The GNSS Active Control Point Concept

Get the {dynamic} Reference Points when You Need

Joel van Cranenbroeck

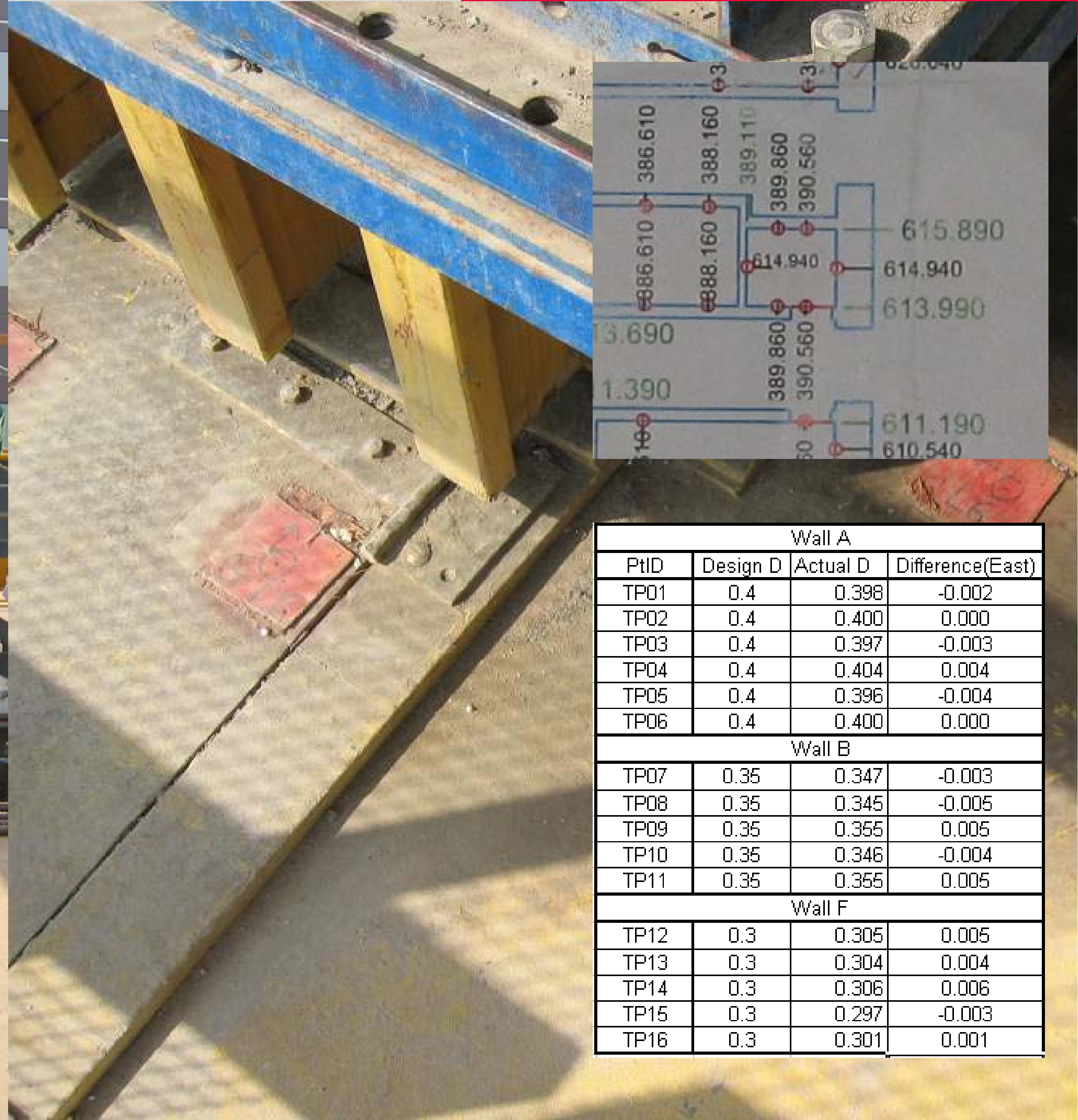
Chair of Commission 6 WG 6.2 International Federation of Surveyors (FIG)

Belgium, Europa

- when it has to be **right**

Leica Geosystems


HAYES



PtID	Design D	Actual D	Difference(East)
Wall A			
TP01	0.4	0.398	-0.002
TP02	0.4	0.400	0.000
TP03	0.4	0.397	-0.003
TP04	0.4	0.404	0.004
TP05	0.4	0.396	-0.004
TP06	0.4	0.400	0.000
Wall B			
TP07	0.35	0.347	-0.003
TP08	0.35	0.345	-0.005
TP09	0.35	0.355	0.005
TP10	0.35	0.346	-0.004
TP11	0.35	0.355	0.005
Wall F			
TP12	0.3	0.305	0.005
TP13	0.3	0.304	0.004
TP14	0.3	0.306	0.006
TP15	0.3	0.297	-0.003
TP16	0.3	0.301	0.001

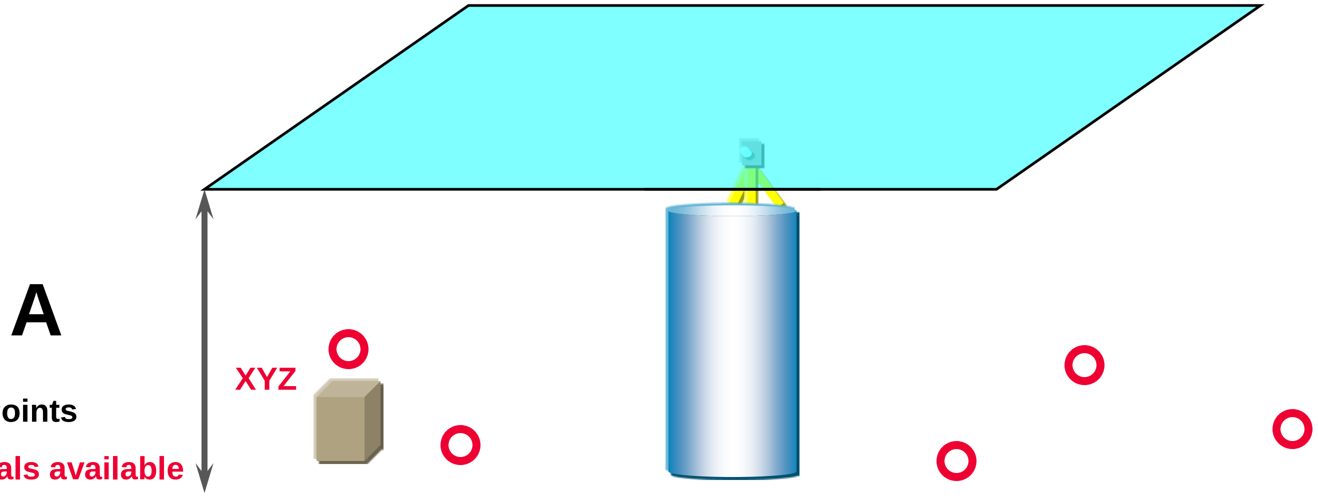
GPS3
GPS 2
GPS1
Antenna AX1202
wireless modem
CPU

