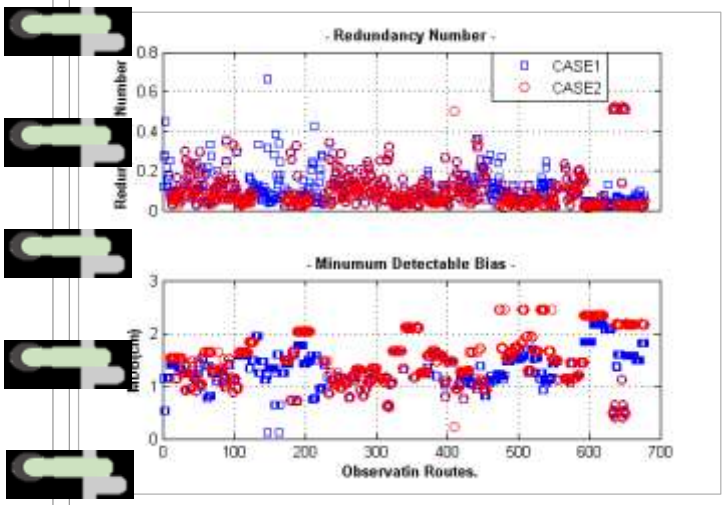



(a) CASE-I (b) CASE-II

# FINAL ADJUSTMENT (3/4)

## Reliability

- Redundancy numbers (RN) and MDBs of CASE I are smaller than that of CASE II in general.
- No. of loops having zero RN of CASE II is larger than that of CASE I
- New installations and survey campaigns generally enhance reliability of the network.
- Note that such a reliability is still not enough to sufficiently checking out outliers



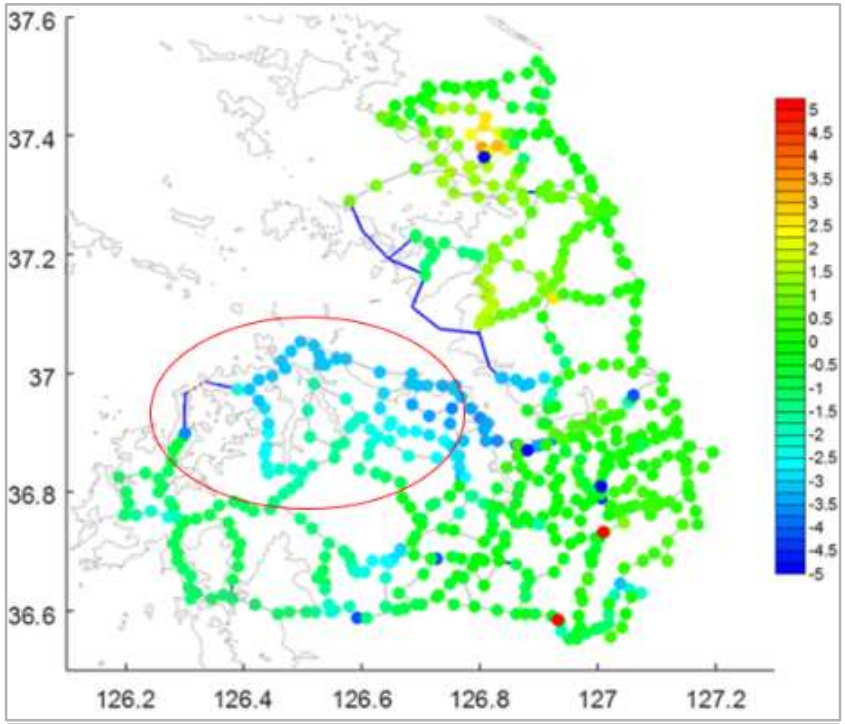

| Case | Redundancy Number | | MDB (unit: cm) | | No. of obs. whose redundancy number is zero |
|---|---|---|---|---|---|
| | Average | Std. Dev. | Average | Std. Dev. | |
| I | 0.096 | ±0.082 | 3.7 | ±1.4 | 22 (3.6%) |
| II | 0.081 | ±0.080 | 4.0 | ±1.8 | 82 (13.6%) |

# FINAL ADJUSTMENT (4/4)

## Height change after the adjustment

- Estimated heights of CASE-I were compared to the published ones
  - ✓ A bias is observed around circled area
  - ✓ The 1st-order BMs are not mostly changed
  - ✓ The difference of heights of 1st -phase UCPs are relatively large

**Considering the accuracy enhancement, the height change, especially the bias along the west coastline might positively impact into the estimated heights.**




Compared results of the CASE-I with the published.

# Concluding Remarks

- **Necessity of UCP**
  - ❖ Legacy reference points(TPs, BMs) has limitation due to the feature of terrestrial surveying
  - ❖ Multi-dimensional and multi-functional control point was designed and has been installing to overcome the limitation of existing reference points
- **Design of the geodetic vertical network based on UCPs**
  - ❖ UCPs based network will supersede the current network and play a role as a single layer network after full implementation with total 7,000 points
  - ❖ Three strategies were suggested to design UCPs based geodetic leveling network
- **Evaluation of the impact of UCPs**
  - ❖ A pilot network was adjusted and analyzed in the aspect of accuracy, reliability, and height
  - ❖ Addition of the UCPs and loops led to improvement of geometric strength of network
  - ❖ The accuracy and reliability were overall enhanced
  - ❖ Considering these results, the impact of additional installation and survey into the height would be positive.

# Thank you for your attention

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