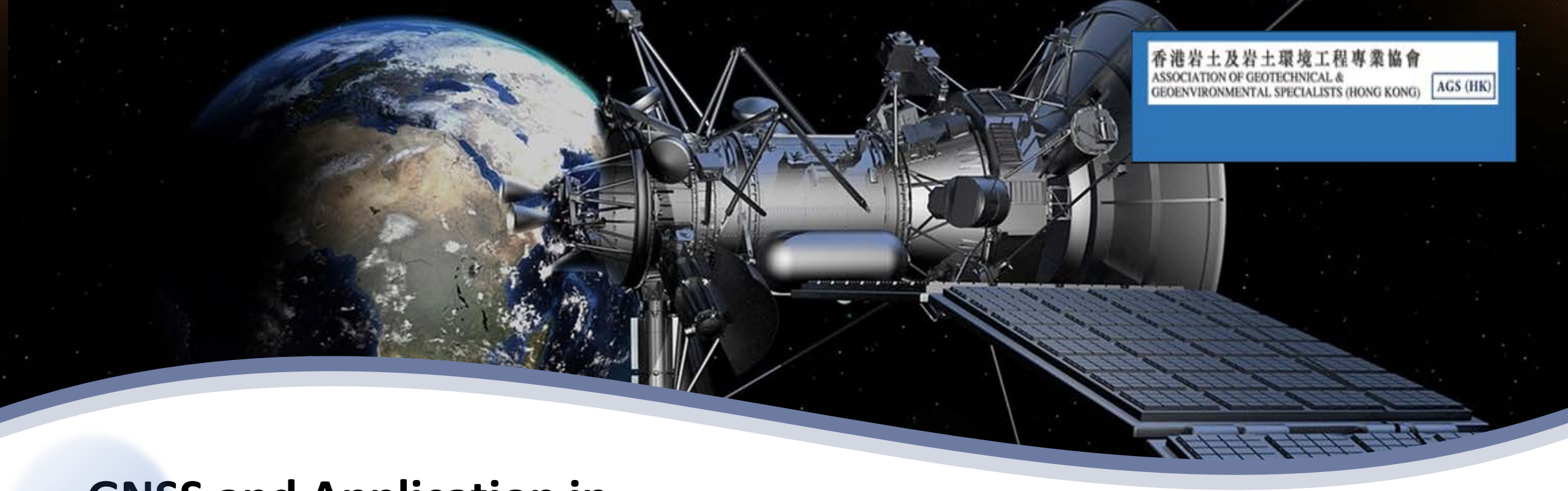


GNSS and Application in Utility Settlement Monitoring

Ir Dr Owen WT YANG
Anchor Monitoring Technology (HK) Limited
Owen@xcanchor.com
27 March 2025

About me

- Ten years of GNSS research experience at Hong Kong Polytechnic University(HKPOLYU).
- A GNSS-based real-time monitoring solution included hardware and software developed.
- Applied in over 100 projects across Hong Kong, mainland China, Taiwan, and South Korea.

Representatives

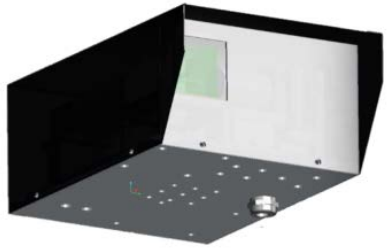
- The settlement monitoring of the third runway reclamation at Hong Kong Airport, HK
- The monitoring of land reclamation in Tung Chung New Town, HK
- The monitoring of dynamic and static load test of the Second Penang Bridge in Malaysia.
- Regional settlement monitoring in Datong, Mainland China.

PATENT AND ACHIEVEMENTS

- Sliding displacement monitoring robotic. Patent (ZL 2019 2 0776881.4)
- Multi-antenna GNSS receiver. Patent (ZL 2019 2 07 90232.X)
- Yang, W.T., Yu, W.K., Huang, Z.A. (2017). Multi-sensor integrated slope monitoring: a case study in Lantau Island, Hong Kong. National Mountain flood Geological disaster Prevention Conservation and Slope Ecological Rehabilitation Summit Forum.
- Yang, W.T. Ding, X.L. Zhang, L.C. (2011) Monitoring slope stability with multi-antenna GPS and inclinometer. Mapping Conference of Hong Kong, Macao and Taiwan.
- Yang, W.T. Ding, X.L. (2012) Integration of GPS and Tilt-meters for Structure Monitoring China Satellite Navigation Conference, CSNC2012, GuangZhou,17-20 May 2012.
- Chen, Y.B., Yang, W.T., Dai, W.J. (2010) Effect of GPS Stochastic Model on Single Epoch Ambiguity Resolution. Journal of Geodesy and Geodynamics.
- 楊文韜,丁曉利,張樂成 Stuart Millis.結合多天線 GPS 及傾斜儀監測山坡穩定. 港澳臺兩岸三地測繪會議, 澳門, 2011-5.
- Yang, W.T. Dai, W.J. Zhu, J.J. A Single Epoch Ambiguity Resolution Method Based on Deformation Characters and Dual Frequency Constraint. Journal of surveying and mapping.

About me

GNSS



Vision Displacement Gauge

Robotic

Accelerometer

Crack meter

Piezometer

Leveling

Tilt meter

Geneva Award of GNSS product

Outline

1. Deformation Monitoring by GNSS Technology
2. The Error Source of GNSS in the Utility Monitoring
3. Deformation Monitoring by Underground-GNSS
4. Conclusions

Deformation Monitoring by GNSS

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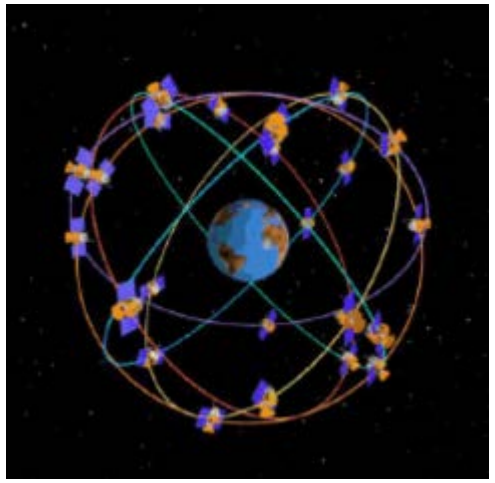
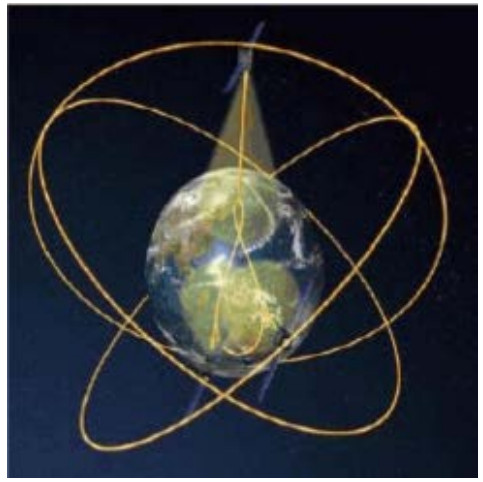
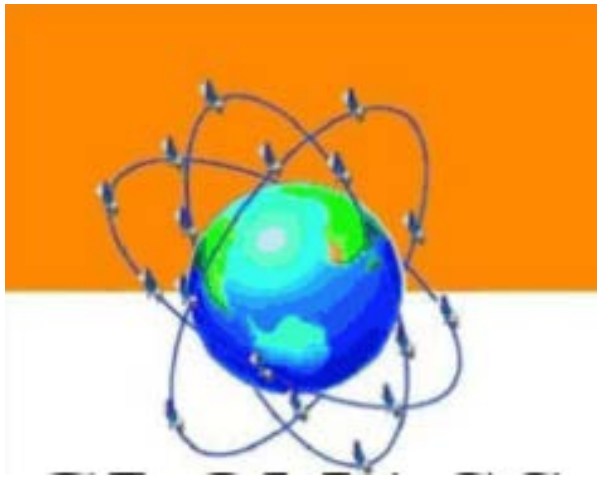
What is GNSS?



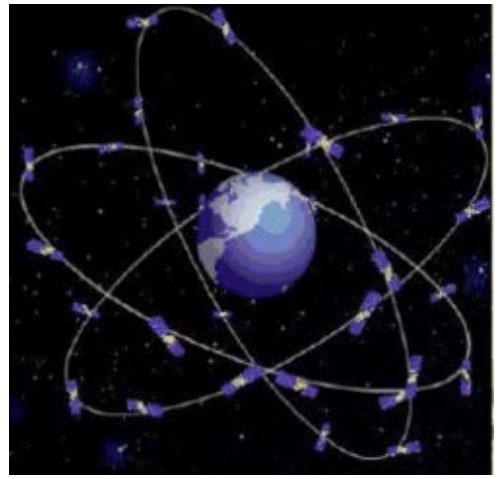
GPS
(USA 1994)



Beidou
(China,2020)



GLONASS
(Russia 2009)



Galileo
(EU,2016)

Global Navigation Satellites System (GNSS) including GPS, Beidou, GLONASS, Galileo, to provide **Positioning**, Navigation and Timing (PNT) Services.

Deformation Monitoring by GNSS

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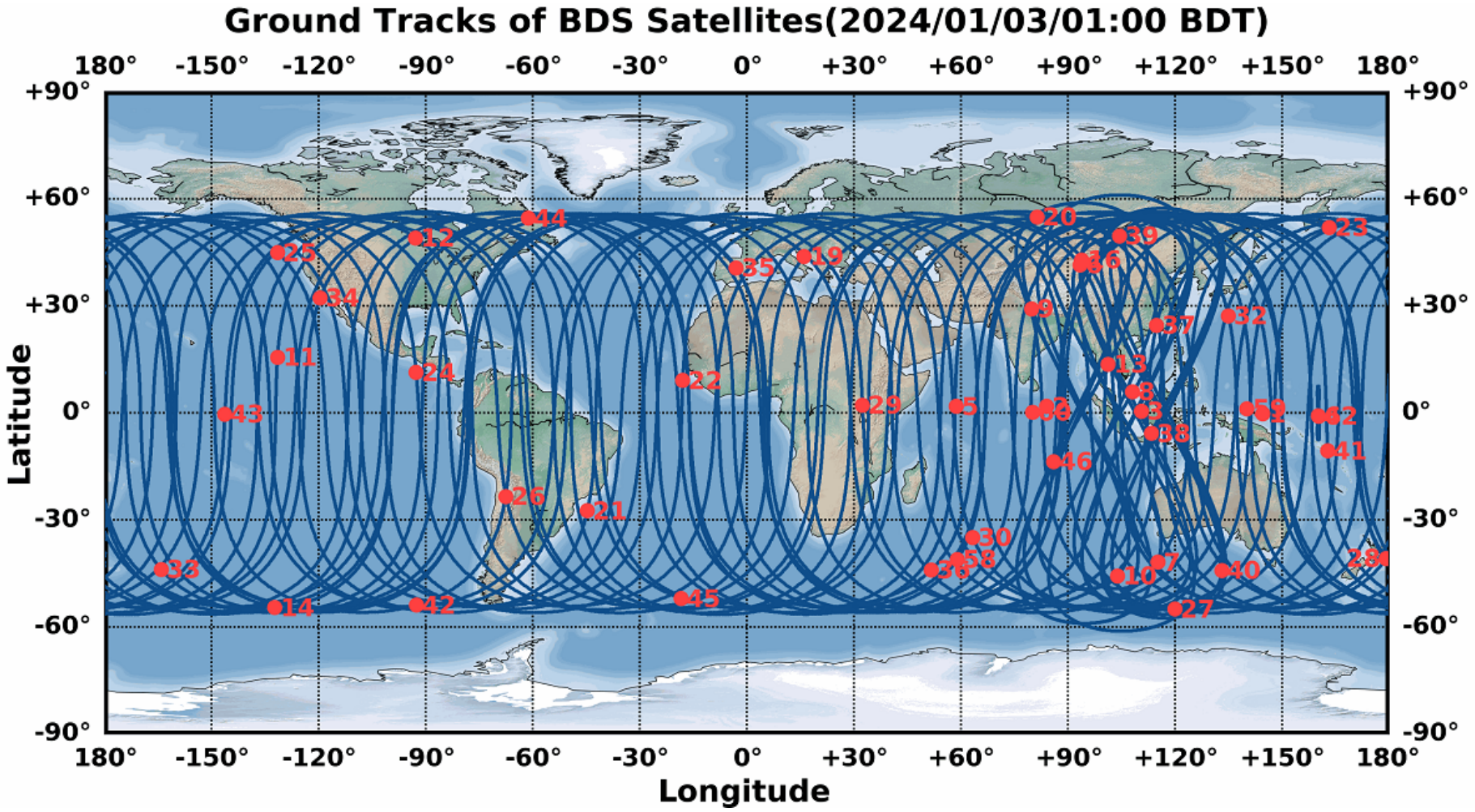
BeiDou System



