Modernization of Height System in Hong Kong

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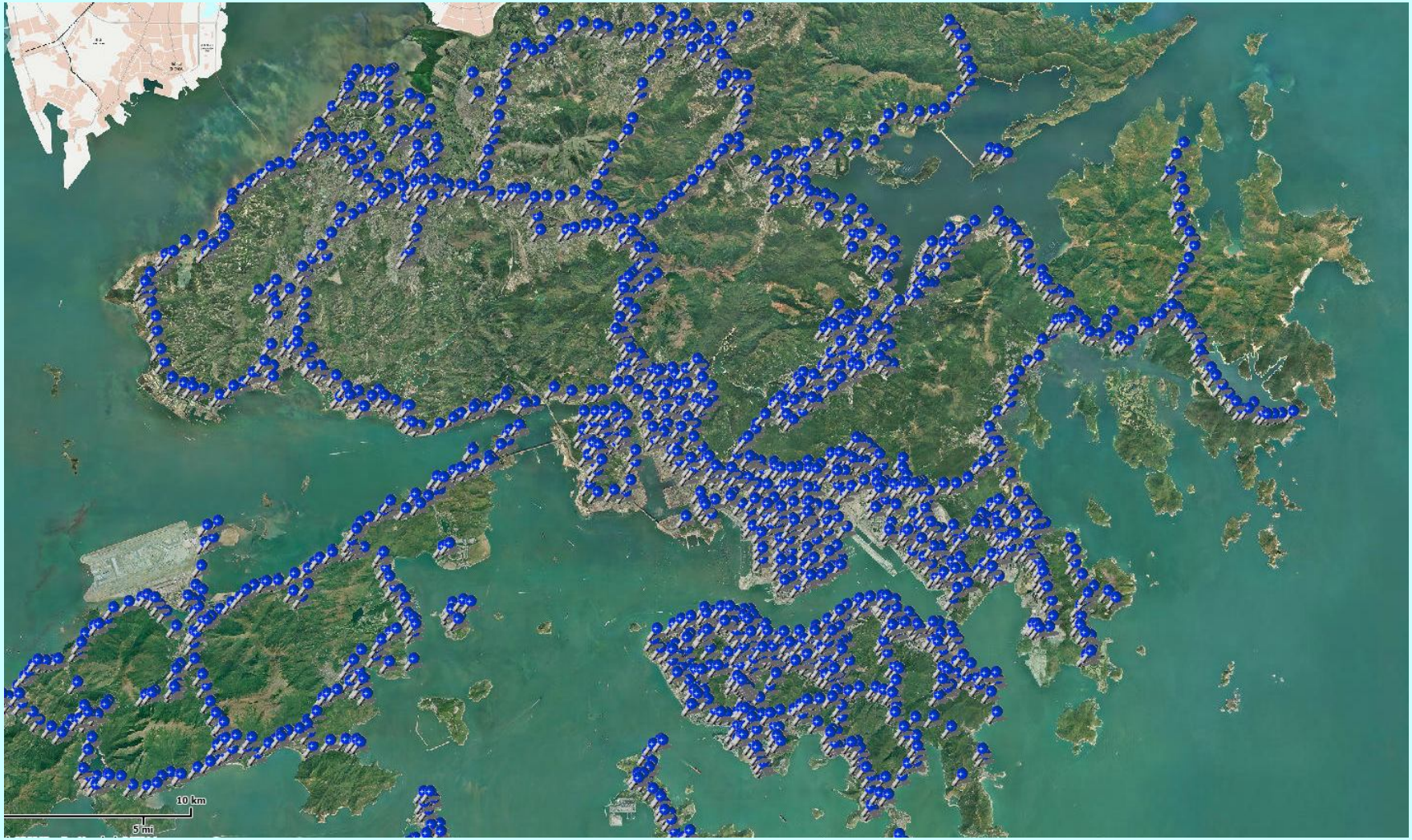
Overview

1. Hong Kong Height System
2. Re-levelling and re-adjustment of the Hong Kong Bench Mark Network
3. Densification of a network of height control points covering Hong Kong with levelling and GNSS observation.
4. Gravity observation.
5. Construction of a digital terrain model of Hong Kong.
6. Creation of a geoid model for GNSS heighting in Hong Kong.

Hong Kong Height System

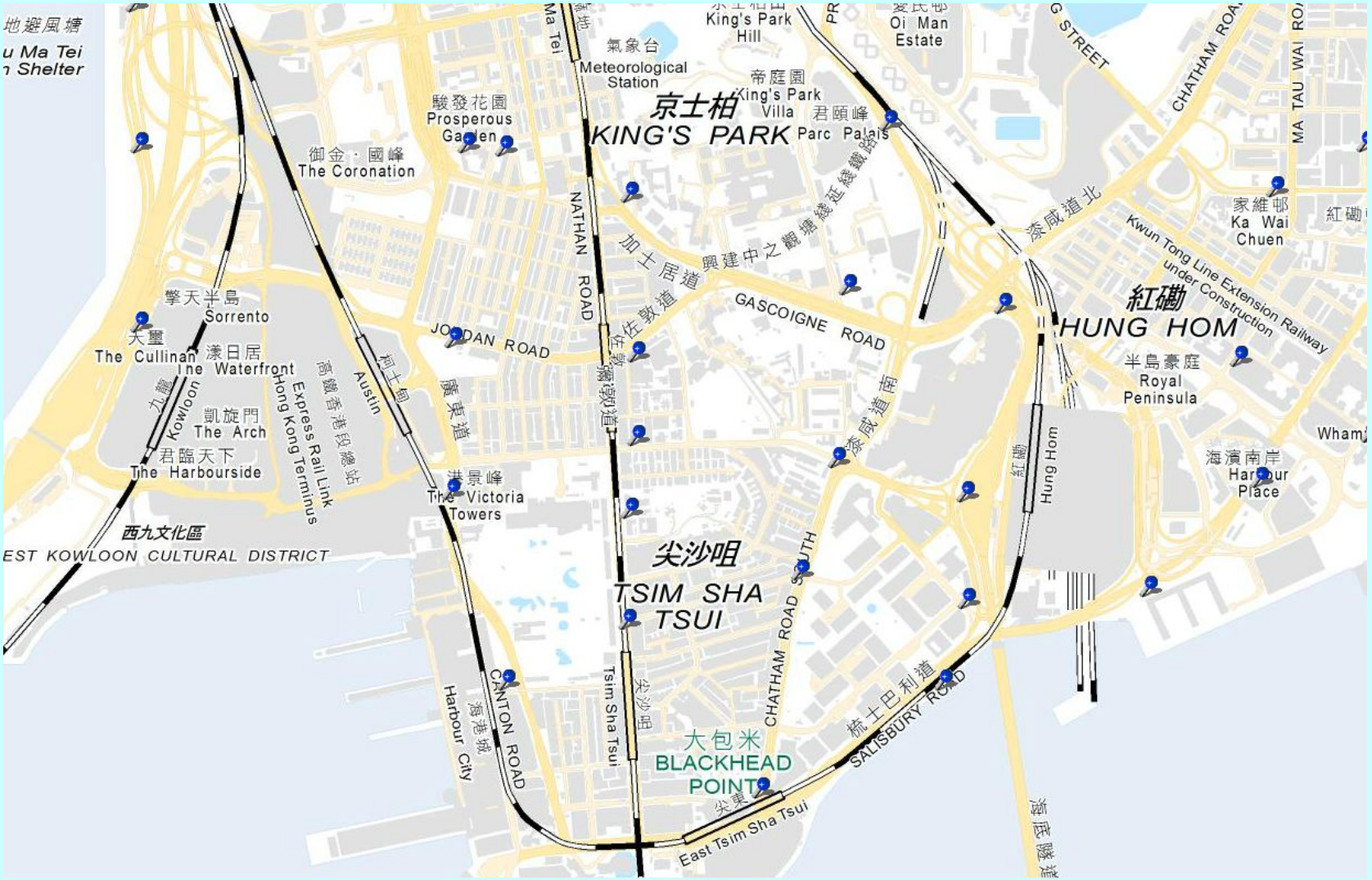
- The Hong Kong vertical reference system is based on the Hong Kong Principal Datum. System.
- It is realised by a network of bench marks covering the territory of Hong Kong.