Total Station and Set-up on the Building Top

Leica Geosystems

How to Setup the Total Station ?

Where are the control points ?

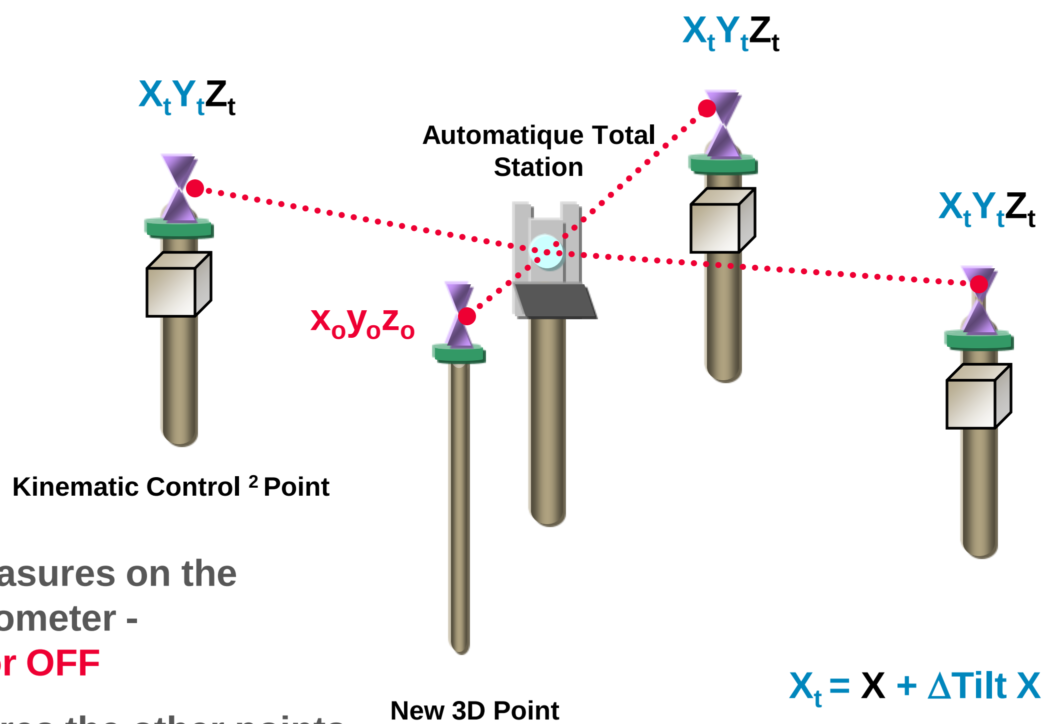


✓ **Control Points**

× **GPS signals available**


$X_t Y_t Z_t$
$X_t = X + \Delta Tilt\ X$
$Y_t = Y + \Delta Tilt\ Y$

Kinematic Control² Point Concept (KC2PC)

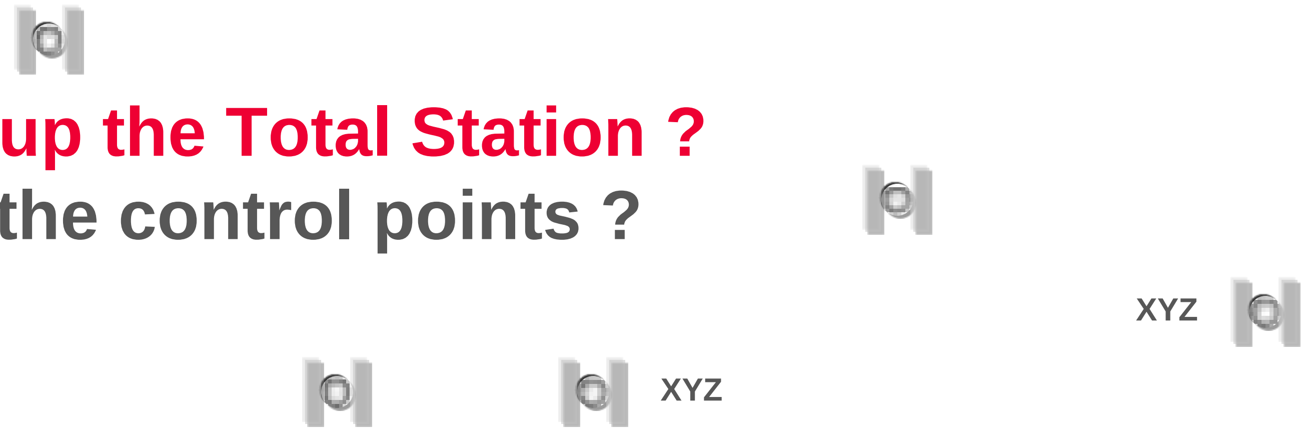


1. The TPS measures on the prism/Inclinometer - **compensator OFF**
2. Then measures the other points on the formwork.
3. The tilts are computed and applied on existing X,Y.
4. A 7 parameters transformation is applied on the other points.