Operational orbit of the BeiDou satellites

Picture from http://www.beidou.gov.cn/

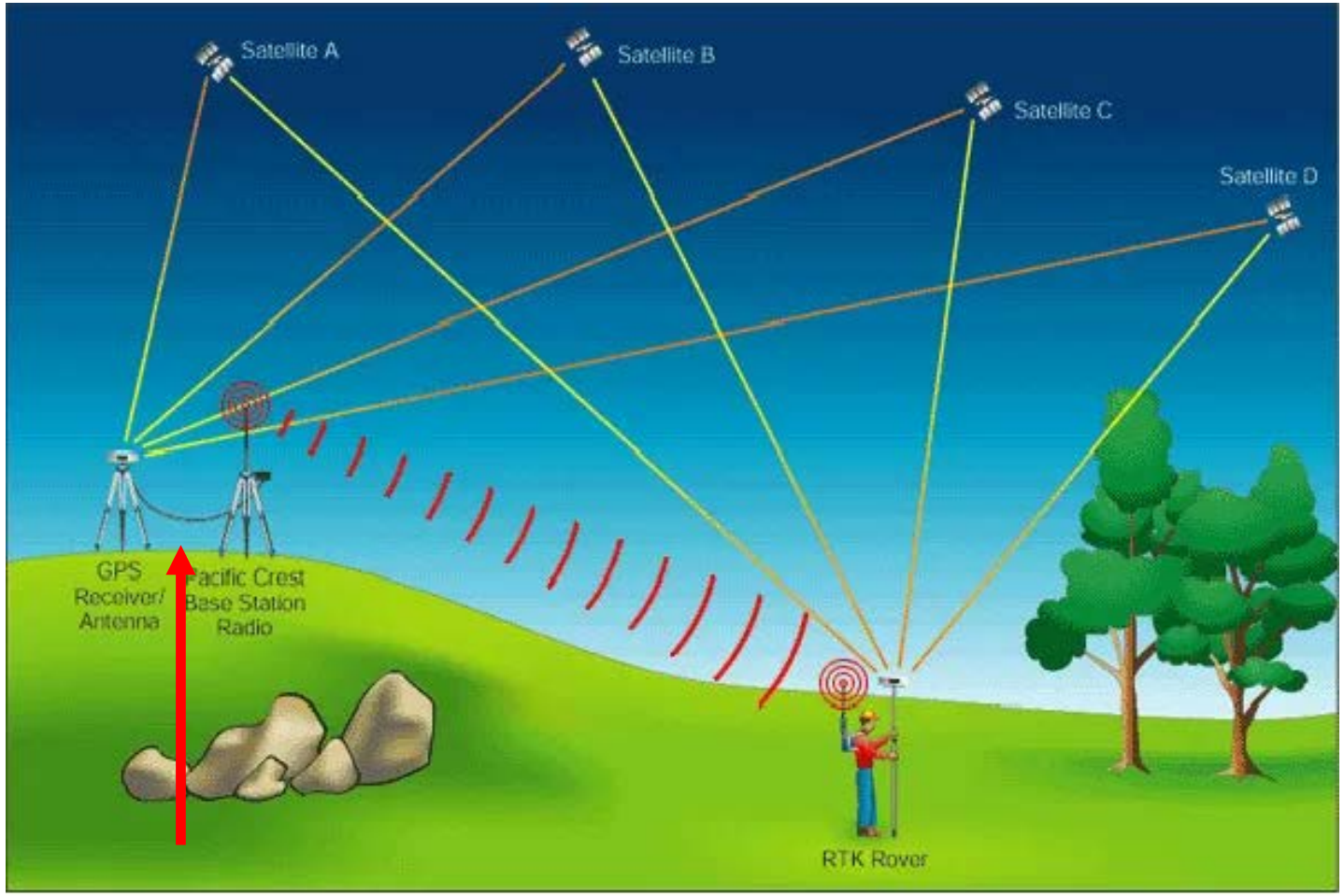
Geosynchronous Earth Orbit(GEO) 9
Inclined Geosynchronous Satellite Orbit (IGSO) 10
Medium Earth Orbit (MEO) 27

Update to 2020.6.15

Deformation Monitoring by GNSS

Positioning Method

- Stand alone Positioning
- **D-GNSS**
- **Real-time Kinematics(RTK)**
- **Network-RTK**
- Precision Point Positioning (PPP)



Reference Point

Difference-GNSS Principle

Deformation Monitoring by GNSS

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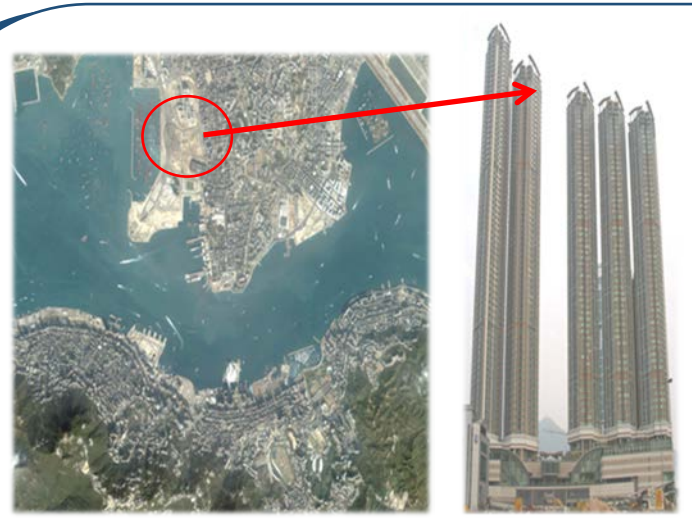
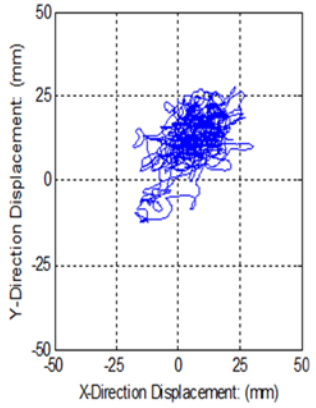
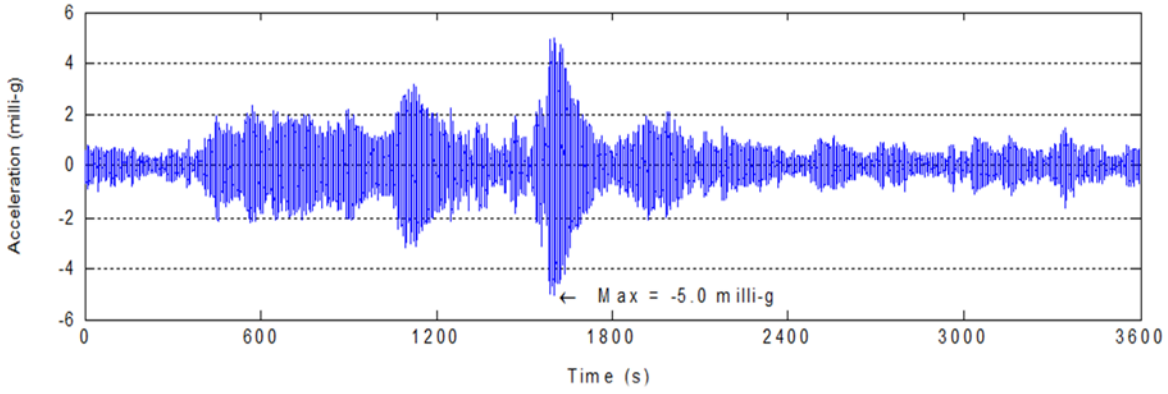
Positioning Method





Displacement 位移量



High-rise Building Monitoring-
Dynamic monitoring of a high-rise building in HK during Typhoon

RTK

Static

Deformation Monitoring by GNSS

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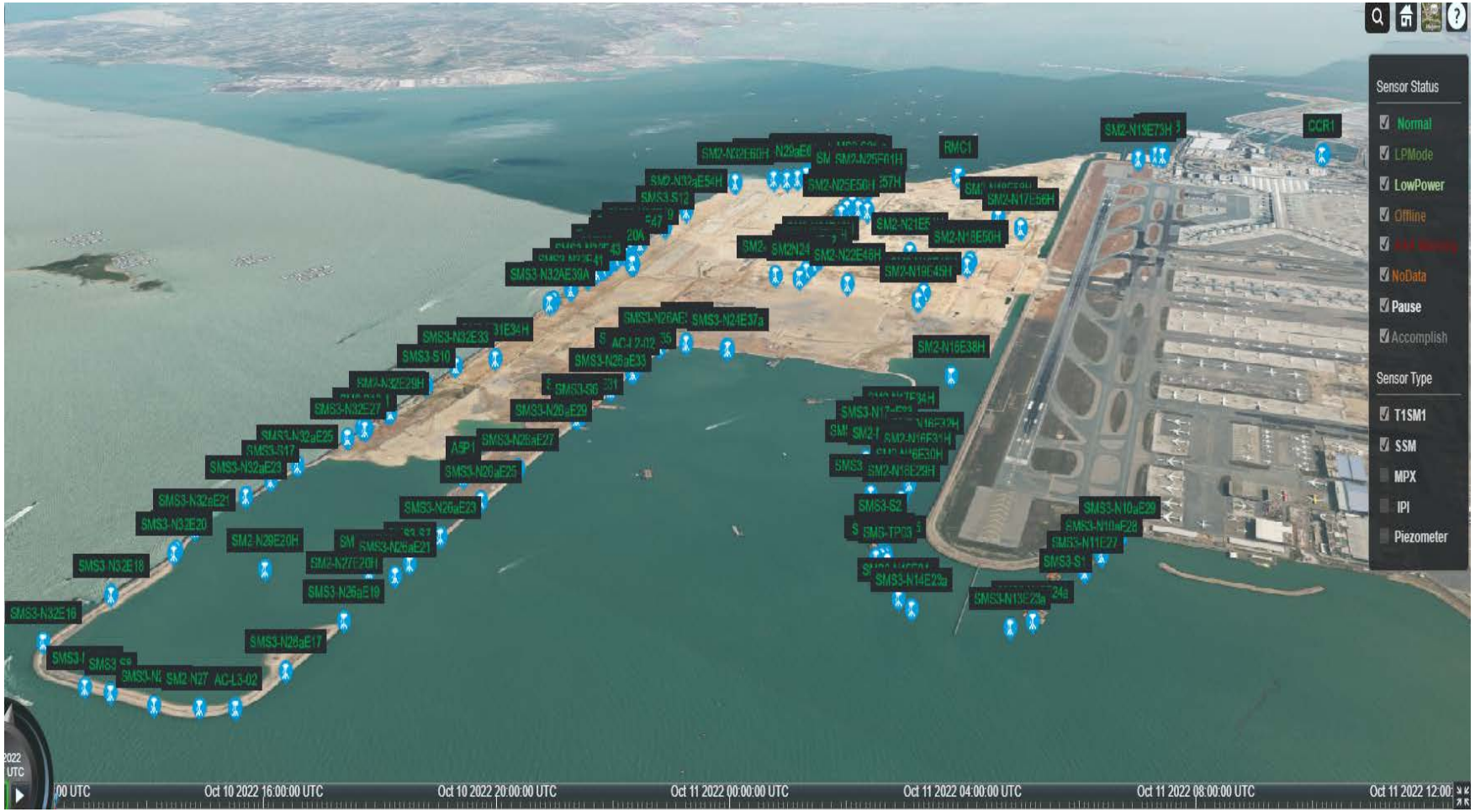
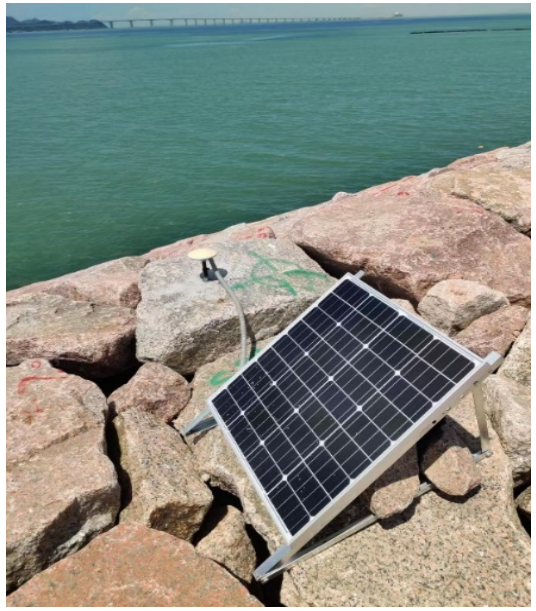
Applications - Reclamation