Hong Kong Bench Mark Network



- About 1700 bench marks.
- Average point spacing : 0.5 km

Hong Kong Bench Mark Network



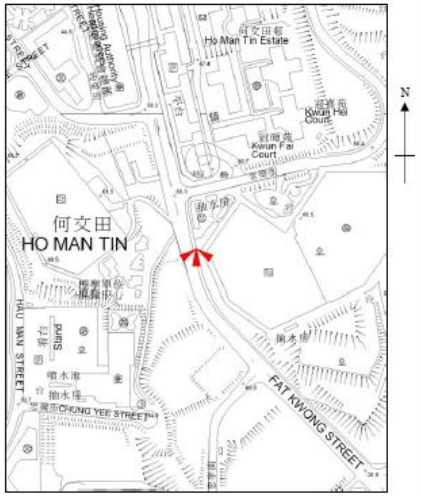
Hong Kong Bench Mark Network

BENCH MARK SUMMARY

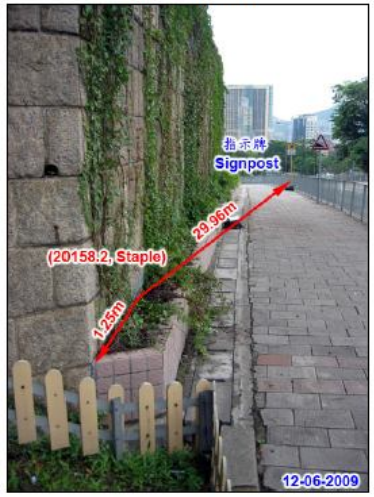
BENCH MARK NO. : 20158.2 (FORMER NO. : 20158.1) CLASS : V1

Height above HKPD :	HK 1980 GRID COORDINATES (APPROX.): N = 819 341 m E = 836 807 m
61.9380 m (To Top of Mark)	LOCALITY : FAT KWONG STREET
	SURVEY SHEET NO.: 11-NW-20D

LOCATION MAP (Scale 1:5000)



STATION PHOTO



REMARKS :

Type of Mark:
Staple

0.46m above ground

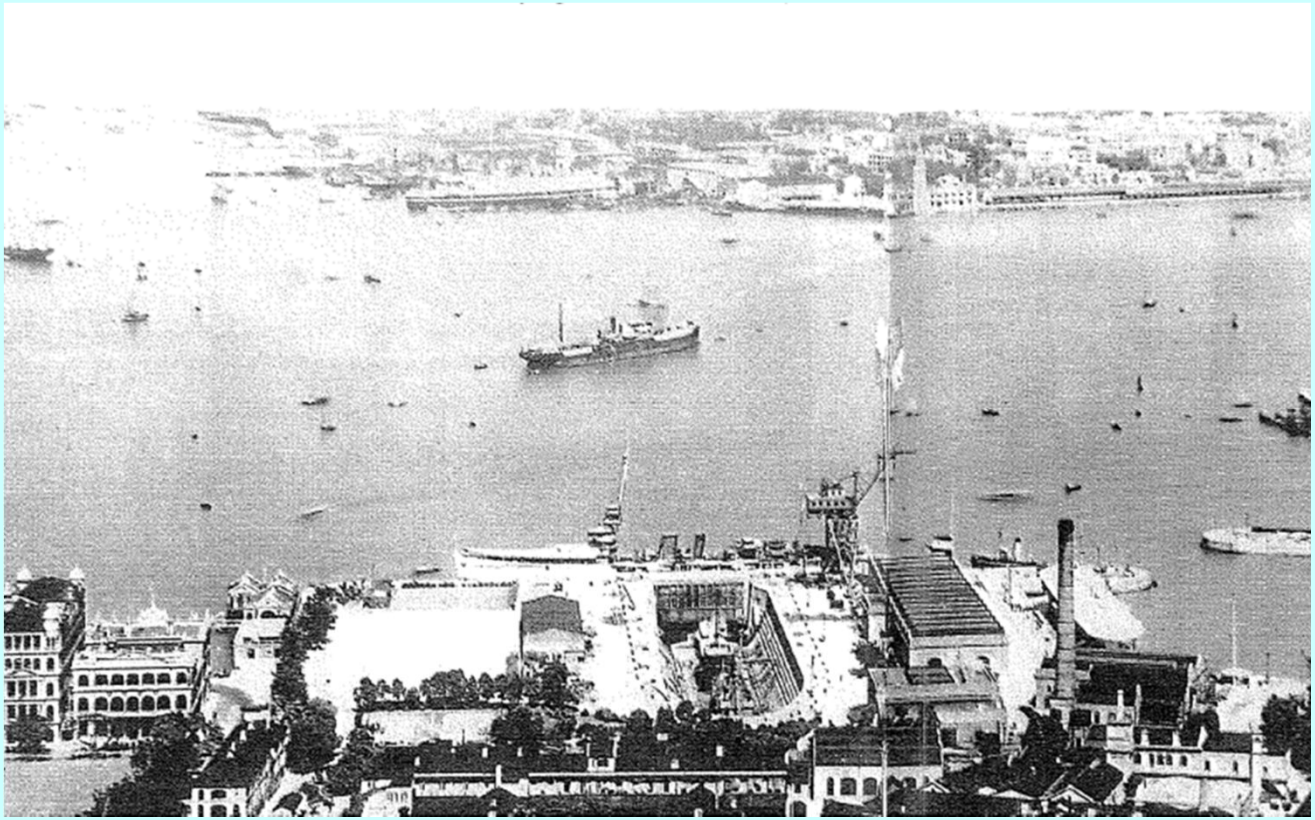
All measurements shown are in horizontal distance unless otherwise specified.

Prepared by : CHU F C Checked by : CHAN K H Approved by : CHOI C T, Asst. LS/G(2)
Date : 29/03/2010

Geodetic Survey Section
SMO, Lands Department

Hong Kong Principal Datum

- In 1866, the surveyors of the surveying vessel Rifleman fixed a bench mark (Rifleman's Bolt) for surveying the foreshore of Victoria Harbour.



Victoria Harbour in the 19 Century

Hong Kong Principal Datum

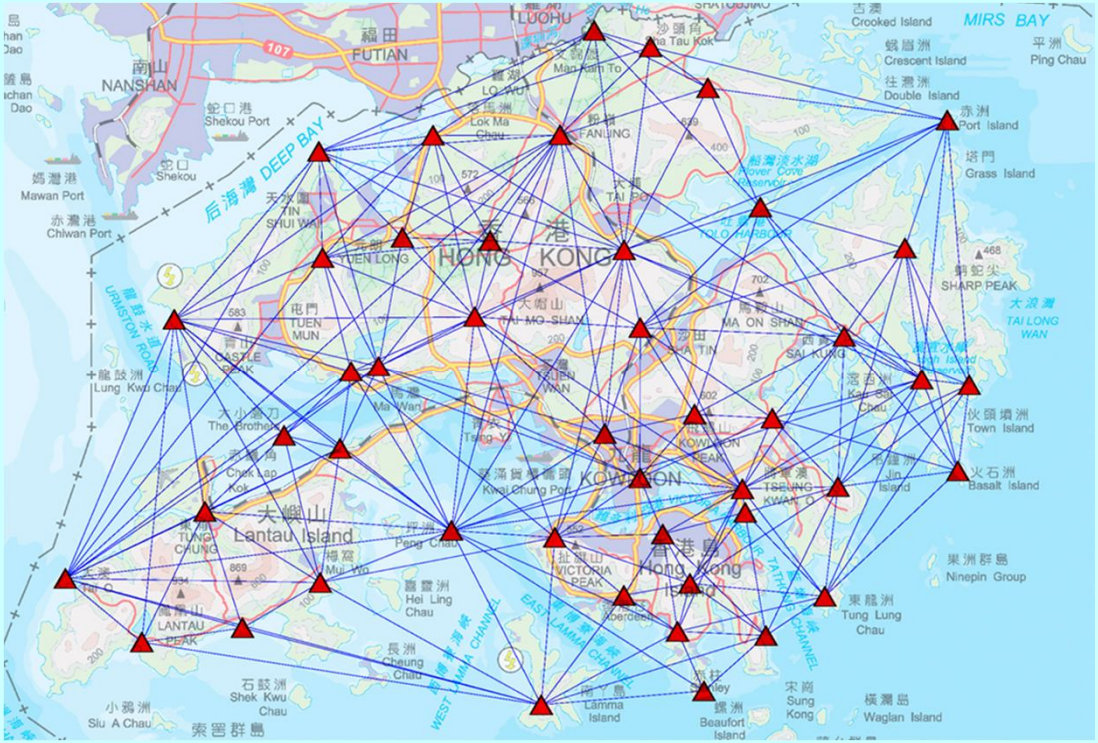
- The bench mark “Rifleman’s Bolt” is a copper bolt fixed in Hong Kong Naval Dockyard in 1866.
- It was the origin of the height datum. The highest point of the Bolt was 17 feet 10 inches above the “zero level” which is now known as the Hong Kong Principal Datum .

Rifleman’s Bolt

Hong Kong Bench Mark

- The Rifleman's Bolt is no longer used as bench mark now. It was preserved as a historical monument.
- The current leveling network has about 1700 bench marks which are the reference points for levelling survey and vertical measurements.