$X_t = X + \Delta Tilt\ X$

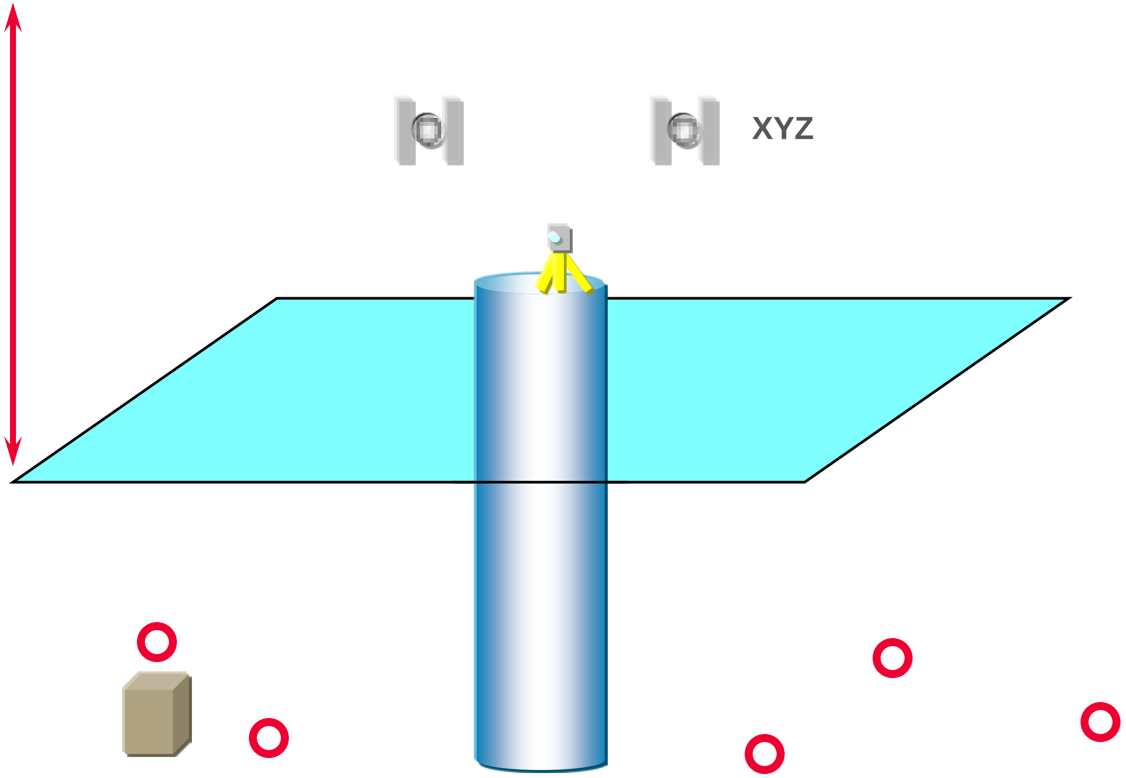
$Y_t = Y + \Delta Tilt\ Y$

How to Setup the Total Station ?
Where are the control points ?