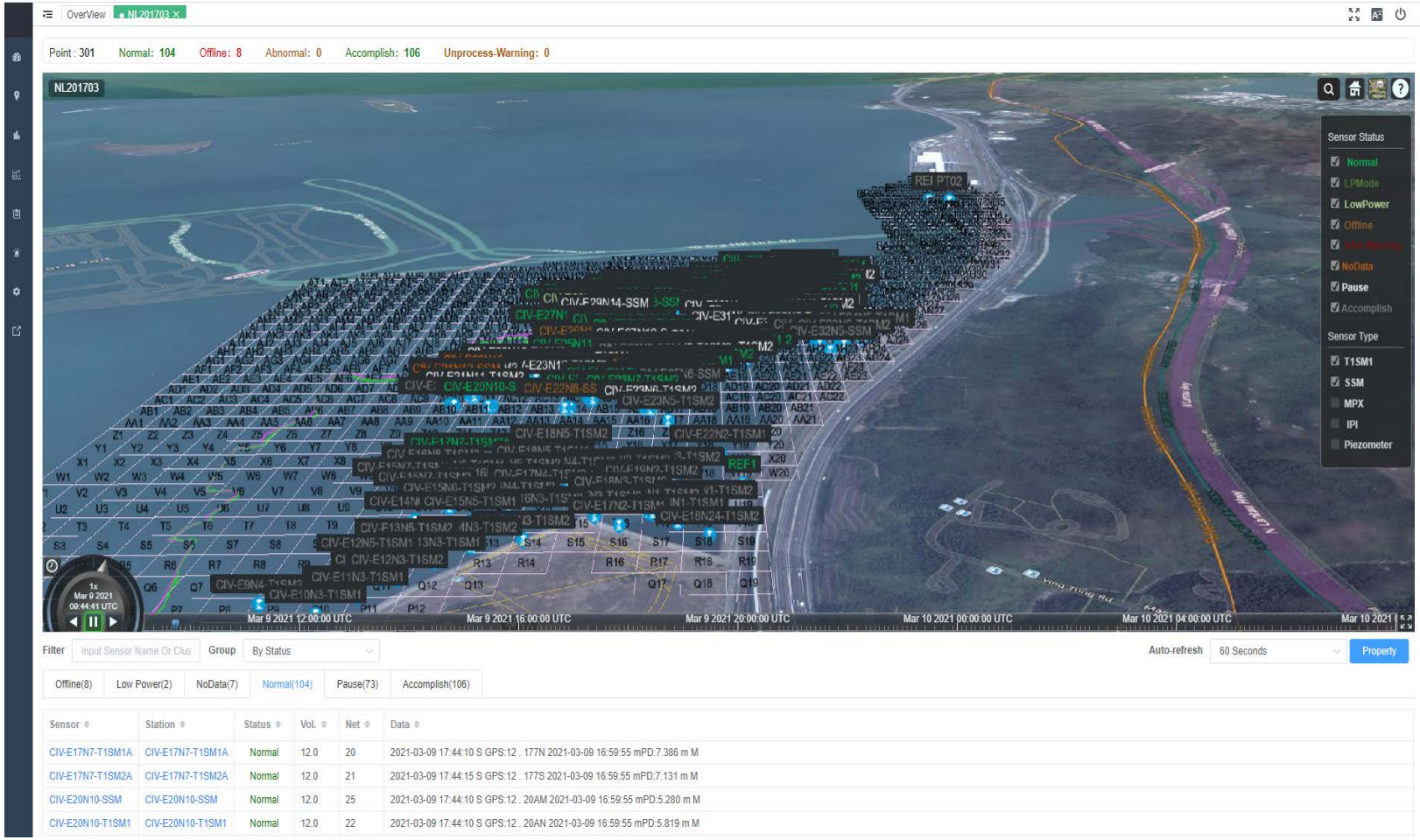


Contract No. C3206

Deformation Monitoring by GNSS

Anchor Monitoring Tech.
安科監測科技(香港)

Applications - Reclamation

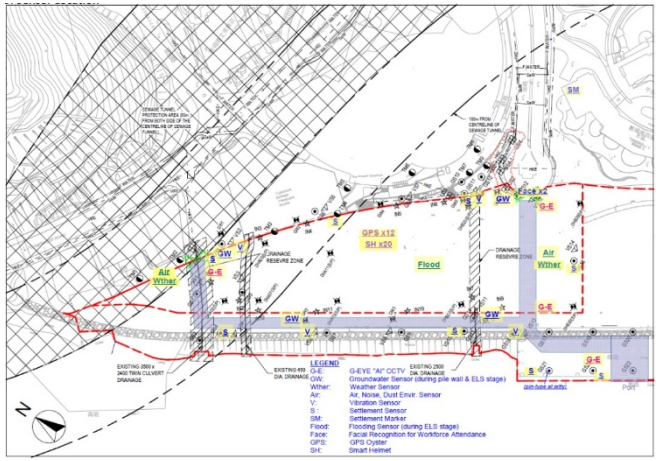


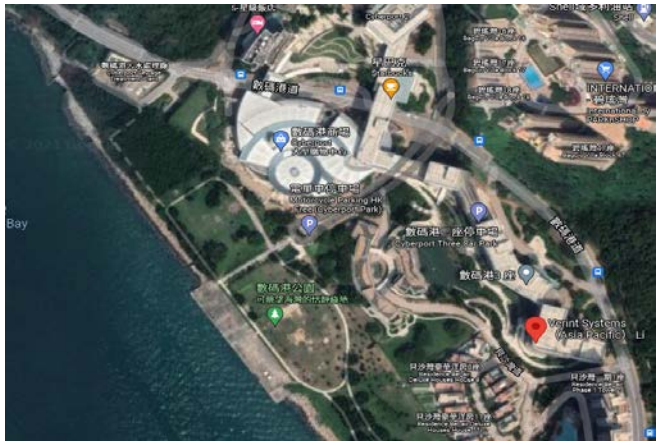
Contract No. NL/2017/03

Deformation Monitoring by GNSS

Anchor Monitoring Tech.
安科監測科技(香港)

Applications - Foundation



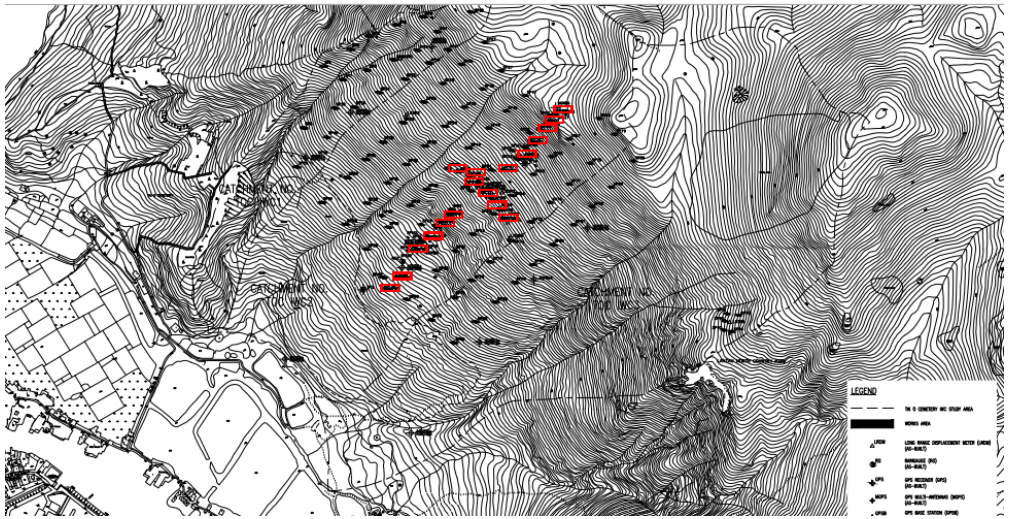


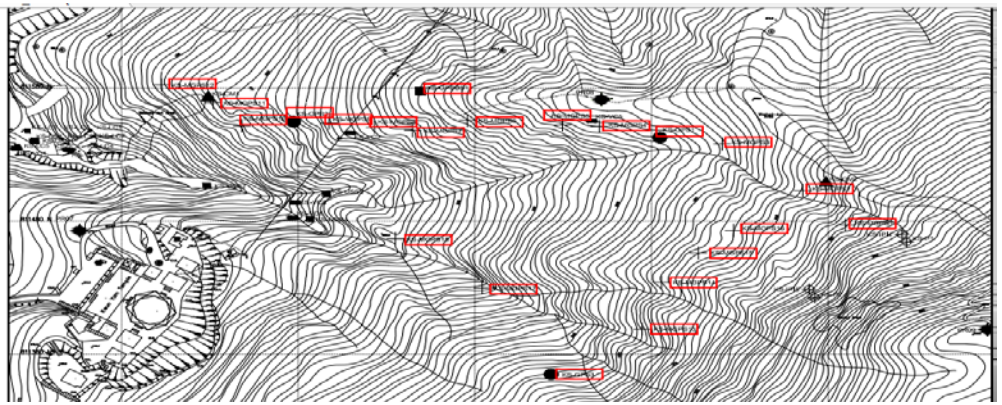
Contract No. GE/ELS/MN/001

Deformation Monitoring by GNSS

Anchor Monitoring Tech.
安科監測科技(香港)

Applications - Slope





Contract No. GE/2013/16

Deformation Monitoring by GNSS

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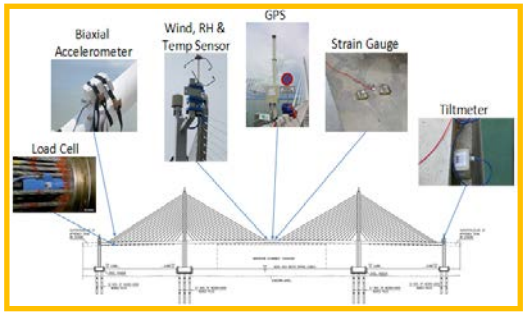
安科監測科技(香港)

Applications - Bridges

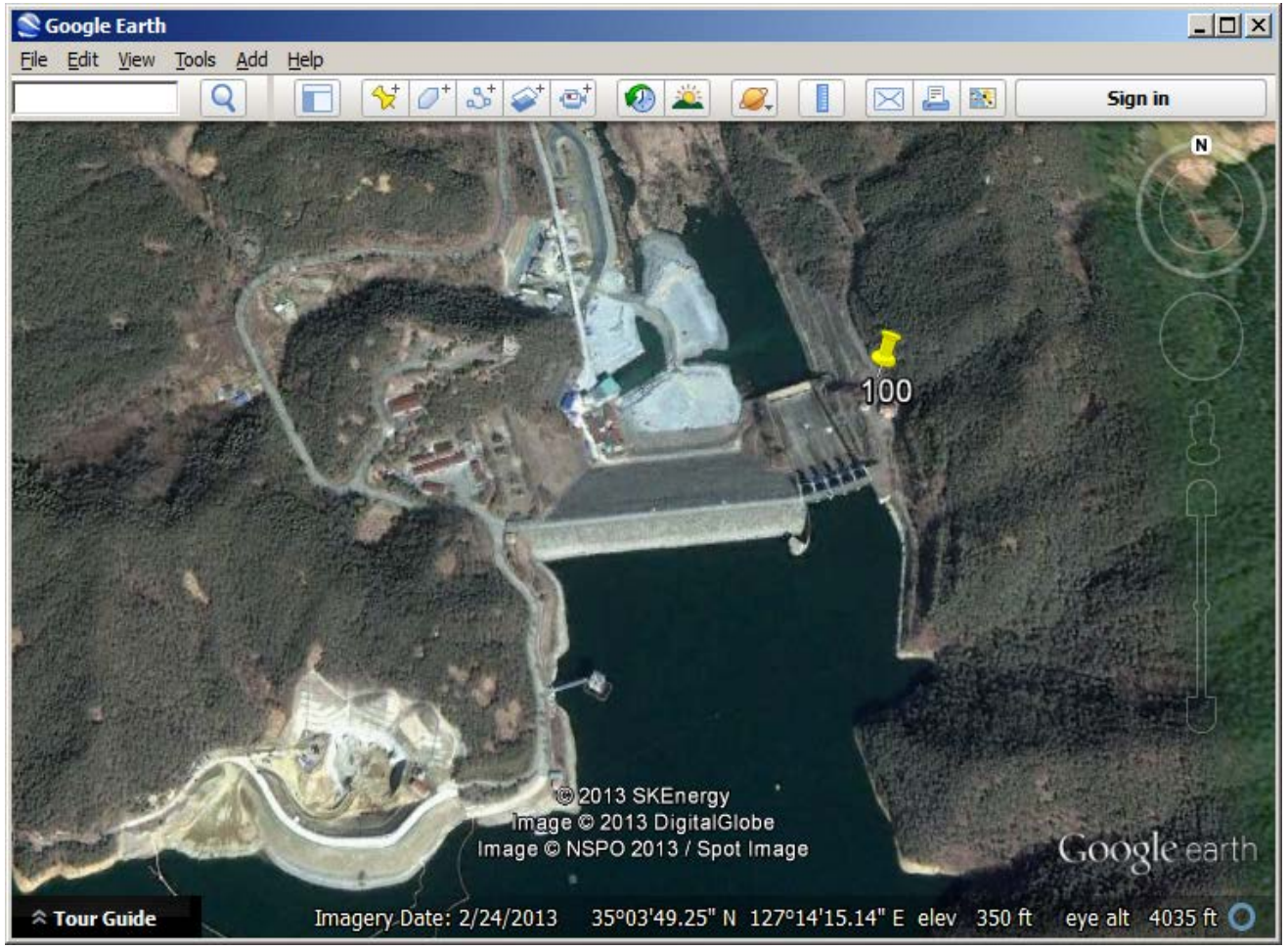


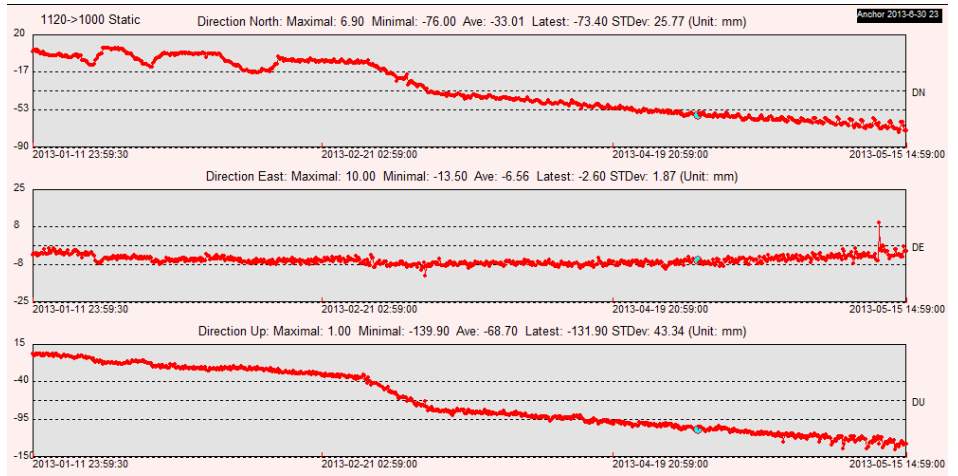
Loading Test of Second Penang Bridge in Malaysia