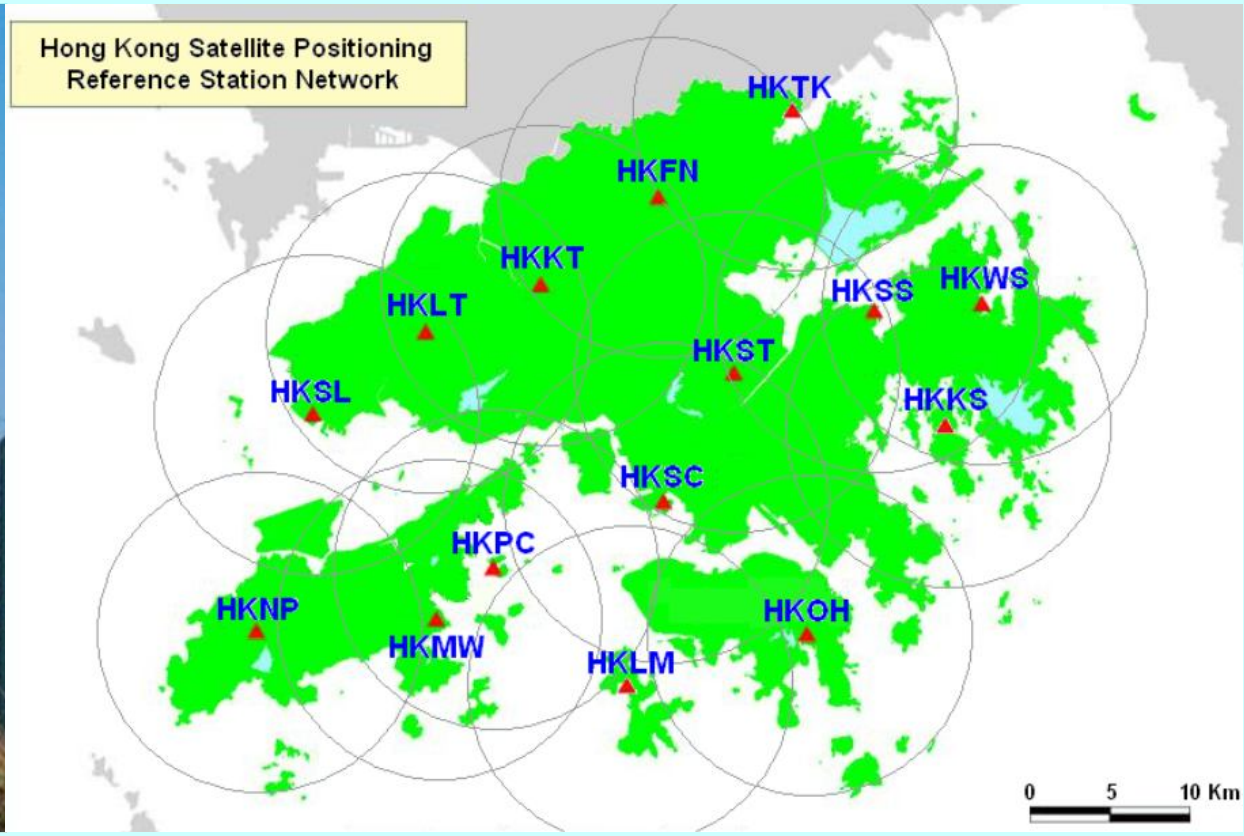
The Hong Kong Satellite Positioning Infrastructure



The Hong Kong 2000 satellite positioning control network.

It establishes a reference system to serve positioning, land surveying, engineering and town planning activities in Hong Kong.

The Hong Kong Satellite Positioning Infrastructure



The Hong Kong Satellite Positioning Reference Station Network.

The Hong Kong Satellite Positioning Infrastructure

The Hong Kong Satellite Positioning Reference Station Network

Users

Data

Data

Data Centre

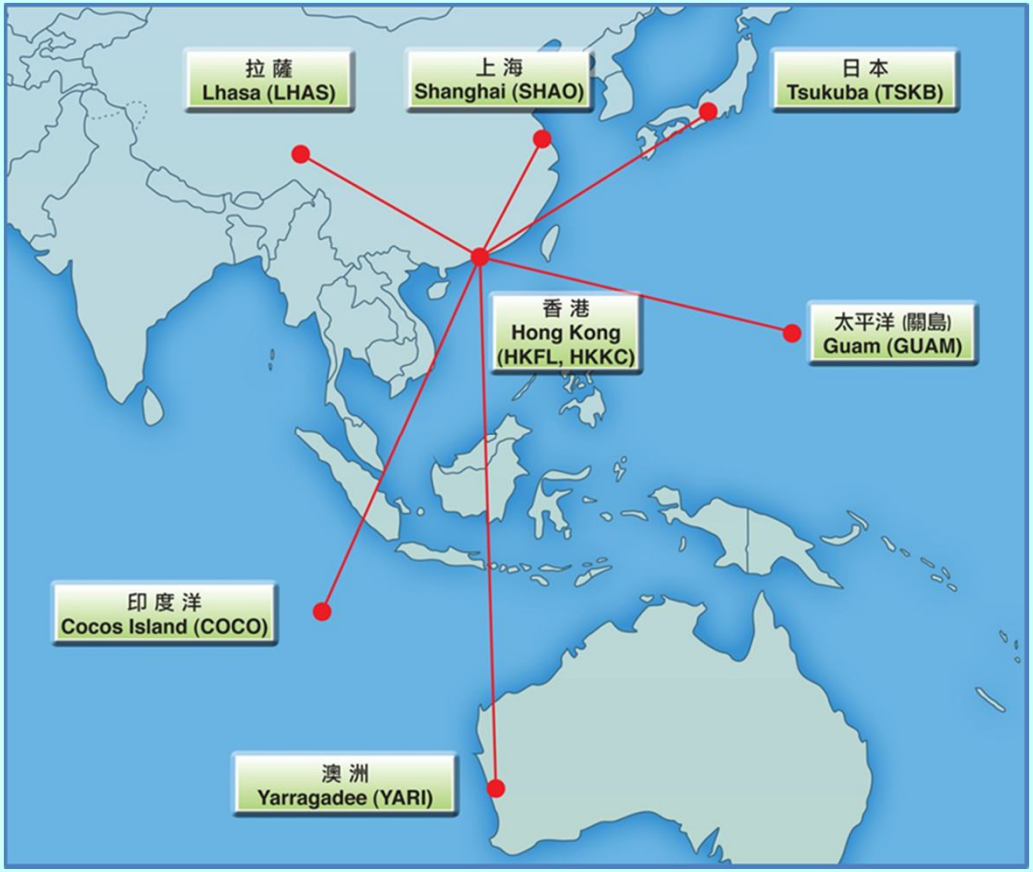
Remote Control

Remote Control

Control Centre

The Hong Kong Satellite Positioning Infrastructure

The satellite positioning reference stations at Fanling and Kau Yi Chau linked the Hong Kong Geodetic Datum to the International Terrestrial Reference Frame, the global positioning infrastructure for studying geodynamics, earthquake and earth science, etc.



Hong Kong Vertical Reference Systems

SATELLITE POSITIONING REFERENCE STATION SUMMARY

STATION NO. : **HKNP** *(FORMER NO.* : _____ *)* *SURVEY SHEET NO.* : **9-SW-25D**

NAME : **NGONG PING SATELLITE POSITIONING REFERENCE STATION** *LOCALITY* : **NGONG PING, LANTAU ISLAND**

HK 80 DATUM	*HK 1980 GRID COORDINATES* : N = **812 282.866** m, E = **807 096.092** m,	Class : **N.A.**
	Transformed from WGS84 (ITRF96) Ht = **354.421** m above HKPD and measured to the top of mark,	Class : **V3**
	SCALE FACTOR : **+ 10.8** ppm to measured distance to give Grid Distance	
	GRID CONVERGENCE : **- 06' 31.4"** to Grid Bearings to give Azimuth	
WGS 84 DATUM	*GEOGRAPHICAL COORDINATES* : Lat = **22° 14' 56.63737"** N, Long = **113° 53' 37.95000"** E,	Class : **GH2**
	Ht = **350.700** m above Ellipsoid and measured to the top of mark,	Class : **GV2**
	Reference Frame = **ITRF96**	
	UTM GRID COORDINATES : **2 463 249** mN, **798 275** mE	
	UTM GRID REFERENCE : **49Q GE 982 632**	

Orthometric Height : reference to the Hong Kong Principal Datum.