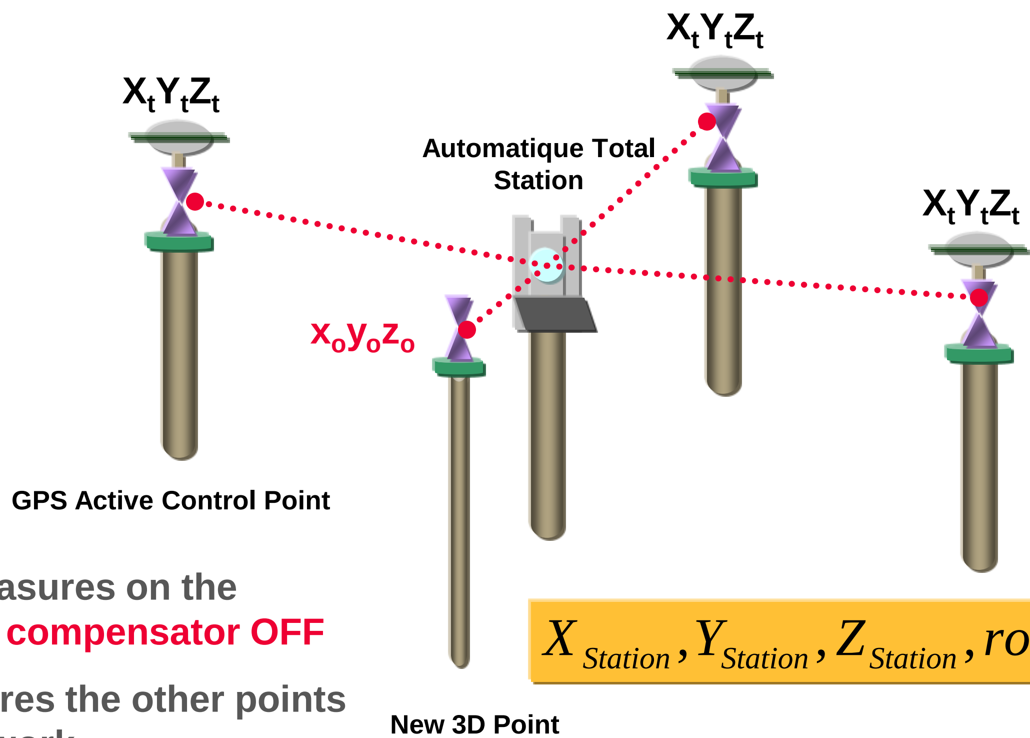


× NO Control Points

✓ GPS signals available



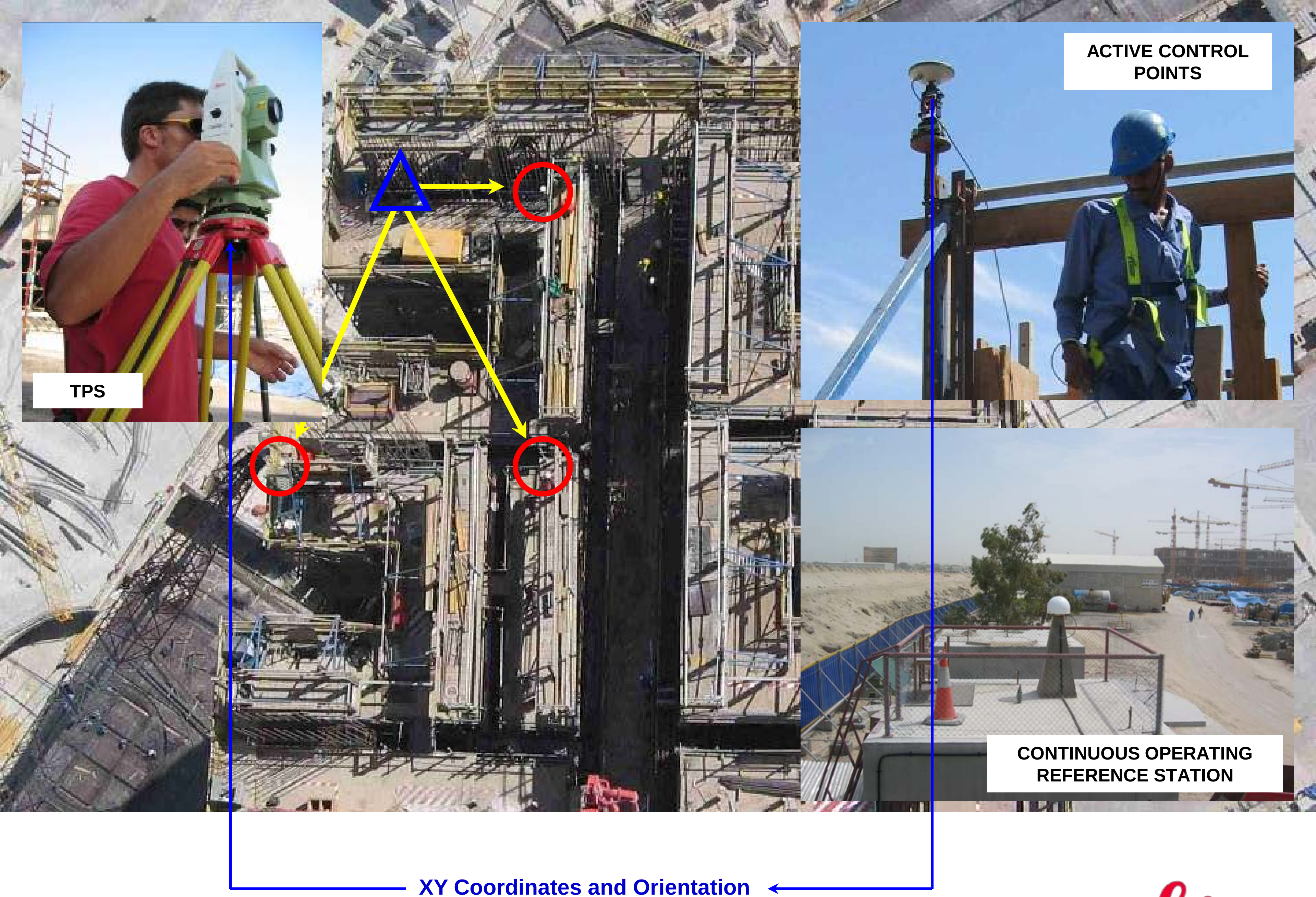
Active GPS Based Control Point Concept



$$X_{Station}, Y_{Station}, Z_{Station}, rot_X, rot_Y, Azimuth$$

1. The TPS measures on the prism/GPS - **compensator OFF**
2. Then measures the other points on the formwork.
3. The GPS fixes are computed and used as « known points ».
4. A 7 parameters transformation is applied on the other points.

GPS Continuous Operating Reference Station


TPS
ACTIVE CONTROL POINTS
CONTINUOUS OPERATING REFERENCE STATION
XY Coordinates and Orientation

Active GNSS Control Points
Post-Processing or Real Time ?

Do we need to to obtain TPS coordinates Immediately on the building's top ?

yes

The surveyor will need to obtain the coordinates provided by GPS immediately on the TPS side