Deformation Monitoring by GNSS

Anchor Monitoring Tech.
安科监测科技(香港)

Applications - Dams



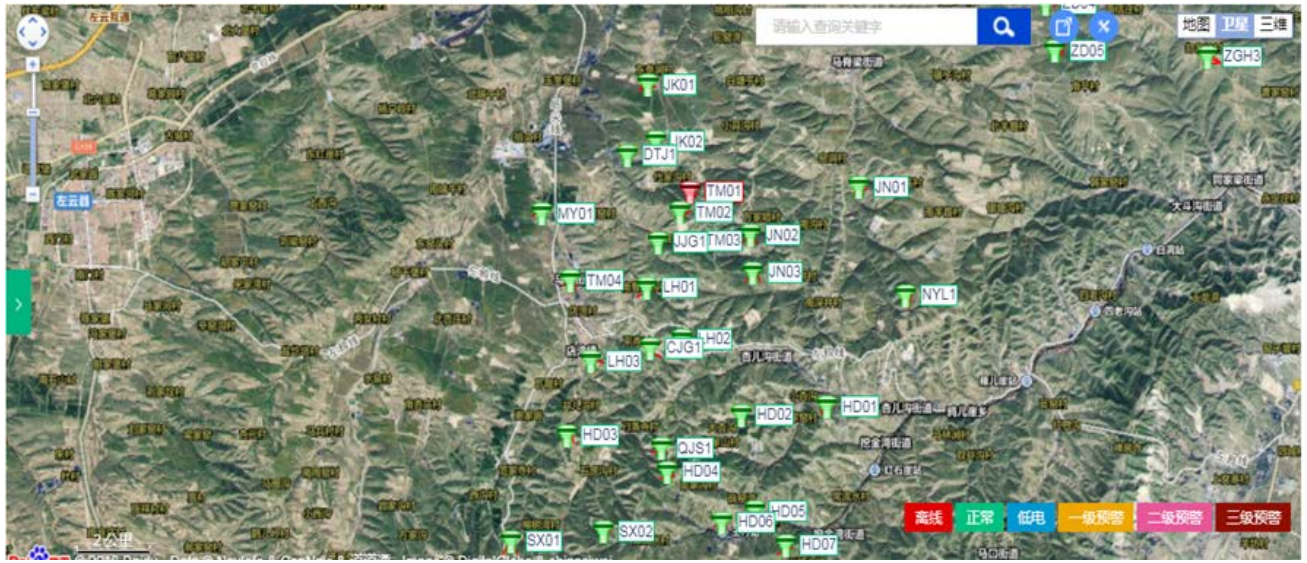


Juam dam project in South Korea

Deformation Monitoring by GNSS

Anchor Monitoring Tech.
安科监测科技(香港)

Applications - Dams



Settlement Monitoring (Datong Photovoltaic base in Shanxi China)

Deformation Monitoring by GNSS

Anchor Monitoring Tech.
安科監測科技(香港)

Features and Applications

- All-weather operation
- Real-time (update seconds, Minutes, hourly level)
- High accuracy (**RTK result**: centimeter level; **Hourly/daily result** : millimeter level)
- High-level of automation
- No inter-visibility required
- Low cost (no human source require)


Dams


Bridge


Slope


High Way


Rail


Foundation


Buildings


Mine


Reclamation

Applications

Outline

1. Deformation Monitoring by GNSS Technology

   All-weather, 24 Hours, Real-time, Automatic Positioning Monitoring Technology

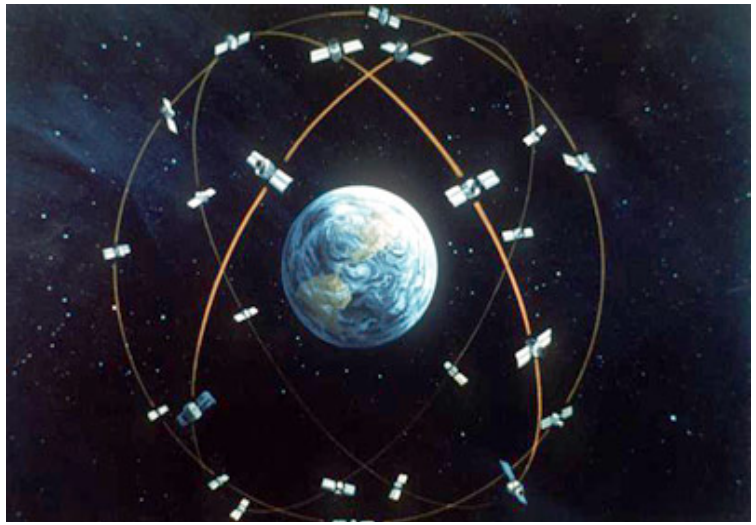
2. The Error Source of GNSS in the Utility Monitoring

3. Deformation Monitoring by Underground-GNSS

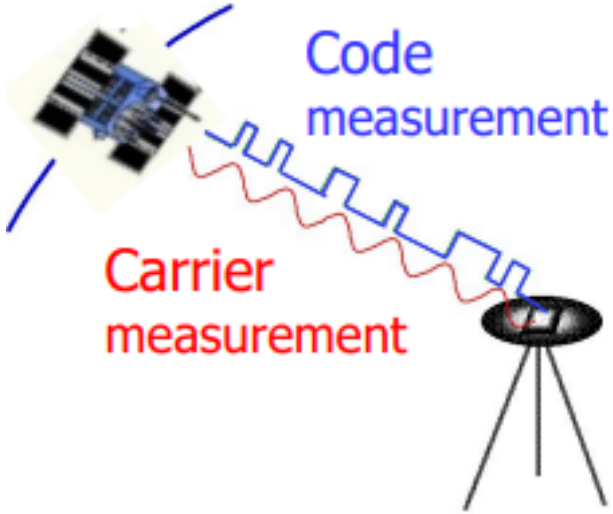
4. Conclusions

The Error Sources of GNSS

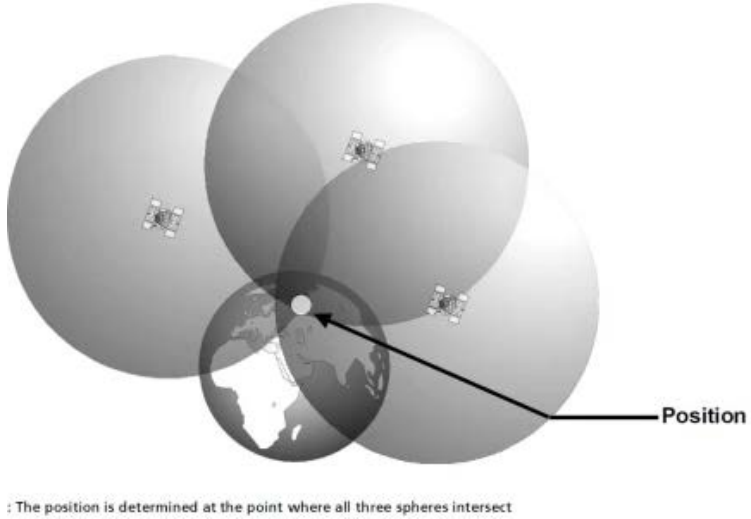
How GNSS Works



To know satellite coordinates



To measure distances from satellites



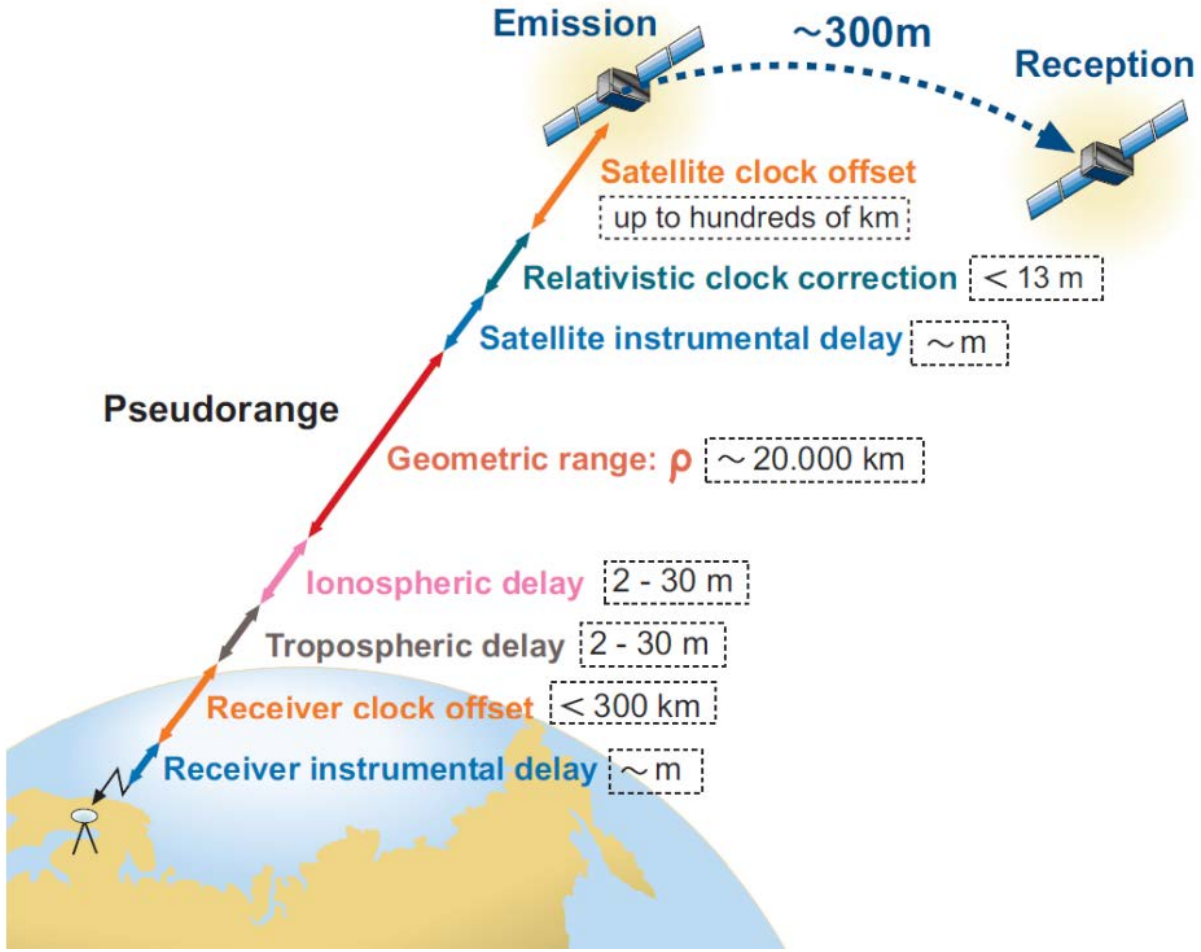
Positioning by Trilateration

Picture form http://gpsfleettrackingexpert

- To know the satellite coordinates and clock synchronism errors:
  Satellites broadcast orbits parameters and clock offsets.
- To measure distances from satellites:
  Code and Carrier phase measurements, Ambiguity fix method(FARA/LAMDA)
- To positioning by trilateration method:
  Error sources must be corrected: Ionospheric delay, Tropospheric delay, Multi-path, Receiver noise, etc...