N = **812 282.866** m, E = **807 096.092** m,

Ht = **354.421** m above HKPD and measured to the top of mark,

+ 10.8 ppm to measured distance to give Grid Distance

- 06' 31.4" to Grid Bearings to give Azimuth

Ellipsoidal Height : reference to ITRF96

Lat = **22° 14' 56.63737"** N, Long = **113° 53' 37.95000"** E,

Ht = **350.700** m above Ellipsoid and measured to the top of mark,

Reference Frame = **ITRF96**

Re-levelling and re-adjustment of the Hong Kong Bench Mark Network

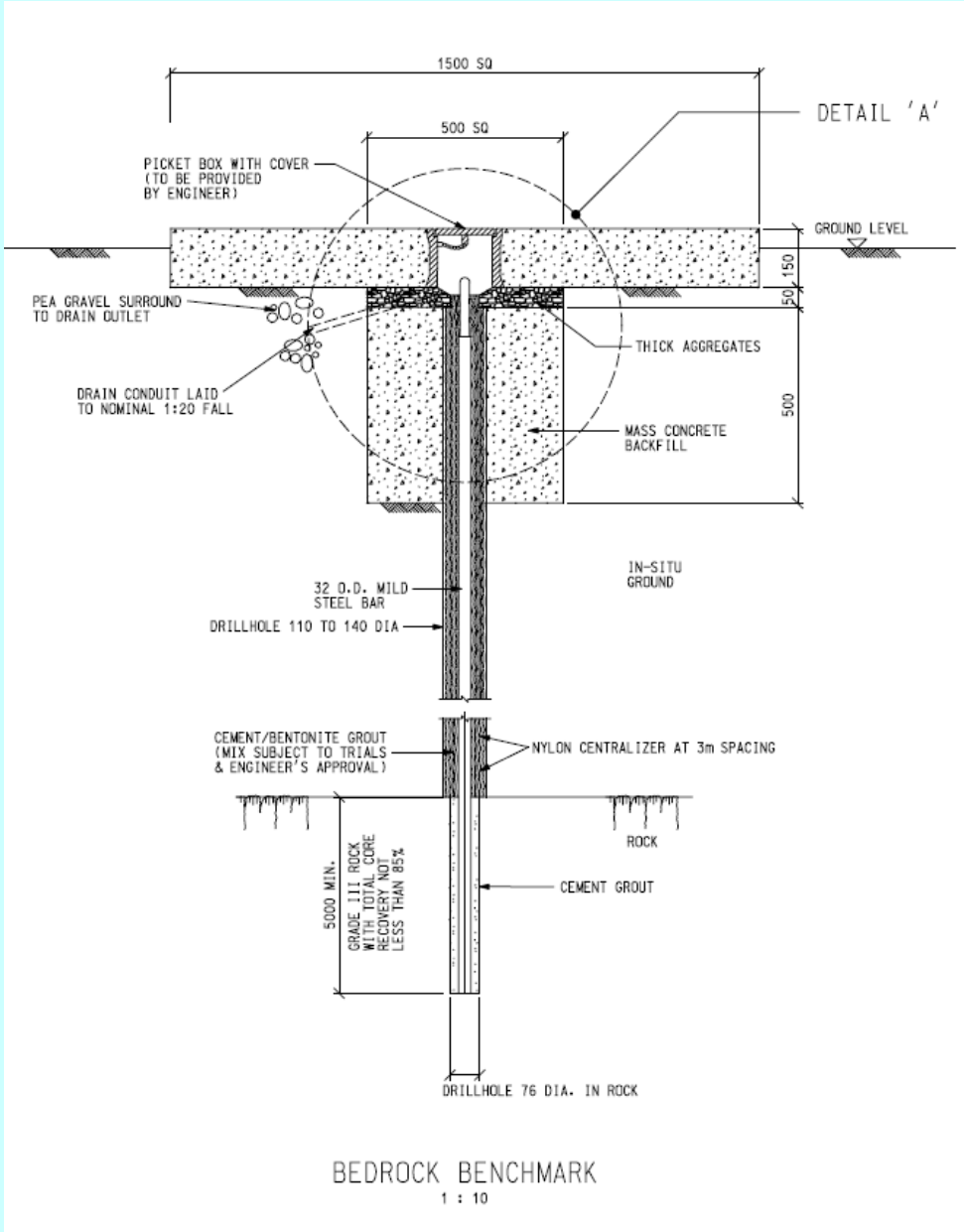
- The origin of the Hong Kong Principal Datum was established in 1866 and the current network of bench marks were installed and replenished during the past decades.
- The accuracy of the bench mark network was deteriorating due to accumulation of error caused by re-measurement, disturbance and ground movement.

Strengthening the Bench Mark Network

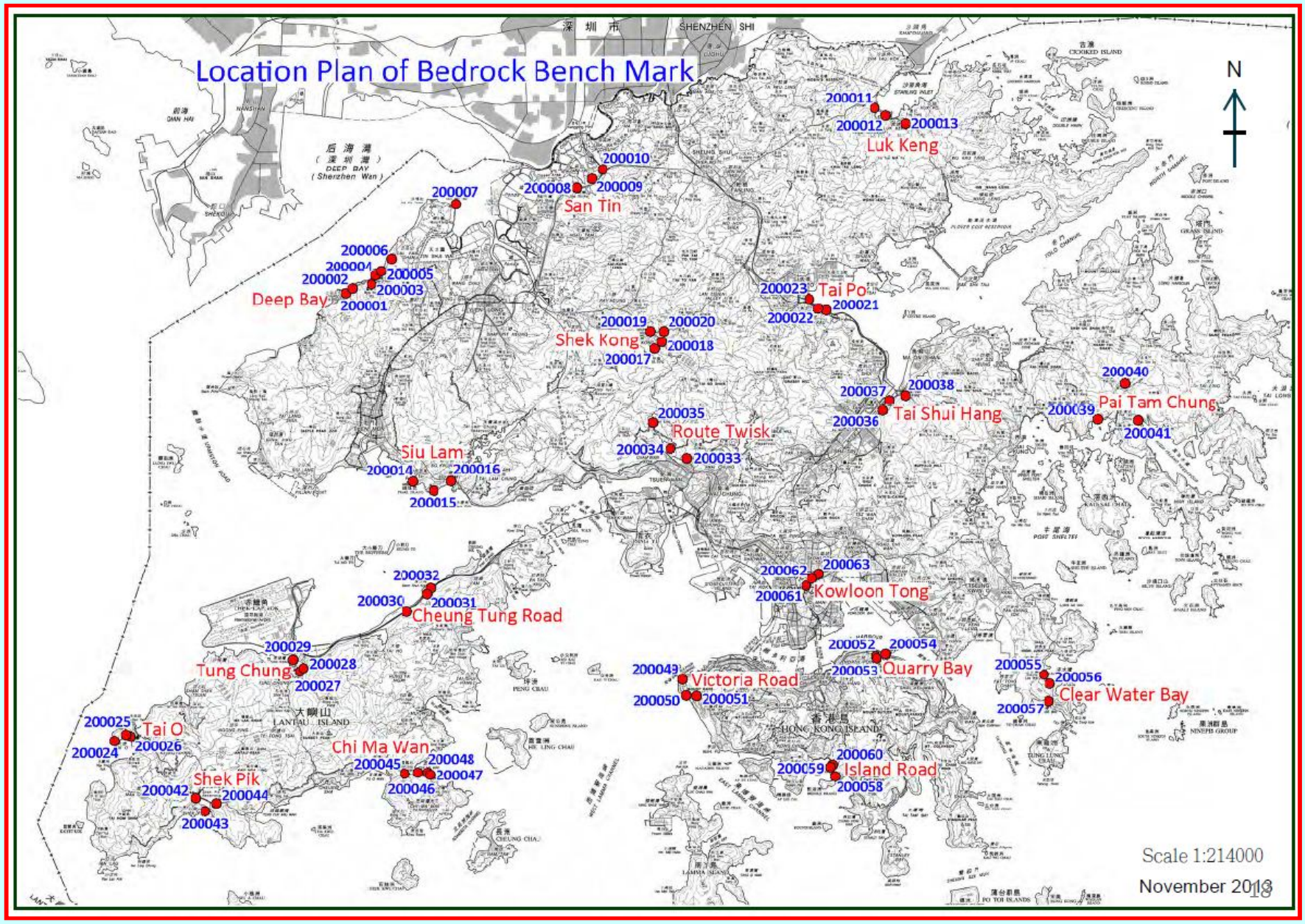
- Install bedrock bench marks to improve stability of the monuments of the network
- Re-survey the bench marks network to improve the relative accuracy between bench marks.
- Re-adjust the levelling network with reference to the Hong Kong Principal Datum to improve absolute accuracy of the published value of the bench marks.