The Active Control Points must operate in Real time mode

Wireless Communication

GMX902 GG

no

The surveyor will need to obtain the coordinates provided by GPS in his office

The Active Control Points can operate in Post-Processing mode

Logging files on MC*

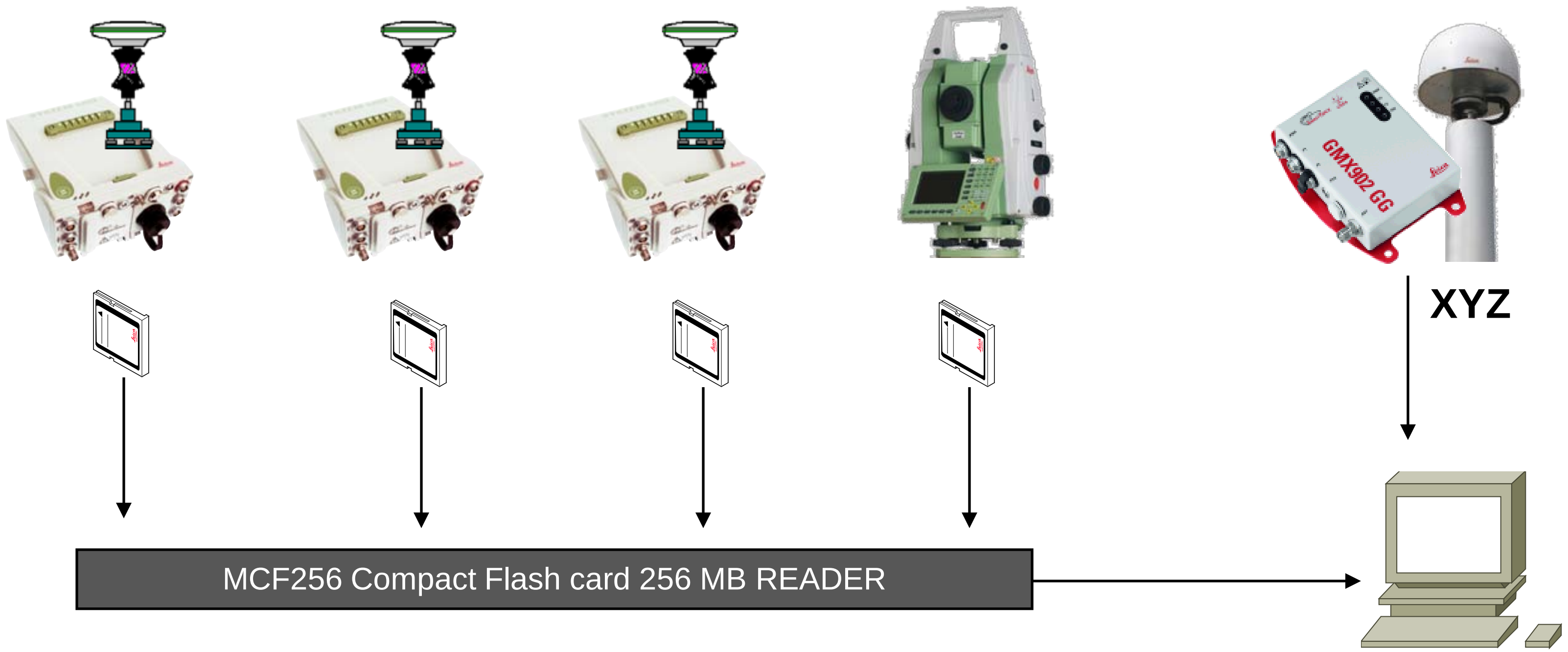
GRX1200 Pro GG

A GNSS Constinuously Operated Reference Station Leica **GMX902 GG is mandatory in both case and must be located closed to the construction side (less than 1 km ideally)**

* MC = Memory Card

Active GNSS Control Points

GNSS Monitoring Stations – POST PROCESSING



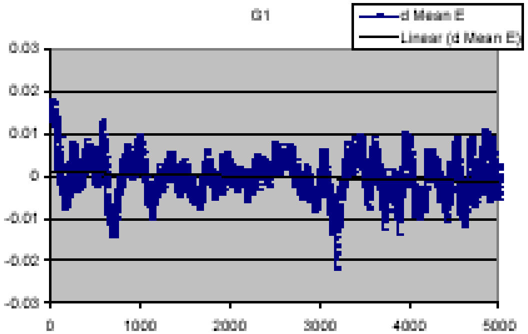
In the Survey Office the PC running Leica GNSS Spider will log the observations of the CORS station continuously (RINEX).

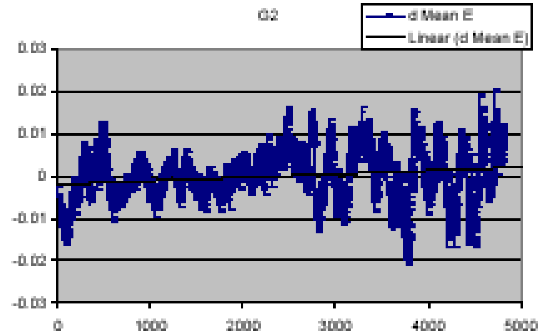
When the MC content will be downloaded on the PC, Leica LGO will be used to post-process the data and obtain the coordinates XYZ that will be used to set-up the coordinates of the TPS by free resection.

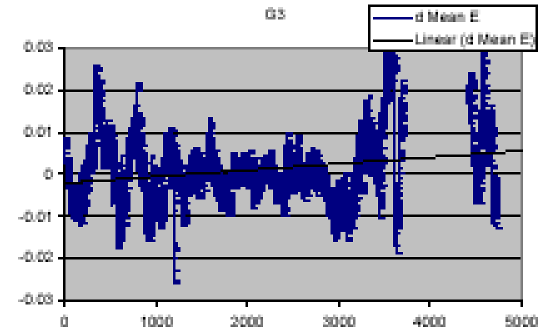
GNSS measurements are processed in « Mixed Tracks » mode using Leica LGO