The Error Sources of GNSS

Errors on the signal



Space Segment Errors

Clock errors	- Common
Ephemeris errors	- Strong spatial correlation

Propagation Errors

Ionospheric delay	- Strong spatial correlation
Tropospheric delay	- Weak spatial correlation

Local Errors

Multi-path	- No spatial correlation
Receiver noise	- No spatial correlation

The Error Sources of GNSS

Anchor Monitoring Tech.
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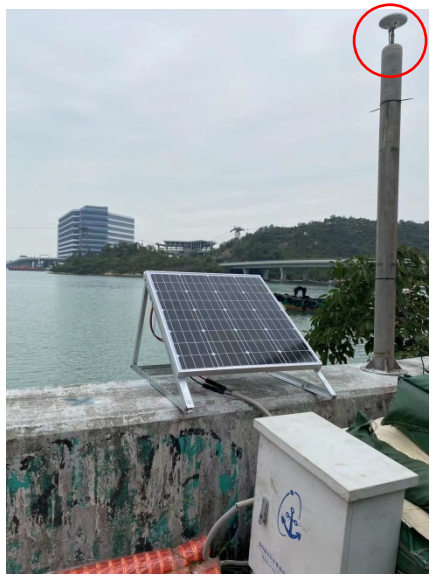
Study Points



Open Sky (REFE)

Trees (TB01)

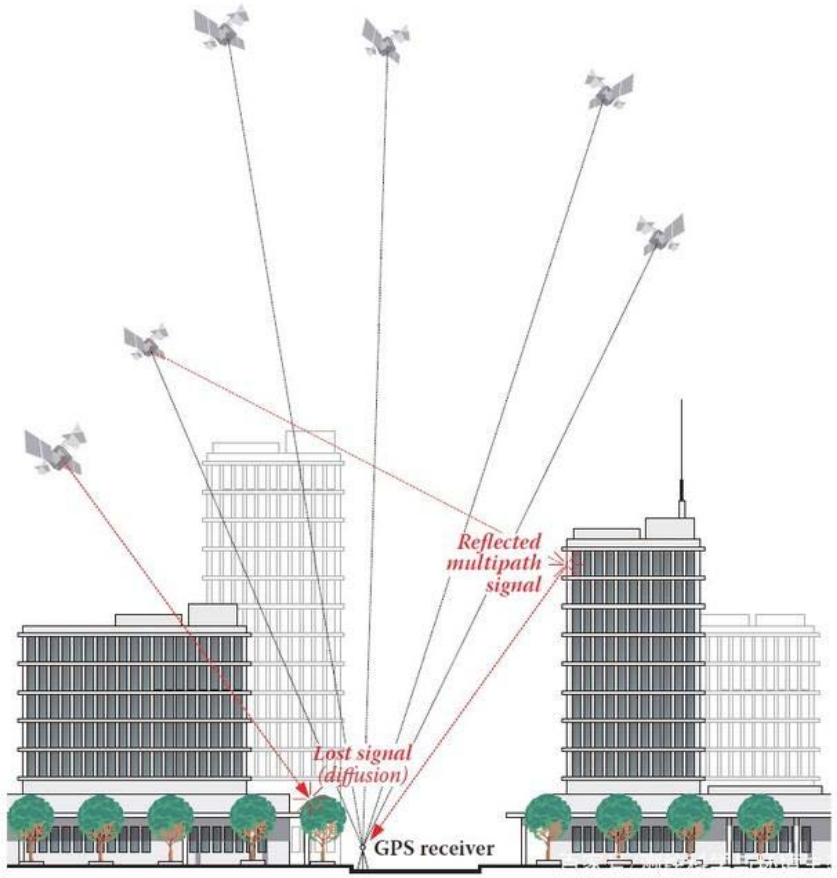
Metal Surrounding (SA01)

Underground GNSS(US01)

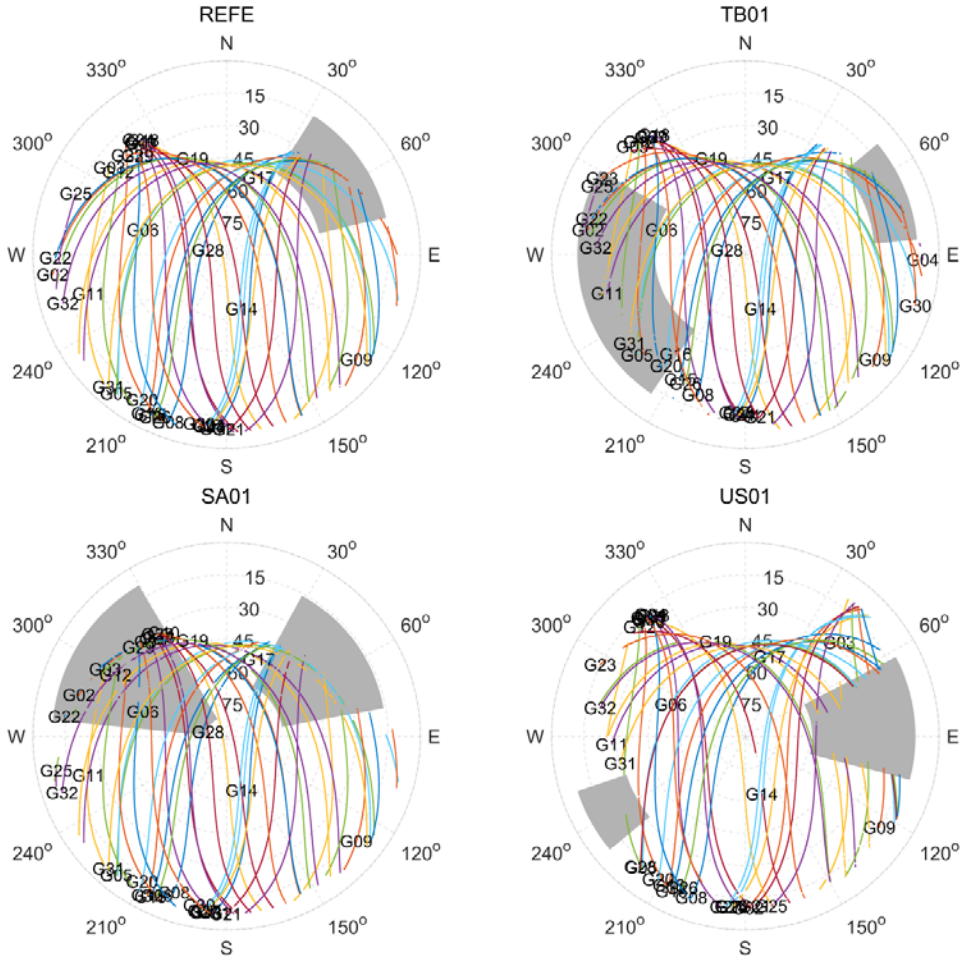
The Error Sources of GNSS

Anchor Monitoring Tech.
安科監測科技(香港)

Multi-path Error



Reflected signal



Sky-plot of REFE, TB01, SA01 and US01

The Error Sources of GNSS

Anchor Monitoring Tech.
安科監測科技(香港)

Multi-path Error

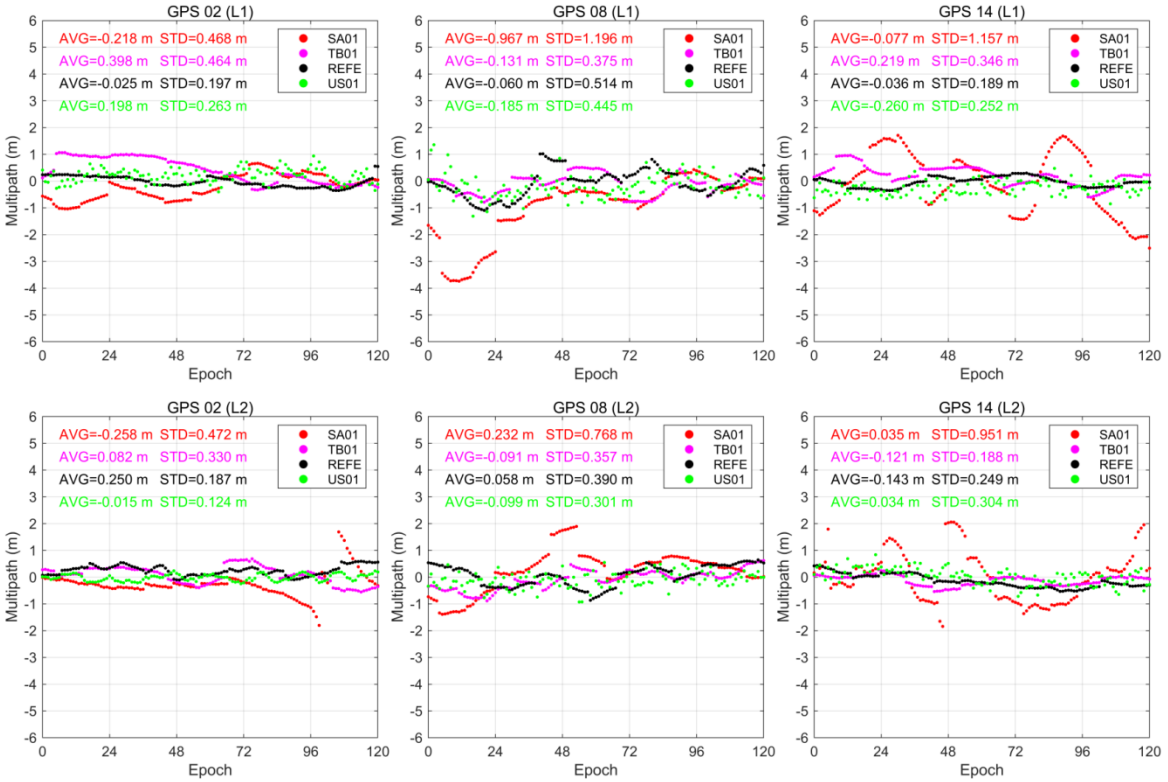


Figure 1. Multipath of **GPS** satellites 02, 08, 14 for REFE, TB01, SA01 and US01

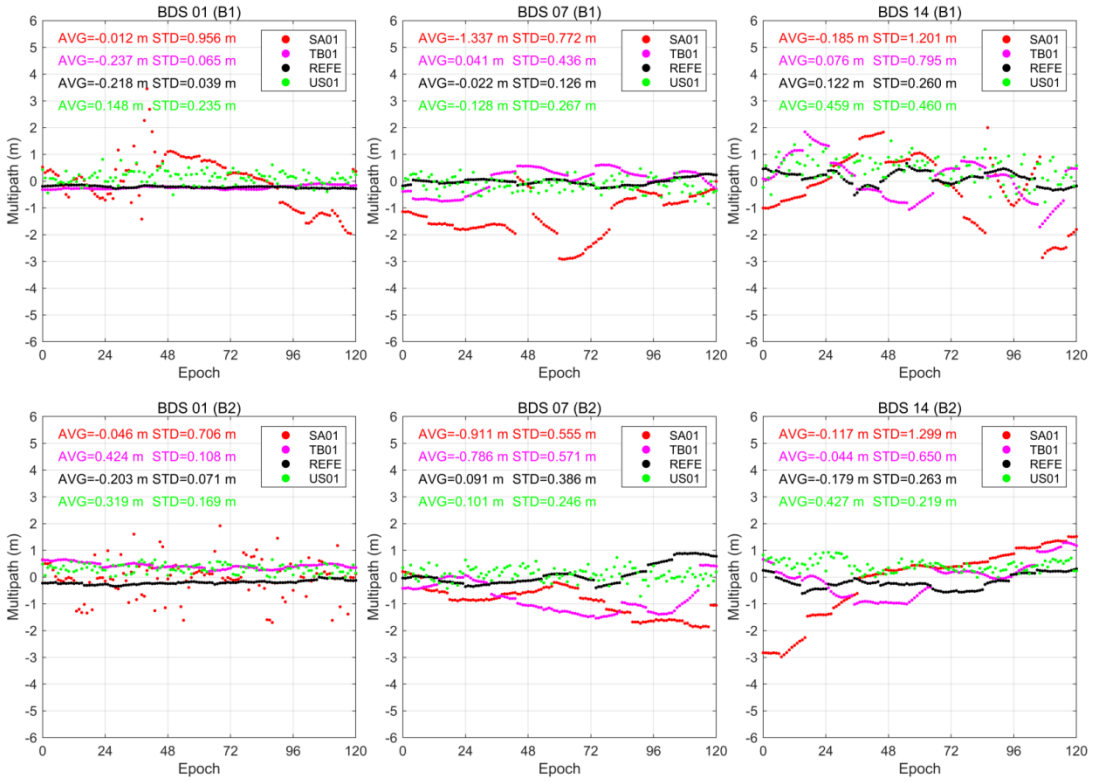


Figure 2. Multipath of **BDS** satellites 01,07,14 for REFE, TB01, SA01 and US01

The Error Sources of GNSS

Multi-path Error

Table 1. Multipath STD of satellites

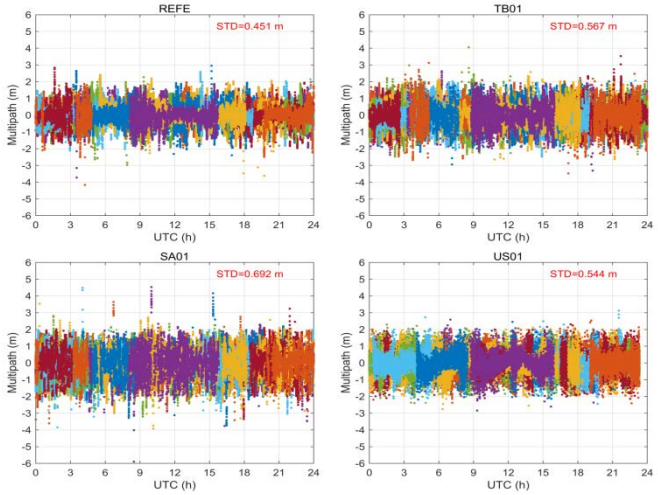
Station Multi-path(STD,m)	REFE	TB01	SA01	US01
GPS-L1	0.451	0.567	0.692	0.544
GPS L2	0.531	0.668	0.721	0.522
BDS B1	0.554	0.687	0.672	0.562
BDS B2	0.542	0.693	0.711	0.535