Bedrock Bench Marks

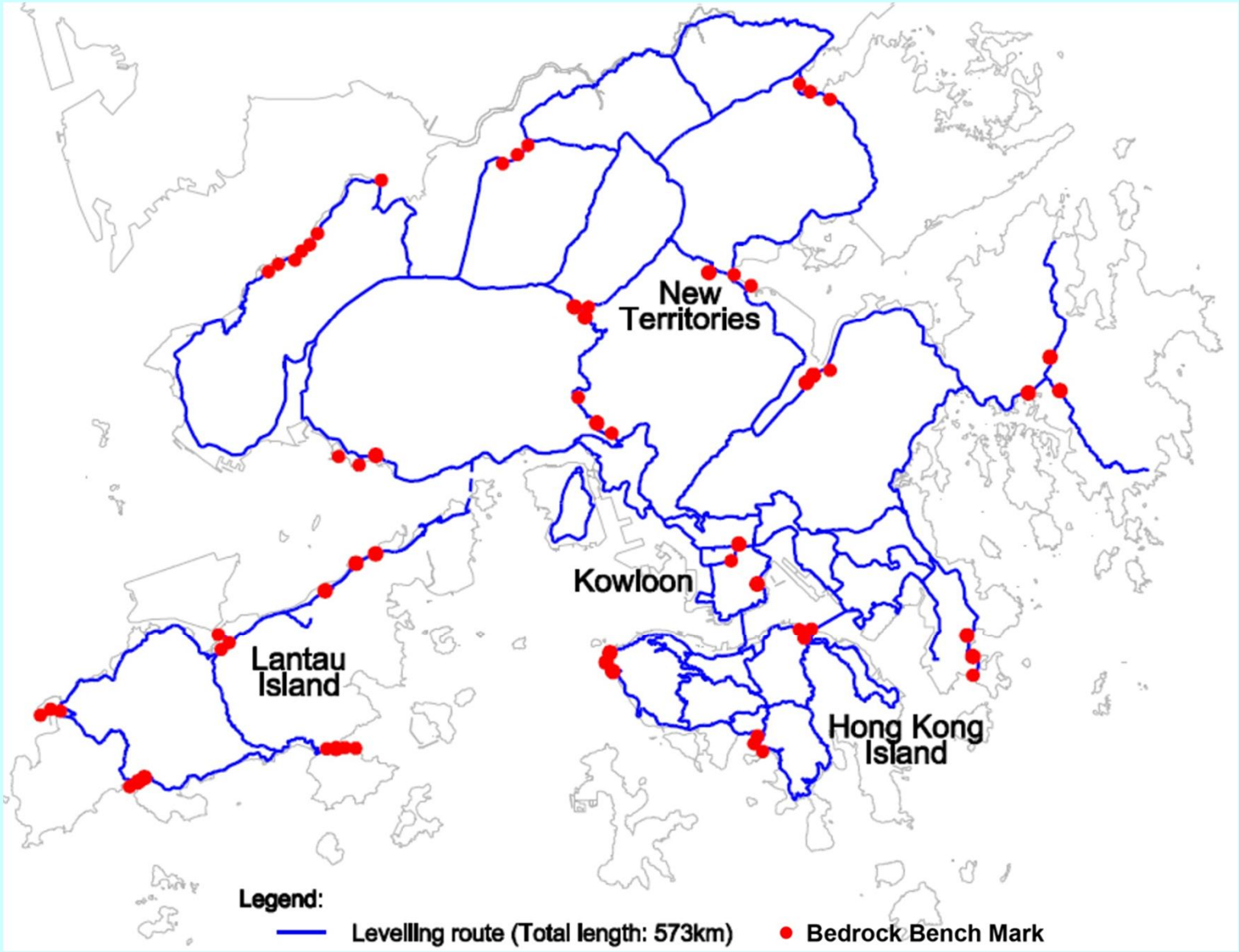
- A bedrock bench mark is a very stable vertical control monument which is composed of a picket box with concrete platform and a reinforced mini-pile (concrete with stainless steel bar) embedded into the bedrock under the ground.
- 63 Bedrock Bench Marks were established over the territory.
- 3 bench marks in a group to facilitate checking of stability of the marks in relation to the adjacent point.



Bedrock Bench Marks



Bedrock Bench Marks



Bedrock Bench Marks

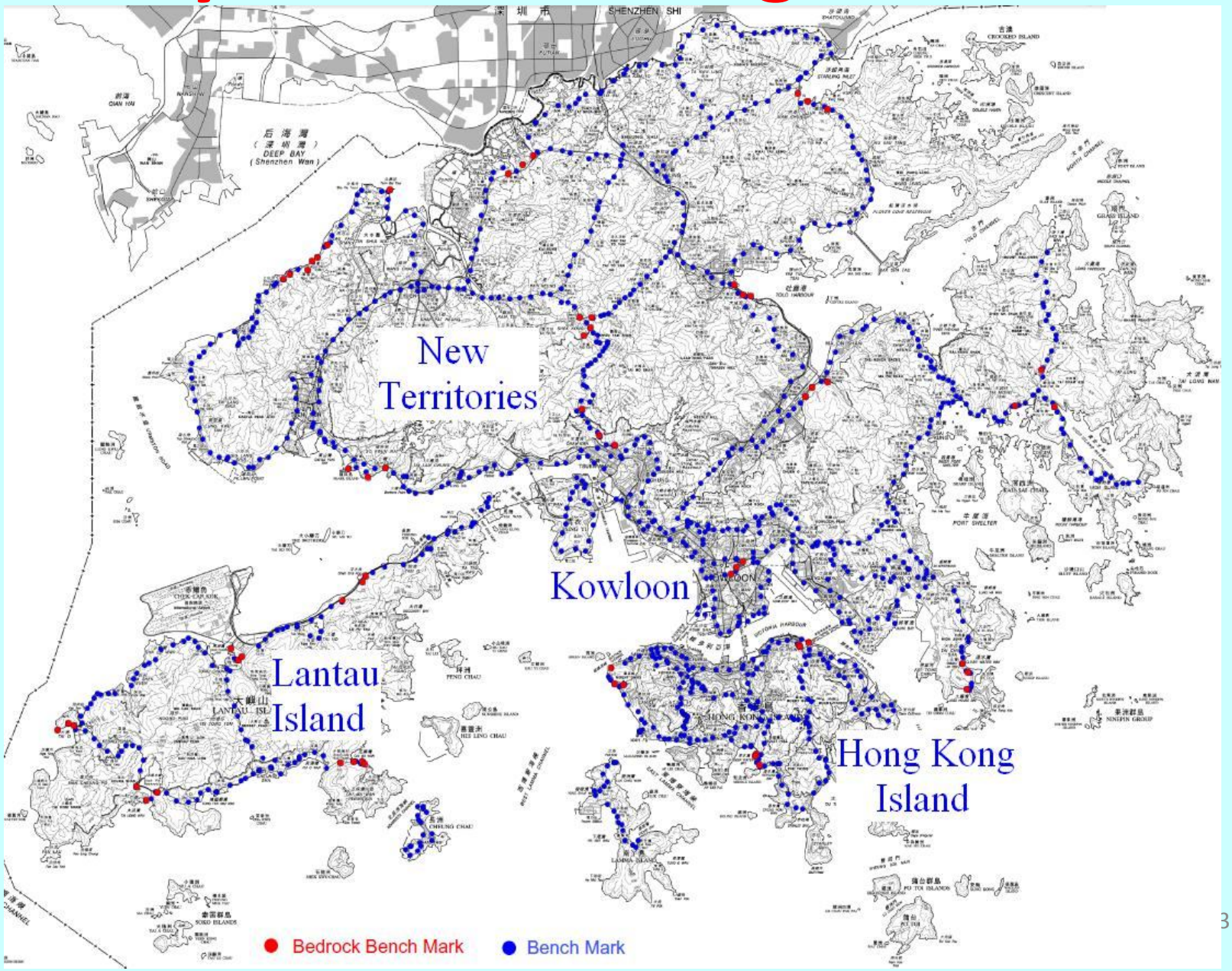
Bedrock Bench Marks embedded into the bedrock under the ground.

Bedrock Bench Marks

Re-survey of the Bench Mark Network

- About 1100 bench marks covering 570 km were re-surveyed by precise levelling.
- To verify the consistency of the existing levelling network
- To form a new network with higher accuracy

Layout of Levelling Route



Re-survey of the Bench Mark Network

- At least two sets of independent observation of height difference for each levelling route were taken.
- The maximum discrepancy of repeated observation is 4 √K mm, (K = length of levelling route in Km).
- Standard error per set up (σ)= 1.3mm .

Readjustment of the Bench Mark Network

Pre- processing to eliminate blunders

- 35 Levelling loops were formed.
- The length of levelling loops vary from 2 Km to 56 Km.
- Any levelling loop with misclosure greater than the allowable error is regarded as outlier.

Readjustment of the Bench Mark Network

Unconstraint Adjustment

- Held one point fixed.
- Lease square adjustment .
- Eliminate outliners of the observed height difference.
- Height difference between adjacent bench marks should have at least two sets of observations after rejection of the outliners.
- Maximum allowable residual: 4 √K mm, (K = length of levelling route in Km).
- σ of the residual = 1.3mm