G1 **G2** **G3**

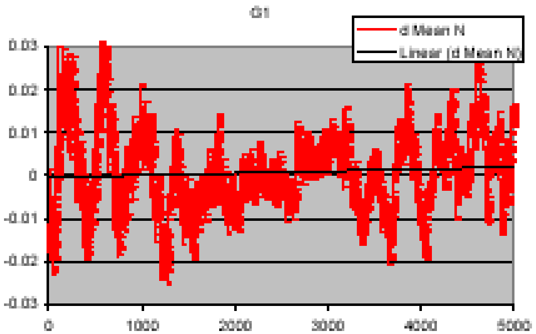
E

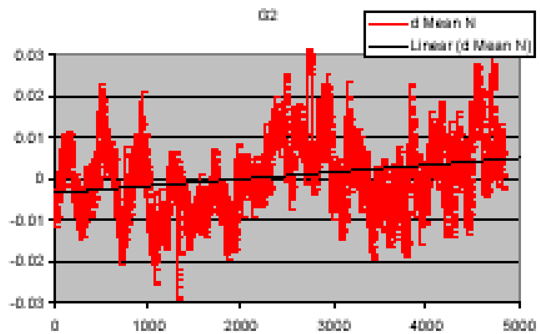


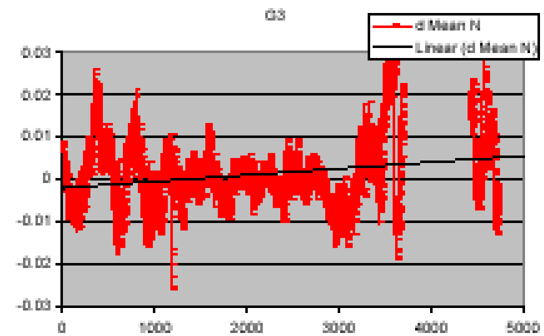




N

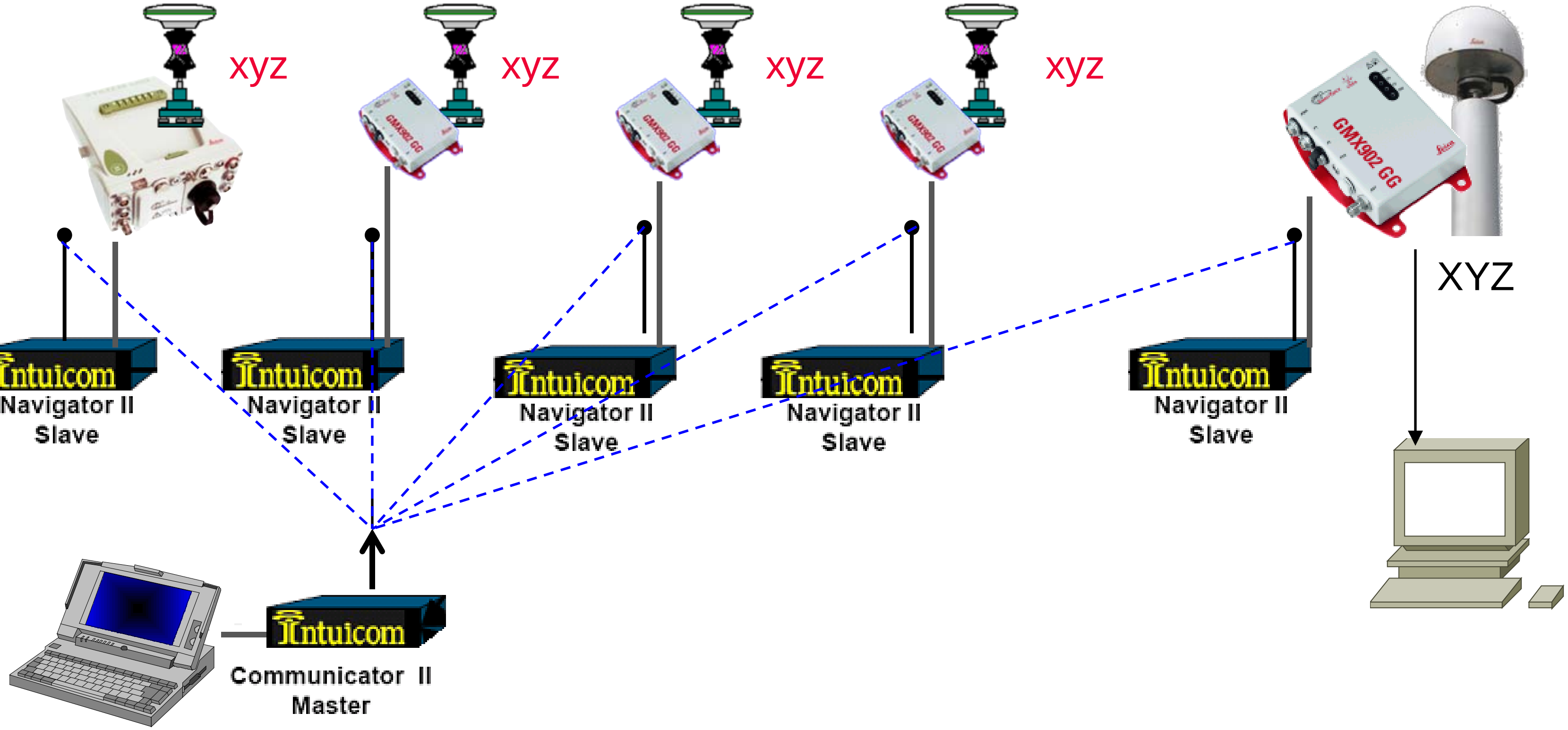






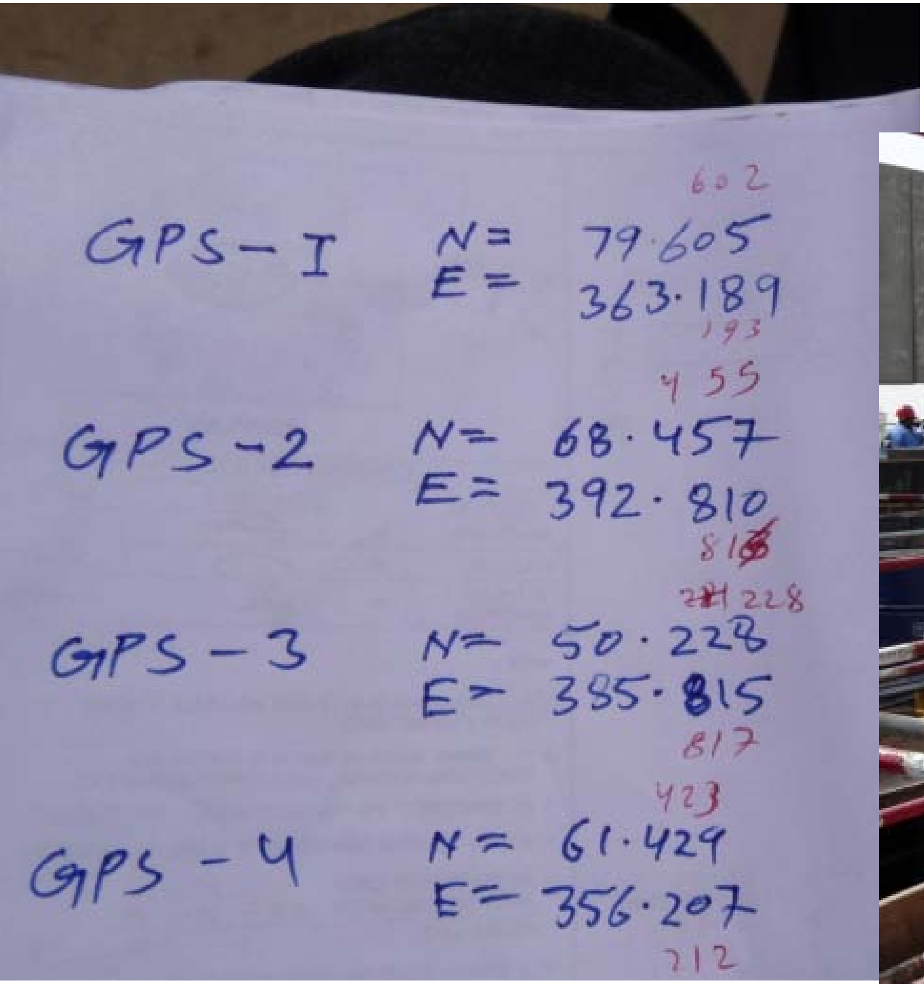
Active GNSS Control Points

GNSS Monitoring Stations – Real-Time



On the top of the buiding where the surveyor is setting up his Total Station, a Laptop PC running Leica GNSS Spider Positioning will be used to gather the data streams from every GNSS receiver in real time and will display the coordinates on the screen with information about the accuracy, availability and reliability.