Open Sky (REFE)

Trees (TB01)

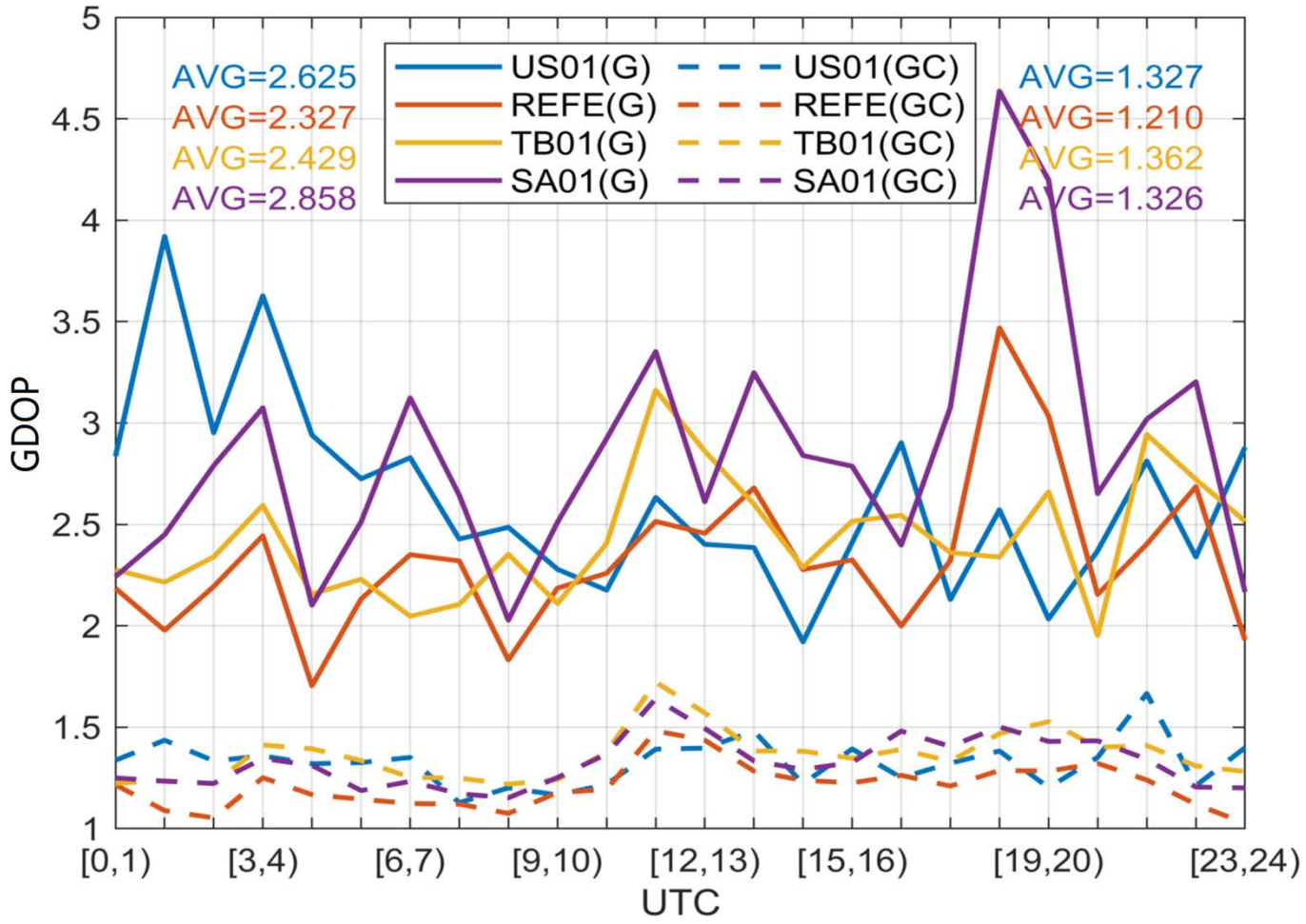
Metal Surrounding (SA01)

Underground GNSS(US01)



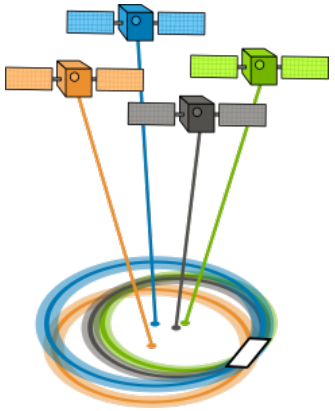
The Error Sources of GNSS

Geometric Dilution of Precision (GDOP)

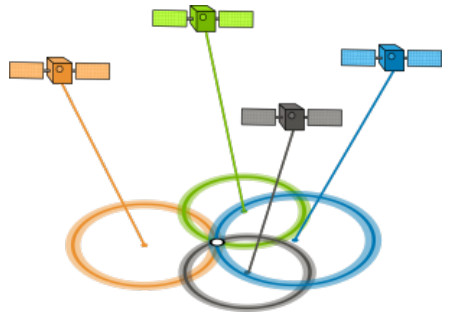


GDOP of REFE, TB01, SA01 and US01

G: GPS only
GC: GPS + Beidou

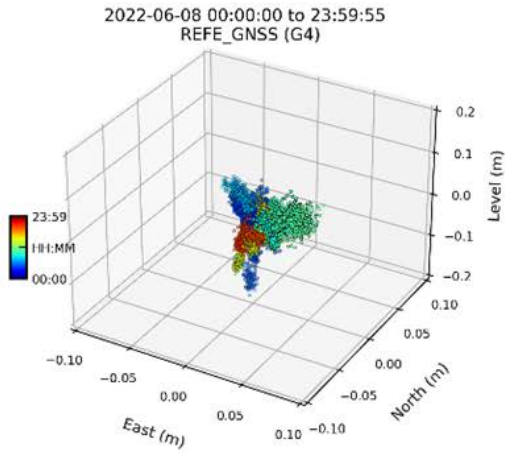


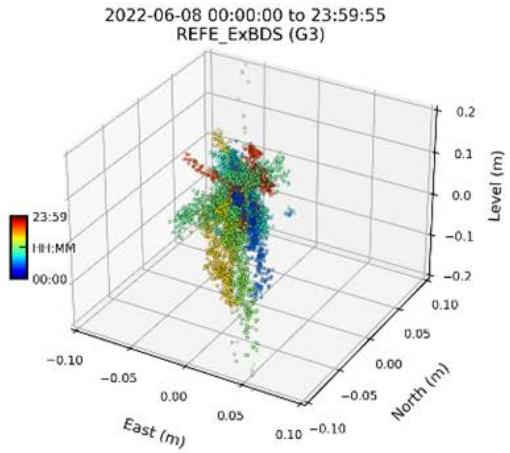
Weak Geometry

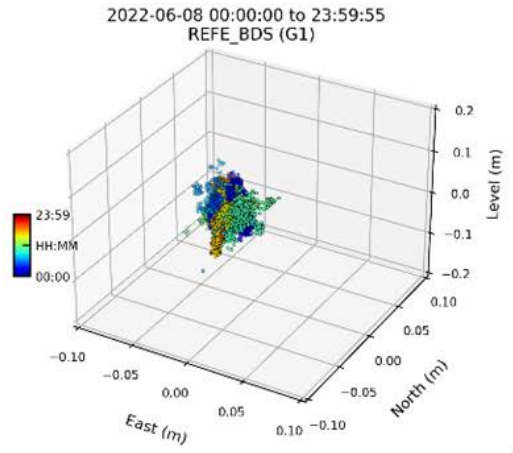


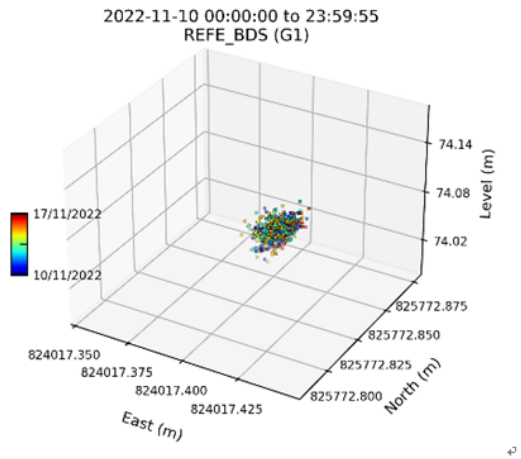
Good Geometry

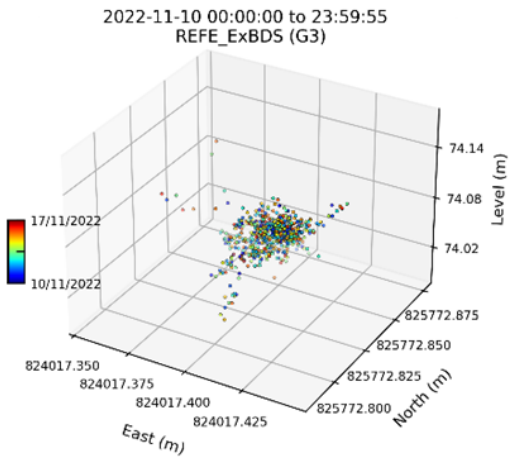
Satellite System Combinations and Observation Time

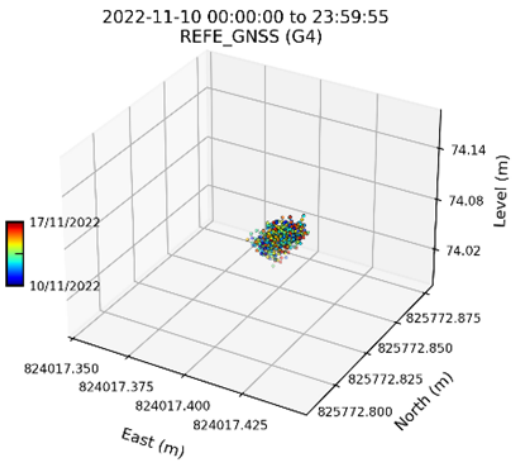












G1: Use Beidou only
G3: Use GPS,GLO,GAL
G4: Use GPS,GLO,GAL,BeiDou

3D point fixing distribution in group G1, G3, G4 with **RTK** (single epoch, interval 5 second)

3D point fixing distribution in group G1, G3, G4 with Time Session 1**5 minutes.**

GNSS Precision

Anchor Monitoring Tech.
安科監測科技(香港)

Compassion with ADMS

CEDD Contract
No. GE/2013/16

Landslip Prevention and Mitigation Programme, 2008,

Both GNSS system and ADMS system detected about 12 mm displacement

ADMS GPS(GNSS)

Station	Displacement (mm)				Ref. GPS	
	North	East	RL	Total		Total
SP	-3.5	11.4	3.1	12.3	MGPS	10.7
SP	-2.7	11.6	2.0	12.1	MGPS	11.2
SP	-3.3	12.8	1.5	13.3	MGPS	10.2
SP	-2.5	12.7	3.5	13.4	MGPS	11.3
SP	-4.0	12.1	3.3	13.2	GPS	11.6
SP	-3.2	12.1	4.9	13.4	MGPS	12.6
SP	-3.3	14.9	3.9	15.8	MGPS	13.5
SP	-2.4	14.7	5.9	16.0	MGPS	13.9
SP	-1.3	13.9	6.5	15.4	MGPS	14.5
SP	-3.5	15.1	4.9	16.3	MGPS	14.9
SP	-6.1	14.9	6.6	17.4	GPS	14.7
SP	-4.3	17.3	3.4	18.1	MGPS	17.5
SP	-4.1	15.6	1.0	16.2	MGPS	14.3
SP	-4.4	15.4	0.4	16.0	MGPS	13.4
SP	-1.5	12.6	3.0	13.0	MGPS	11.2
SP	-4.7	16.4	4.2	17.6	MGPS	15.3
SP	-3.0	15.5	3.3	16.1	MGPS	15.9
SP	-5.0	17.1	5.3	18.6	GPS	14.8
SP1	-2.7	16.4	4.5	17.2	MGPS	15.2
SP1	-2.1	16.0	3.6	16.5	MGPS	14.8
SP1	-3.9	18.1	3.9	18.9	MGPS	17.5