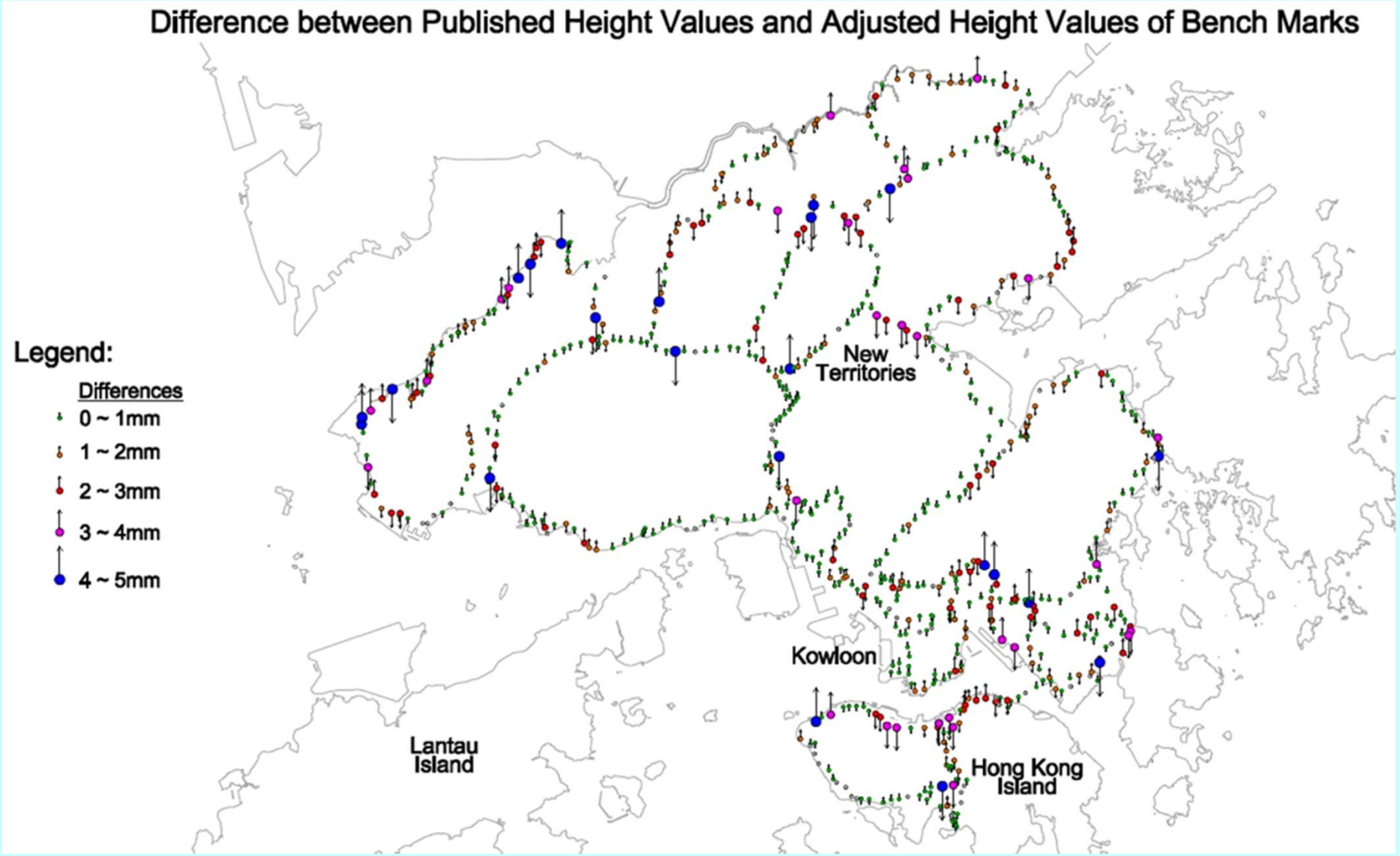
Readjustment of the Bench Mark Network

Constraint Adjustment

- Use a step by step approach to estimate the error of the published height values of the known bench marks.
- Start the first iteration of the adjustment with a larger estimated error of the height value. Then reduce the estimated error step by step in the subsequent iterations.

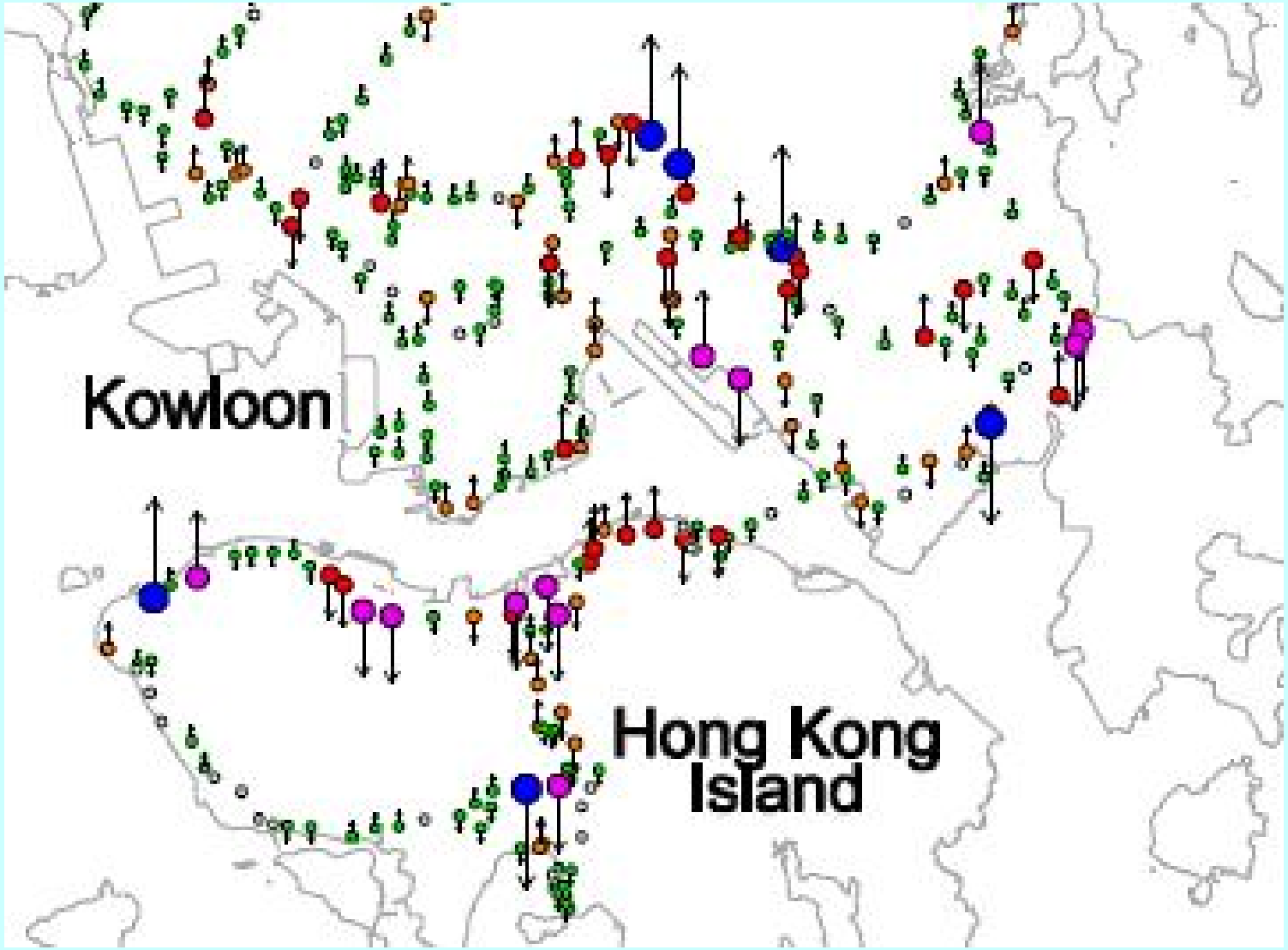
  e.g. 1st iteration, $\sigma H = 4mm$.
  2nd iteration, $\sigma H = 3mm$
  3rd iteration, $\sigma H = 2mm$
  4th iteration, $\sigma H = 1mm$
- Points identified as outliners in each iteration was free in the subsequent iteration.

Constraint Adjustment



Constraint Adjustment

Difference between published height values and the adjusted height values of bench marks



Constraint Adjustment

Final iteration

- Bench marks with residuals of the height values (V_H) larger than ±1mm were free.
- 635 out of 1092 bench marks were kept fixed in the final adjustment.
  - Maximum residuals of height values : Max V_H = 1 mm
  - Mean residuals of height values : Mean V_H = 0.3 mm
  - Maximum residuals of height difference : Max V_{dh} = 3 mm
  - Mean residuals of height difference : Mean V_{dh} = 0.5 mm

Improvement of the Levelling Network

- The relative and absolute accuracy of the bench mark network was improved.
- The height values of 635 out of 1092 bench marks remain unchanged.
- The height values of 457 out of 1092 bench marks were updated.
- For those points updated, the difference between the new height values and the old value are ranged from 1mm to a few cm.
- All the new height values are still based on the Hong Kong Principal Datum .
- The adjustment results were named as “Vertical Control Network 2013” results.

GNSS Heighting

- The height of points on land are traditionally surveyed by leveling.
- Leveling is a time-consuming and labor-intensive operation, though it provides precise height values with reference to the Hong Kong Principle Datum (HKPD).
- With the development of GNSS survey technique, the height of points can be surveyed with much better efficiency.
- However, GNSS derived heights are referred to ITRF reference frame, while the leveled heights are referred to HKPD.
- Precise geoid must be developed for transforming GNSS derived heights to leveled heights.