Active Control Point in Real Time Mode …



Depending of the environment (vibrations) and the application (moving platform) …

Steady Environment

COMPENSATOR is ON

CALCULATOR is ON

One FACE measurements

Vibrations

COMPENSATOR is OFF

CALCULATOR is ON

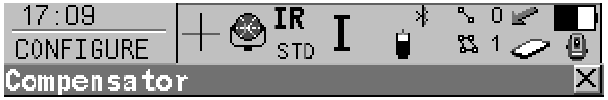
One FACE measurements

3D Space – no gravity

COMPENSATOR is OFF

CALCULATOR is OFF

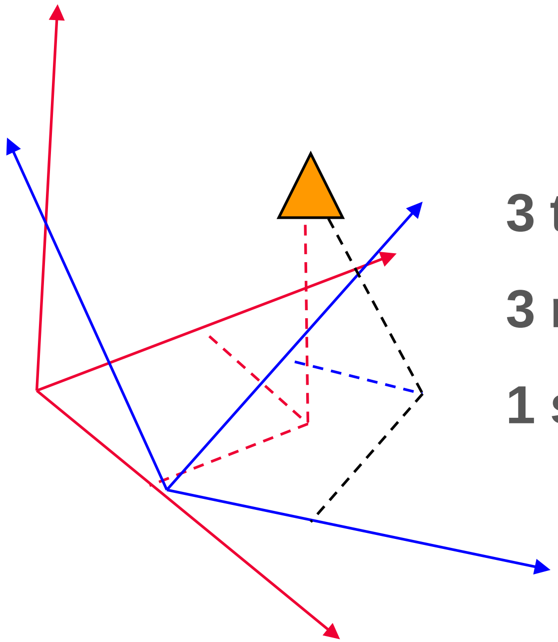
Two FACE measurements



3D transformation …

By using the measurement and the approximate (or setup with local axis) coordinates of the station and an approximate Hz orientation (or any direction) we are computing the “local” coordinate of all the “control” points.

Then we basically have to compute a 3D transformation from the “local” coordinates into the “control” points reference system.



3 translations along X, Y and Z axis

3 rotations along the X,Y and Z axis

1 scale factor

$$R = \begin{bmatrix} \cos\phi \cdot \cos\kappa & -\cos\phi \cdot \sin\kappa & \sin\phi \\ \cos\omega \cdot \sin\kappa + \sin\omega \cdot \sin\phi \cdot \cos\kappa & \cos\omega \cdot \cos\kappa - \sin\omega \cdot \sin\phi \cdot \sin\kappa & -\sin\omega \cdot \cos\phi \\ \sin\omega \cdot \sin\kappa - \cos\omega \cdot \sin\phi \cdot \cos\kappa & \sin\omega \cdot \cos\kappa + \cos\omega \cdot \sin\phi \cdot \sin\kappa & \cos\omega \cdot \cos\phi \end{bmatrix}$$

$$s \cdot R = (1 + ds) \cdot dR = \begin{bmatrix} 1+ds & -d\kappa & d\phi \\ d\kappa & 1+ds & -d\omega \\ -d\phi & d\omega & 1+ds \end{bmatrix} = I + \begin{bmatrix} ds & -d\kappa & d\phi \\ d\kappa & ds & -d\omega \\ -d\phi & d\omega & ds \end{bmatrix}$$

$$X = dX + (1 + ds) \cdot dR \cdot X_0$$

$$\begin{bmatrix} X_i \\ Y_i \\ Z_i \end{bmatrix} = \begin{bmatrix} x_i & 0 & z_i & -y_i & 1 & 0 & 0 \\ y_i & -z_i & 0 & x_i & 0 & 1 & 0 \\ z_i & y_i & -x_i & 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} ds \\ d\omega \\ d\phi \\ d\kappa \\ dT_x \\ dT_y \\ dT_z \end{bmatrix}$$

For 3 common points the following equations are solved using Least Squares Adjustment …