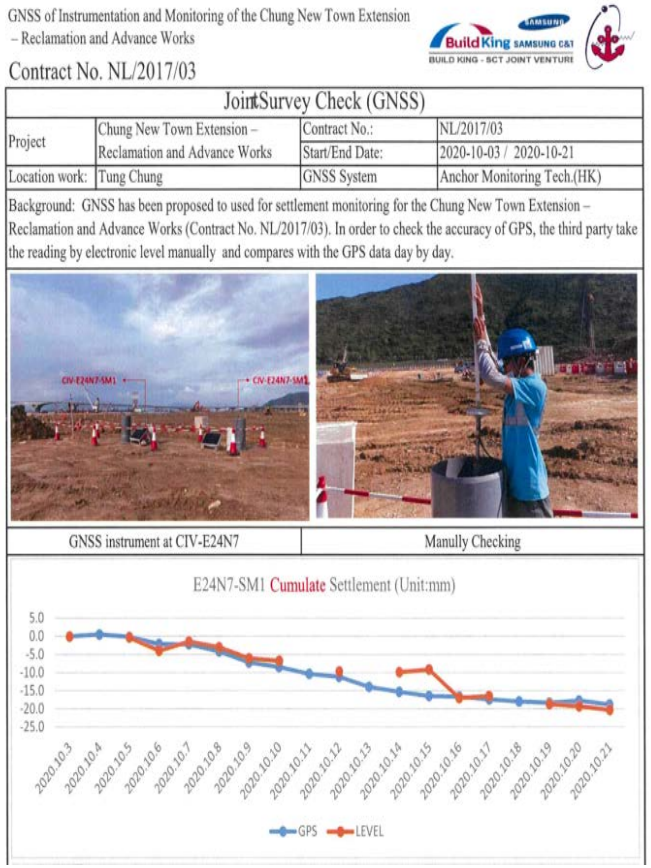
GNSS Precision

Anchor GNSS Monitoring System GNSS Precision (1 sigma)

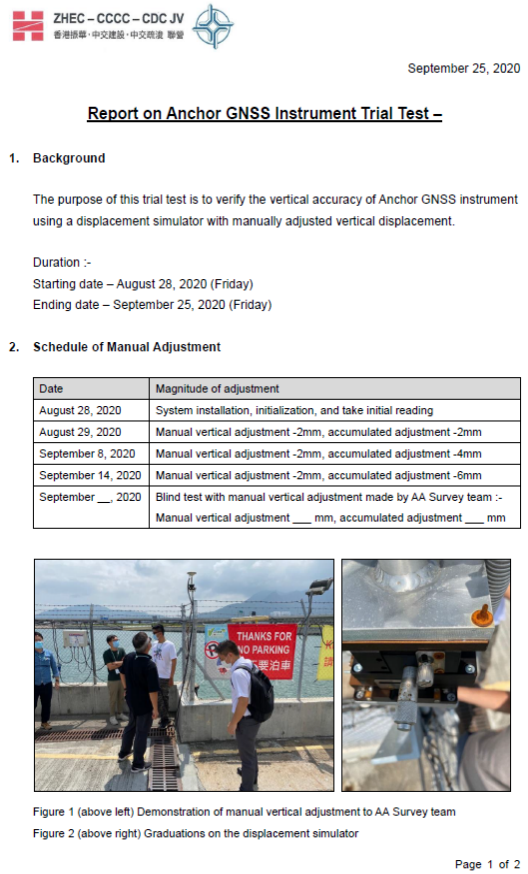
	Time	5 minutes	1 hour	3 hours
Accuracy (∂)	horizontal	10+1ppm	3.5+0.5ppm	2.5+0.5ppm
	vertical	20+1.5ppm	7+1ppm	5+1ppm
	Time	**6 hours**	**12 hours**	**24 hours**
Accuracy (∂)	horizontal	1+0.5ppm	0.8+0.5ppm	0.7+0.5ppm
	vertical	2.5+1ppm	1.5+0.5ppm	1.0+0.5ppm

Accuracy of the results from actual project statistics with **good condition**

GNSS Device



Compassion with Manually Survey



ZHEC – CCCC – CDC JV

September 25, 2020

Report on Anchor GNSS Instrument Trial Test –

1. **Background**

The purpose of this trial test is to verify the vertical accuracy of Anchor GNSS instrument using a displacement simulator with manually adjusted vertical displacement.

Duration :-
Starting date – August 28, 2020 (Friday)
Ending date – September 25, 2020 (Friday)

2. **Schedule of Manual Adjustment**

Date	Magnitude of adjustment
August 28, 2020	System installation, initialization, and take initial reading
August 29, 2020	Manual vertical adjustment -2mm, accumulated adjustment -2mm
September 8, 2020	Manual vertical adjustment -2mm, accumulated adjustment -4mm
September 14, 2020	Manual vertical adjustment -2mm, accumulated adjustment -6mm
September __, 2020	Blind test with manual vertical adjustment made by AA Survey team :- Manual vertical adjustment ___ mm, accumulated adjustment ___ mm

Figure 1 (above left) Demonstration of manual vertical adjustment to AA Survey team
Figure 2 (above right) Graduations on the displacement simulator

Page 1 of 2

Compassion with Simulation Test

Outline

1. Deformation Monitoring by GNSS Technology

2. The Error Source of GNSS in the Utility Monitoring

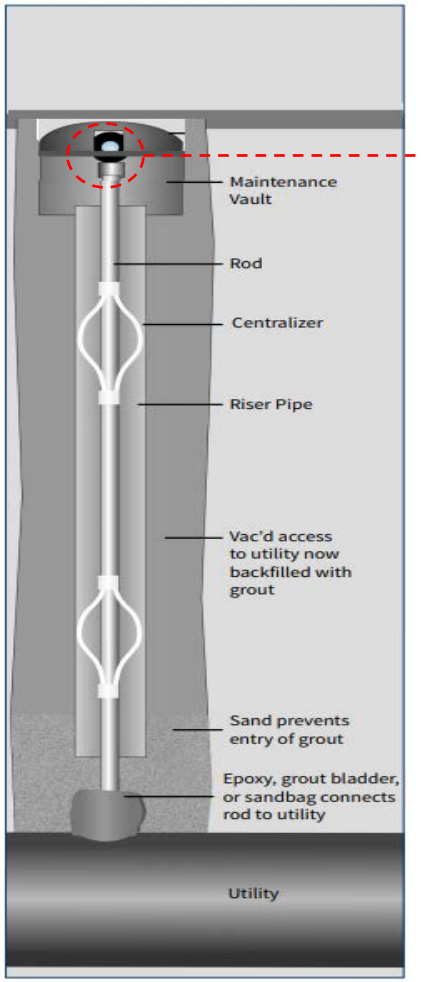
   Accuracy:
   RTK result: centimeter level
   Hourly/daily result :1-2 mm horizontal, 2-4 mm vertical

3. Deformation Monitoring by Underground-GNSS

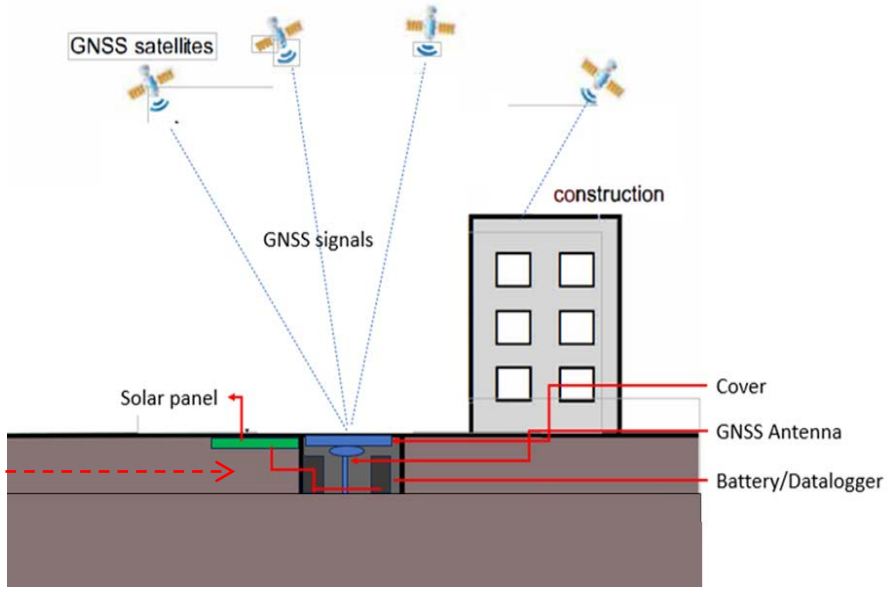
4. Conclusions

Deformation Monitoring by Underground-GNSS

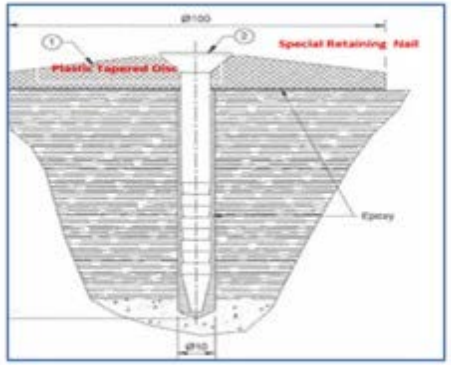
Underground GNSS



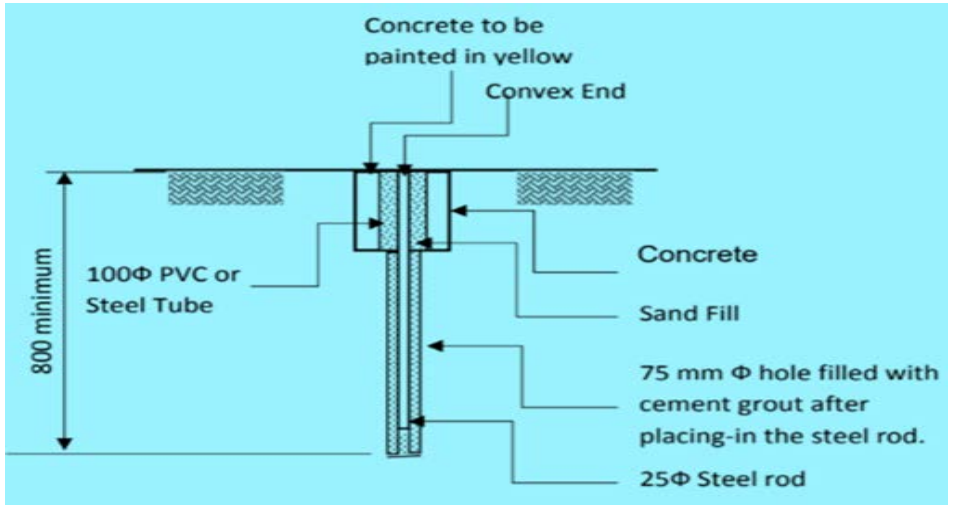
Picture from
www.geo-instruments.com/



The GNSS antenna is installed below the ground level and is equipped with a special cover to receive satellite signals. By connecting the antenna to underground utility through connecting rods to monitor the vertical displacement.



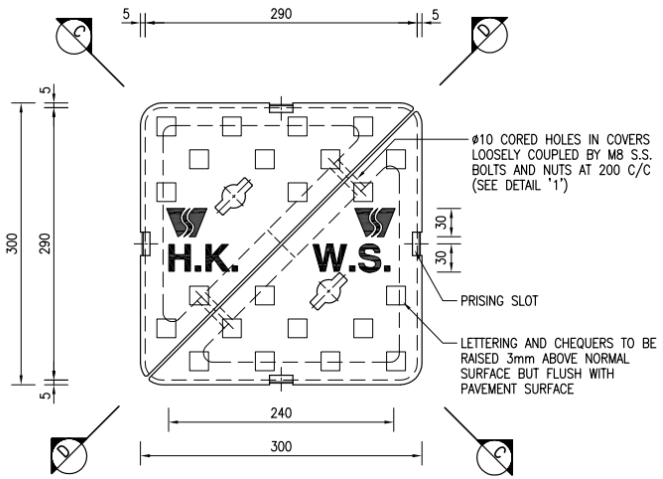
Typical Survey Nail Settlement Marker



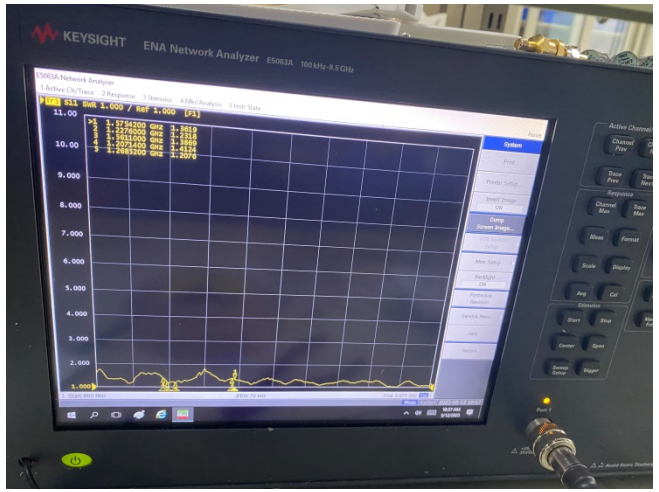
Typical Survey Nail Settlement Marker in Soil
Picture from Land Reclamation Guideline AGS(HK)