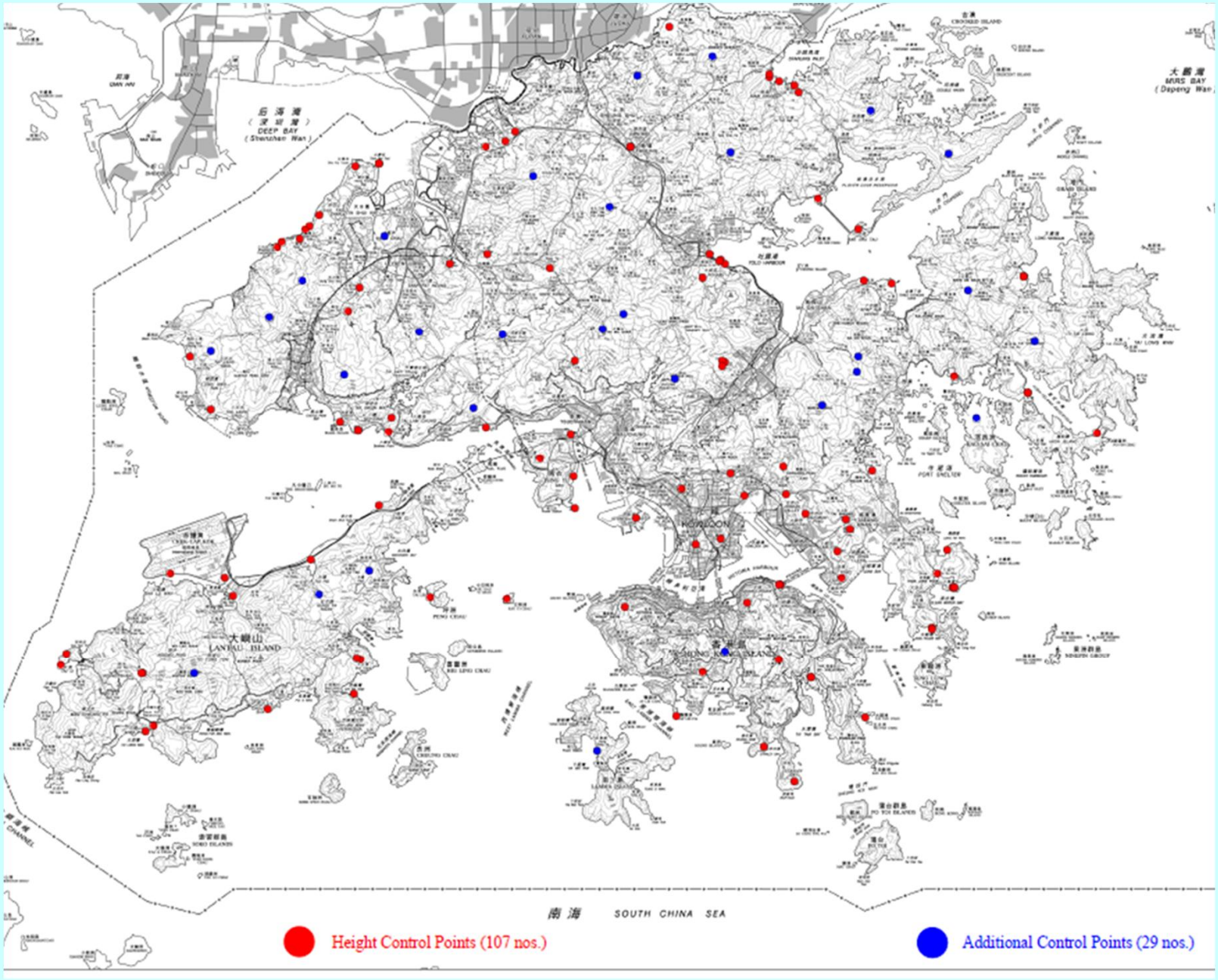
GNSS Heighting

- For creation of a geoid model, it requires a network of height control points covering the territory of Hong Kong with levelling, GNSS and gravity observations.

GNSS / Levelling Data for Creation of Geoid Model

- There were 74 GNSS / Levelling height control points covering Hong Kong. Most of them were at low ground.
- 29 new height control points were added to strengthen the coverage at the mountain areas.

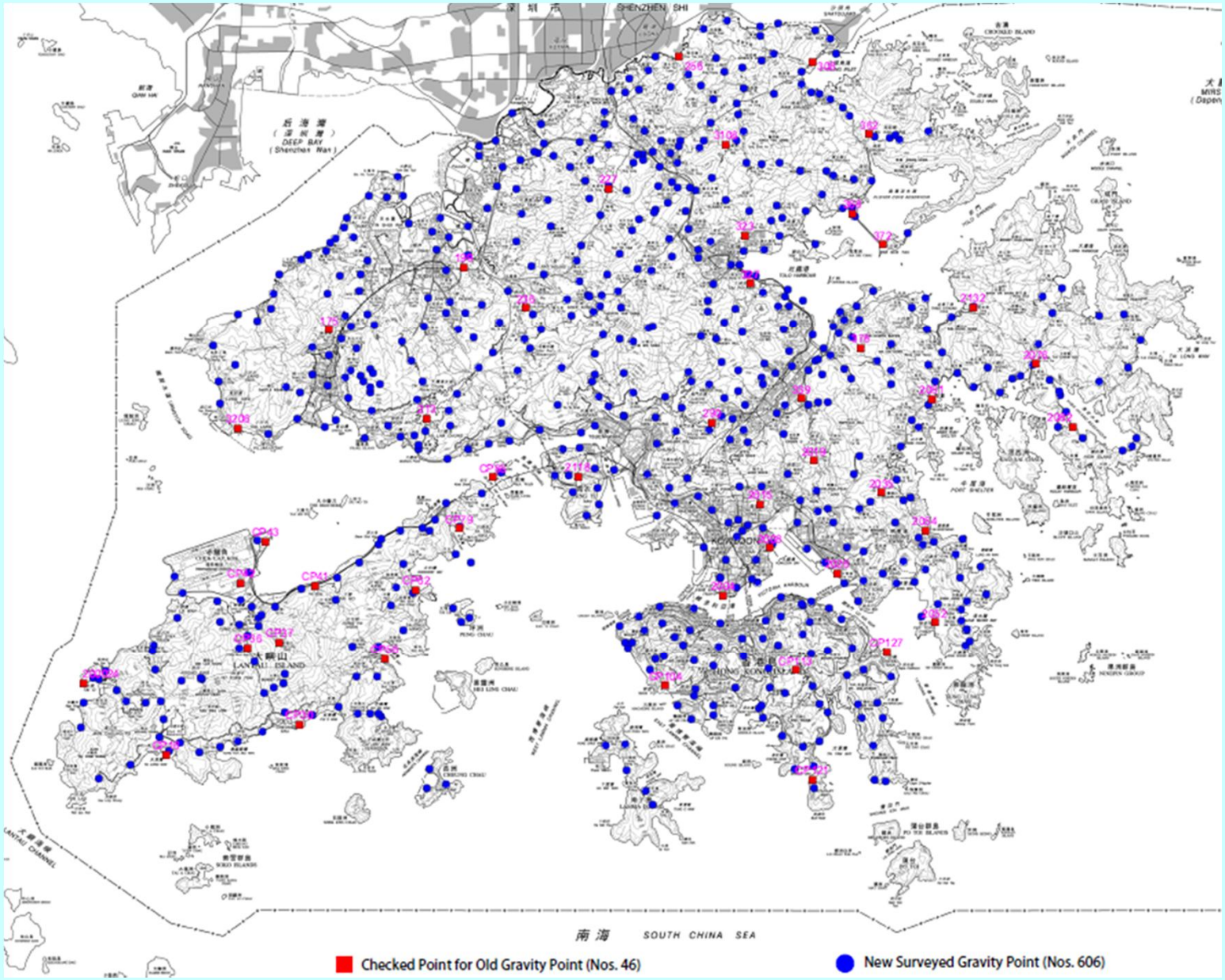
Survey of height control point with GNSS and levelling



Gravity Data

- A gravity survey was conducted in Hong Kong in early 1990s.
  - There was 640 gravity observations with station spacing 2 km on land and 2-4 km on sea.
  - They were collected using Lacoste and Romberg model 'G' land gravity meter and model 'H/U' seabed gravity meter.
- 606 new gravity points were surveyed using CG-5 Autograv gravity meter in 2015.
  - 46 old (1990s) gravity points were re-surveyed for comparing the 2015 data with the 1990s data.