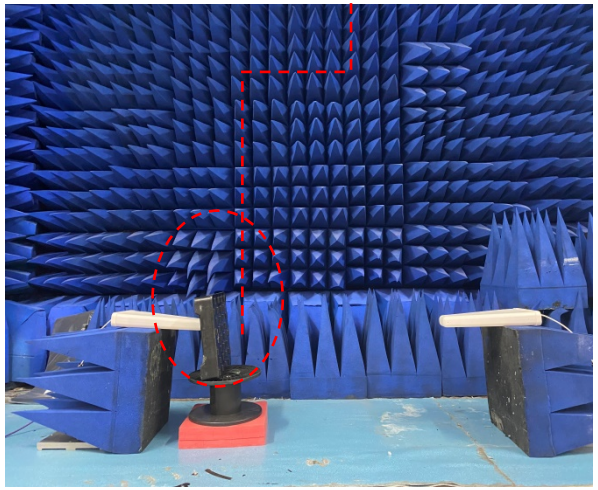
Deformation Monitoring by Underground-GNSS

Underground GNSS



Compatible Stand Drawing





Signal Refraction Test at Microwave Anechoic Chamber

Features of the U-GNSS System

- All instruments positioned below the ground's surface
- Reinforced Design (200 KN)
- Anti-Slip and Anti-Corrosion Design
- Compatible to Standard Drawing WSD 7.47-C
- Easy Installation

Instruments:

- GNSS Receiver, GNSS Antenna
- Chamber for Storing Instruments
- Batteries

Deformation Monitoring by Underground-GNSS

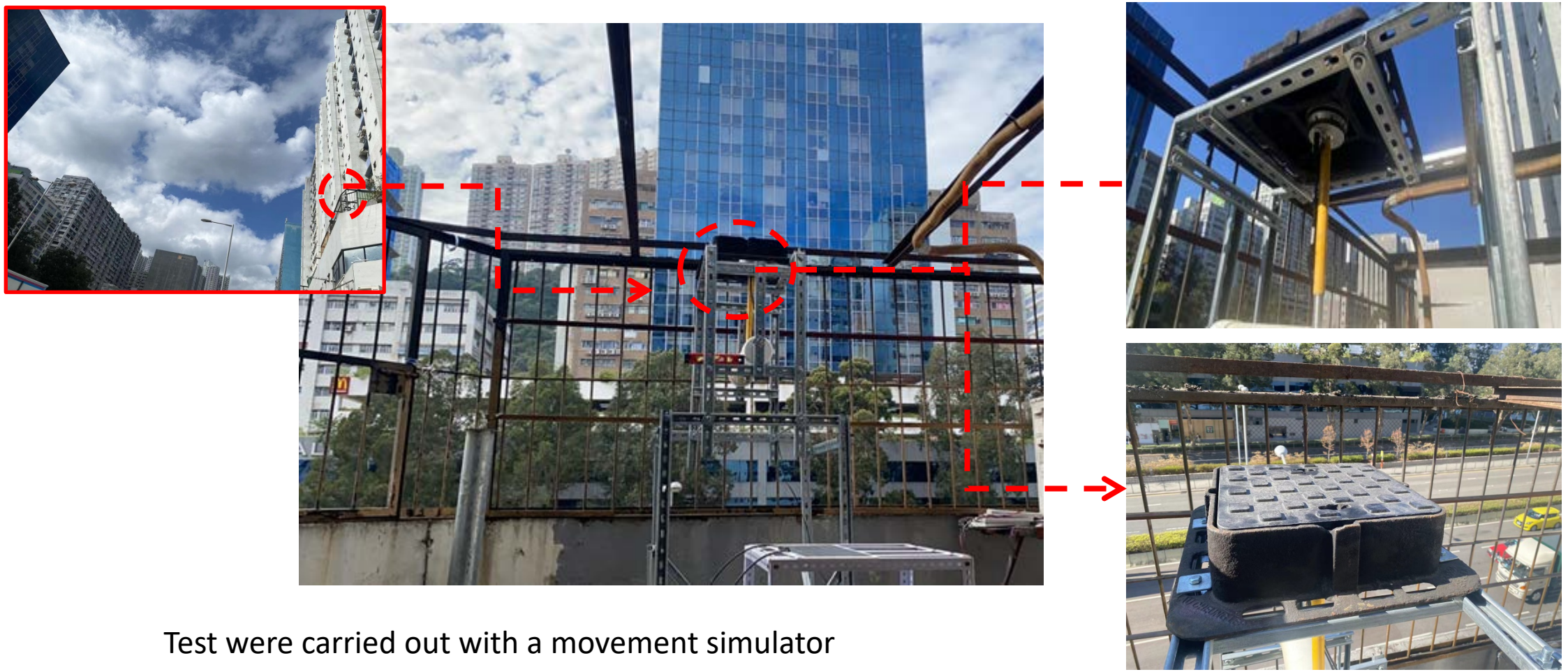
Underground GNSS

- Integration of multi-sensor GNSS, Tilt-meter, and Accelerometer and temperature sensor
- Integrated design of antenna and receiver
- 4G modem/ Lora integrated
- Extra data collecting port (Modbus, Bluetooth)
- Low power consumption (About 1.3 W)
- IP68 waterproof

Deformation Monitoring by Underground-GNSS

Anchor Monitoring Tech.
安科監測科技(香港)

Simulation Test

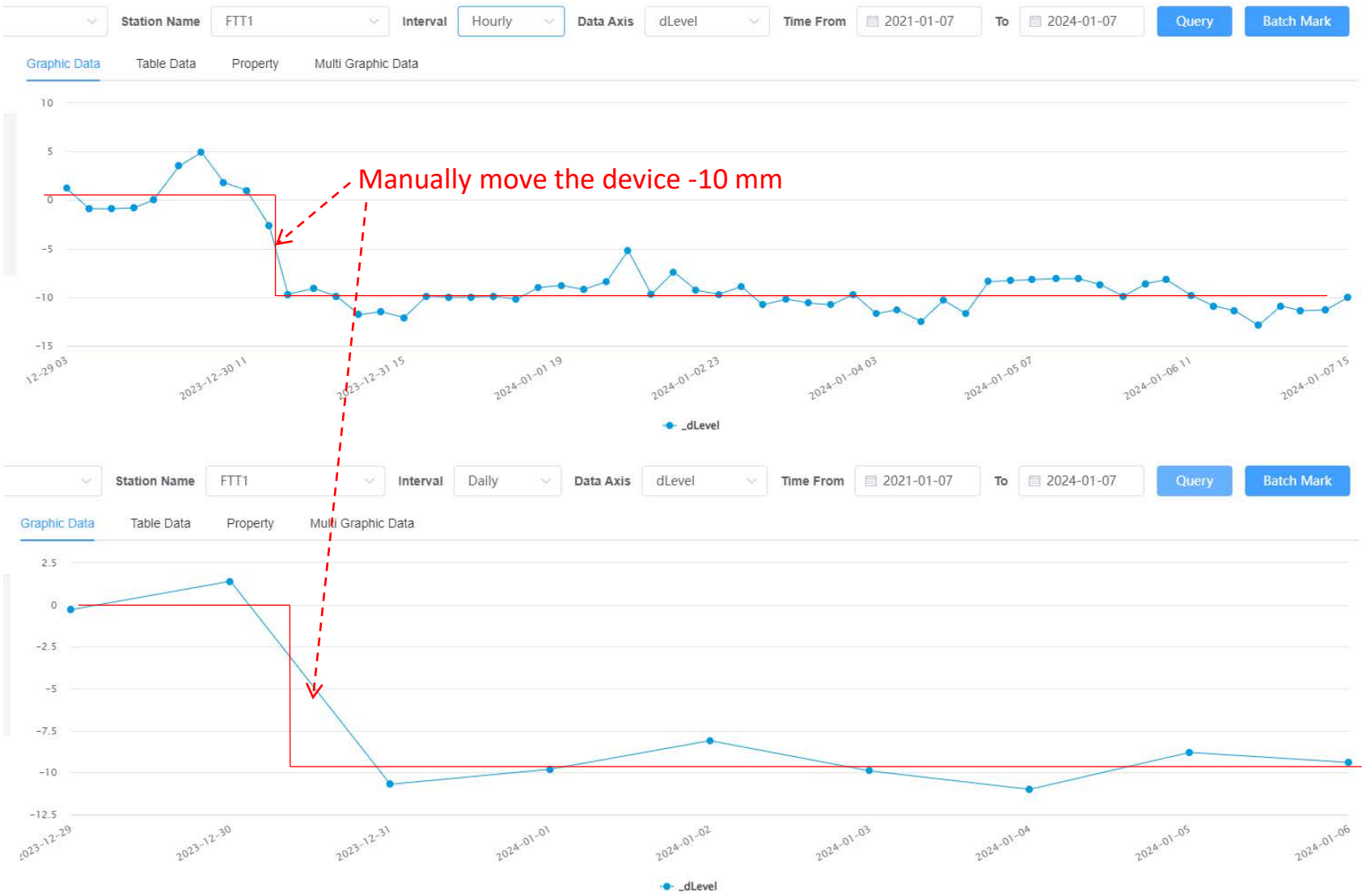


Test were carried out with a movement simulator

Deformation Monitoring by Underground-GNSS

Anchor Monitoring Tech.
安科监测科技（香港）

Simulation Test



Session Length： one hour

Std. 3.42mm (Accuracy)

Session Length： 24 hours

Std. 1.68mm (Accuracy)

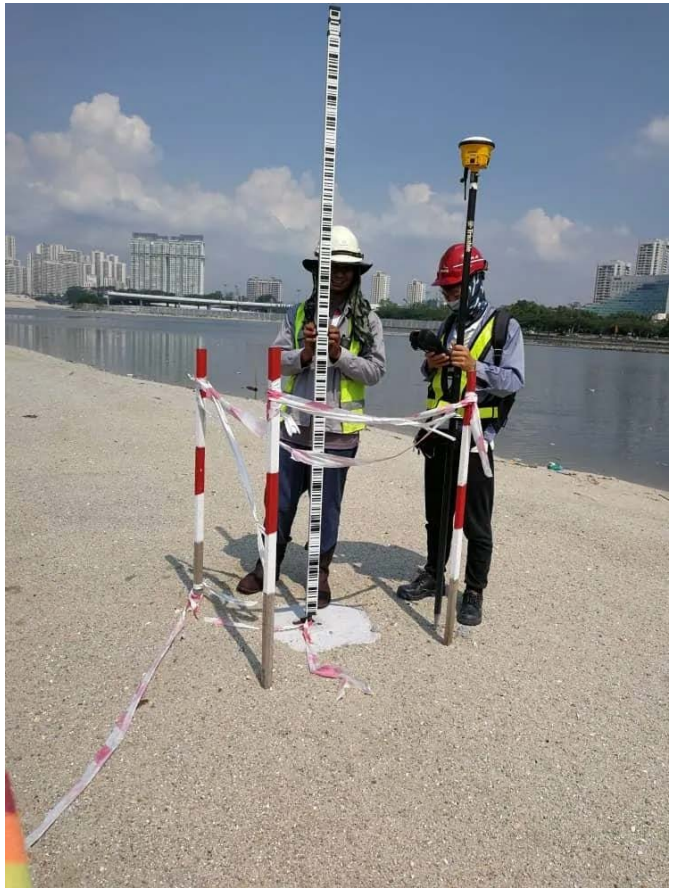
True Value

Measured by GNSS

Deformation Monitoring by Underground-GNSS

Anchor Monitoring Tech.
安科監測科技(香港)

Comparison



Manual Survey

Monitoring by U-GNSS

Advantages

- **Automated** 24/7, fully operation
- **Continuously** Data measured every second
- **Safety** Unhindered pedestrian and vehicular
- **High accuracy** 2-3 mm in daily result / centimeter level in real-time result
- **Low cost** Minimal human resources investment

Deformation Monitoring by Underground-GNSS

Settlement Monitoring for Utilities

Deformation Monitoring by Underground-GNSS

Anchor Monitoring Tech.
安科監測科技(香港)

Settlement Monitoring for Underground Pipeline

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Outline

1. Deformation monitoring by GNSS
2. The error source of GNSS in the utility monitoring
3. Study case - using U-GNSS for settlement monitoring
4. Conclusions

Conclusions

1) The U-GNSS device is designed to penetrate satellite signals, enabling accurate positioning even in underground environments. It has been engineered to withstand pressure loading, suitable for installation in pedestrian walkways and roadways.

2) In terms of accuracy, the U-GNSS system can provide approximately 4 mm accuracy in the vertical direction for a one-hour session length, and about 2 mm accuracy in the vertical direction for a 24-hour session length.

3) The U-GNSS system is designed with low power consumption and is IP68 level waterproof, allowing for long-term continuous operation when installed underground.

Thank You

support01@anchor.net.hk

WhatsApp