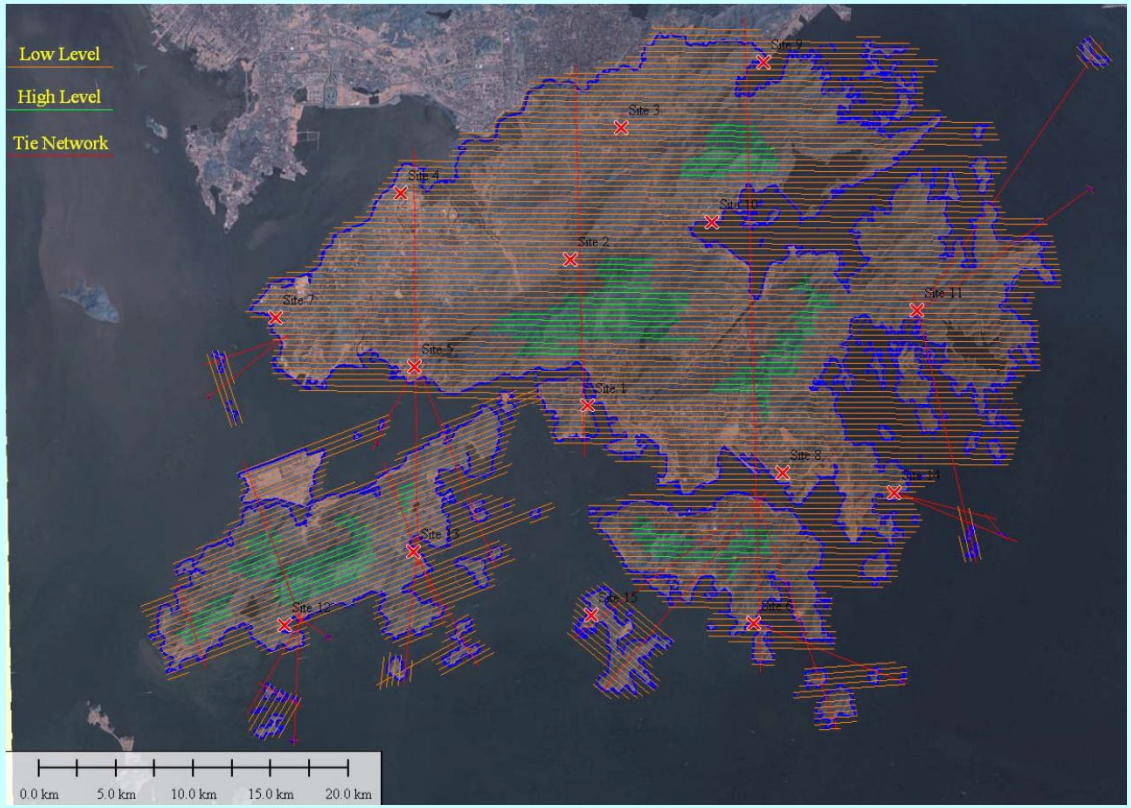
Gravity Data (2015 measurement)



Taking Gravity Measurement

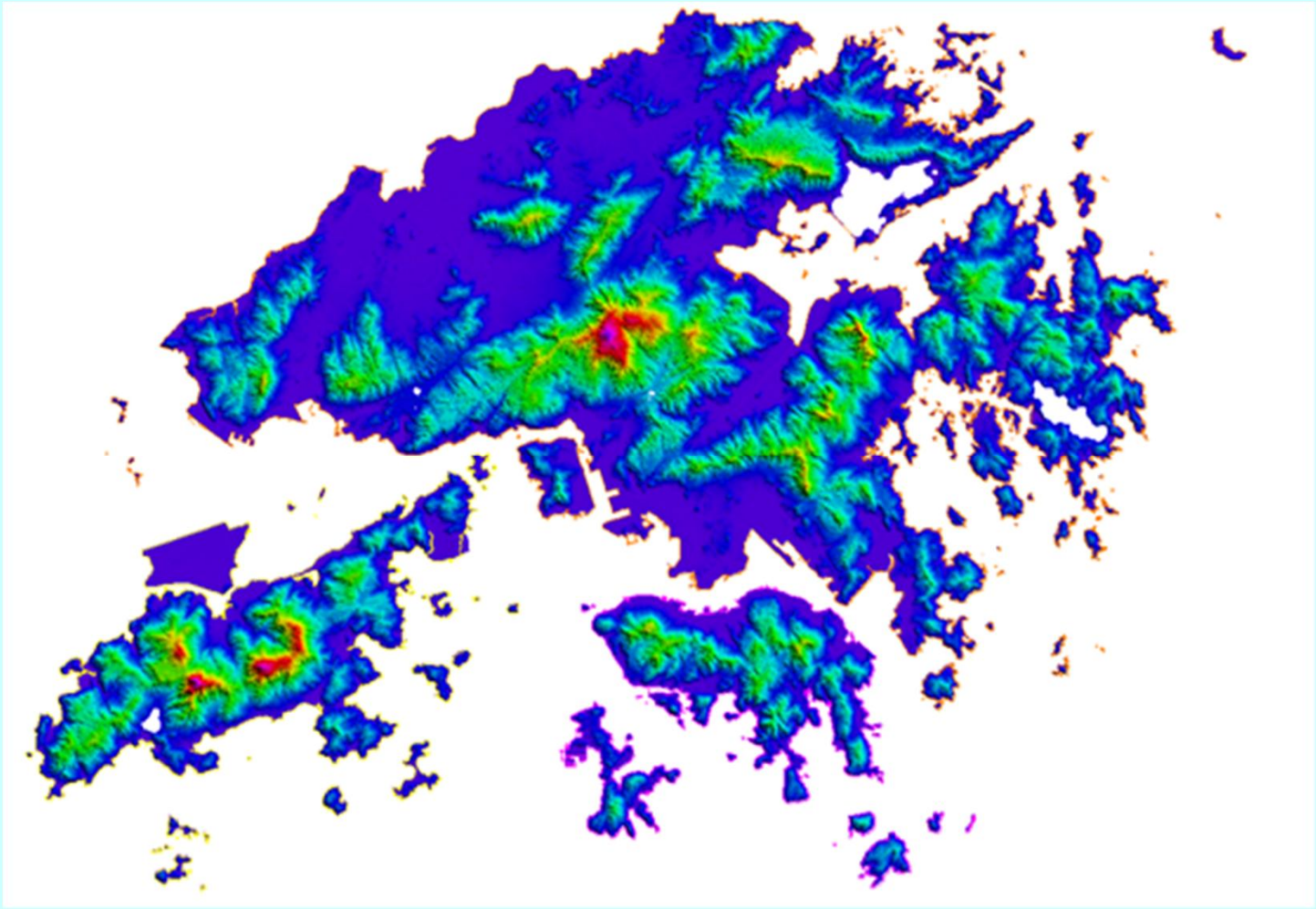
Creation of the Digital Terrain Model of Hong Kong using Lidar Data

- Lidar survey of the whole territory of Hong Kong was conducted in 2010.
- Average ground point spacing: 0.5 m
- Numbers of Passes: 463
- Total Length of flight lines: 4,700 km (about)



Flight Plan of the 2010 Lidar Survey

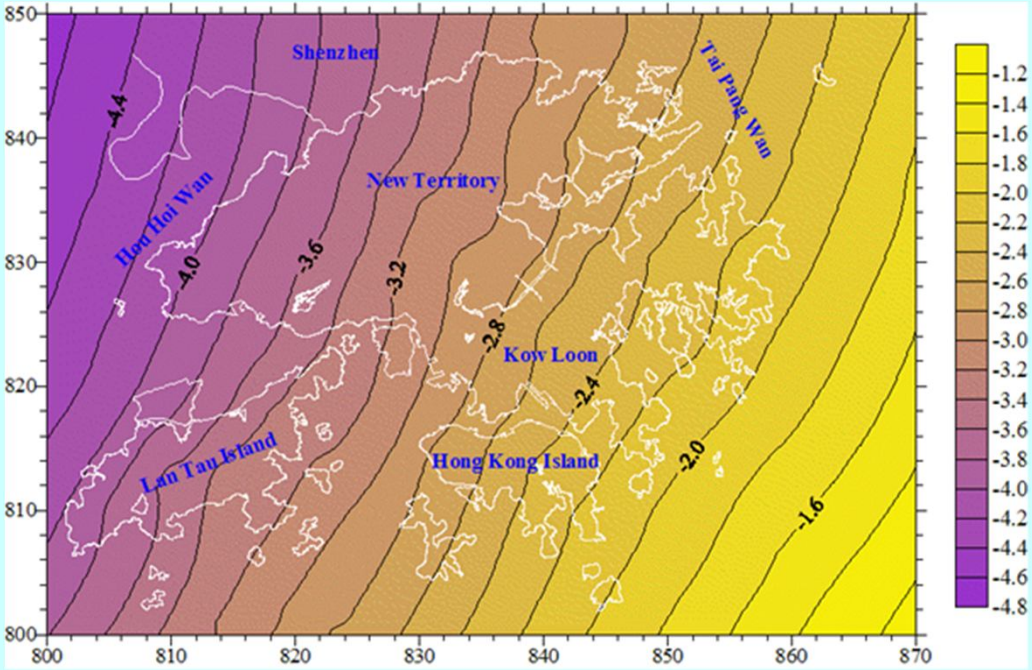
Digital Terrain Model of Hong Kong



The Digital Terrain Model (20 meters resolution) used for creation of the Hong Kong geoid was generated from the 2010 Lidar data.

Creation of the precise geoid model

- With the GNSS data, levelling data, gravity data and digital terrain model data of Hong Kong, development work for creation of the geoid model is underway.
- The geoid model will be available after completion of the project to support GNSS heighting.



Conclusion

- The Hong Kong Height System was modernized.
  - Re-levelling and re-adjustment of the Hong Kong Bench Mark Network
  - Densification of a network of points covering the whole territory of Hong Kong with levelling, GNSS and gravity observation.
  - Construction of a digital terrain model of Hong Kong.
  - Creation of a geoid model for GNSS heighting in Hong Kong.
- Improved the accuracy and reliability of the vertical reference frame.

Thank You