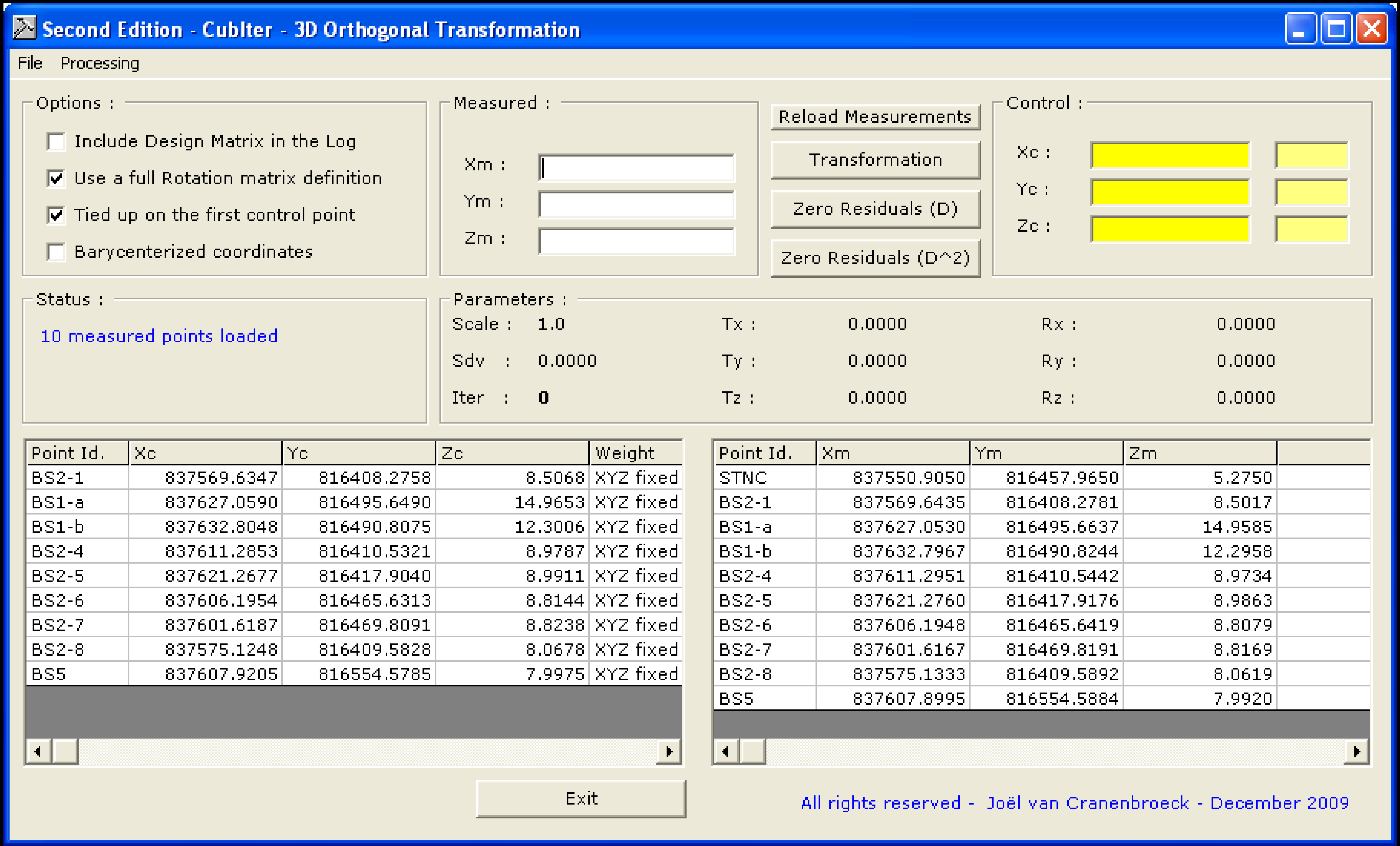
$$
\begin{bmatrix} X_i \\ Y_i \\ Z_i \\ X_j \\ Y_j \\ Z_j \\ X_k \\ Y_k \\ Z_k \end{bmatrix}
=
\begin{bmatrix}
x_i & 0 & z_i & -y_i & 1 & 0 & 0 \\
y_i & -z_i & 0 & x_i & 0 & 1 & 0 \\
z_i & y_i & -x_i & 0 & 0 & 0 & 1 \\
x_j & 0 & z_j & -y_j & 1 & 0 & 0 \\
y_j & -z_j & 0 & x_j & 0 & 1 & 0 \\
z_j & y_j & -x_j & 0 & 0 & 0 & 1 \\
x_k & 0 & z_k & -y_k & 1 & 0 & 0 \\
y_k & -z_k & 0 & x_k & 0 & 1 & 0 \\
z_k & y_k & -x_k & 0 & 0 & 0 & 1
\end{bmatrix}
\cdot
\begin{bmatrix} ds \\ d\omega \\ d\phi \\ d\kappa \\ dT_x \\ dT_y \\ dT_z \end{bmatrix}
$$

[HONG KONG FREE STATION MEASUREMENTS]

STNC ,	837550.905 ,	816457.965 ,	5.275
BS2-1,	837569.6435 ,	816408.2781 ,	8.5017
BS1-a,	837627.0530 ,	816495.6637 ,	14.9585
BS1-b,	837632.7967 ,	816490.8244 ,	12.2958
BS2-4,	837611.2951 ,	816410.5442 ,	8.9734
BS2-5,	837621.2760 ,	816417.9176 ,	8.9863
BS2-6,	837606.1948 ,	816465.6419 ,	8.8079
BS2-7,	837601.6167 ,	816469.8191 ,	8.8169
BS2-8,	837575.1333 ,	816409.5892 ,	8.0619
BS5 ,	837607.8995 ,	816554.5884 ,	7.9920

[HONG KONG CONTROL POINTS]

BS2-1	, 837569.6347	, 816408.2758	, 8.5068	,7
BS1-a	, 837627.0590	, 816495.6490	, 14.9653	,7
BS1-b	, 837632.8048	, 816490.8075	, 12.3006	,7
BS2-4	, 837611.2853	, 816410.5321	, 8.9787	,7
BS2-5	, 837621.2677	, 816417.9040	, 8.9911	,7
BS2-6	, 837606.1954	, 816465.6313	, 8.8144	,7
BS2-7	, 837601.6187	, 816469.8091	, 8.8238	,7
BS2-8	, 837575.1248	, 816409.5828	, 8.0678	,7
BS5	, 837607.9205	, 816554.5785	, 7.9975	,7


Second Edition - CubIter - 3D Orthogonal Transformation
File
Processing
Options :
Include Design Matrix in the Log
Use a full Rotation matrix definition
Tied up on the first control point
Barycenterized coordinates
Measured :
Xm :
Ym :
Zm :
Reload Measurements
Transformation
Zero Residuals (D)
Zero Residuals (D^2)
Control :
Xc :
Yc :
Zc :
Status :
10 measured points loaded
Parameters :
Scale : 1.0
Sdv : 0.0000
Iter : 0
Tx : 0.0000
Ty : 0.0000
Tz : 0.0000
Rx : 0.0000
Ry : 0.0000
Rz : 0.0000

Point Id.	Xc	Yc	Zc	Weight
BS2-1	837569.6347	816408.2758	8.5068	XYZ fixed
BS1-a	837627.0590	816495.6490	14.9653	XYZ fixed
BS1-b	837632.8048	816490.8075	12.3006	XYZ fixed
BS2-4	837611.2853	816410.5321	8.9787	XYZ fixed
BS2-5	837621.2677	816417.9040	8.9911	XYZ fixed
BS2-6	837606.1954	816465.6313	8.8144	XYZ fixed
BS2-7	837601.6187	816469.8091	8.8238	XYZ fixed
BS2-8	837575.1248	816409.5828	8.0678	XYZ fixed
BS5	837607.9205	816554.5785	7.9975	XYZ fixed

Point Id.	Xm	Ym	Zm
STNC	837550.9050	816457.9650	5.2750
BS2-1	837569.6435	816408.2781	8.5017
BS1-a	837627.0530	816495.6637	14.9585
BS1-b	837632.7967	816490.8244	12.2958
BS2-4	837611.2951	816410.5442	8.9734
BS2-5	837621.2760	816417.9176	8.9863
BS2-6	837606.1948	816465.6419	8.8079
BS2-7	837601.6167	816469.8191	8.8169
BS2-8	837575.1333	816409.5892	8.0619
BS5	837607.8995	816554.5884	7.9920

Exit
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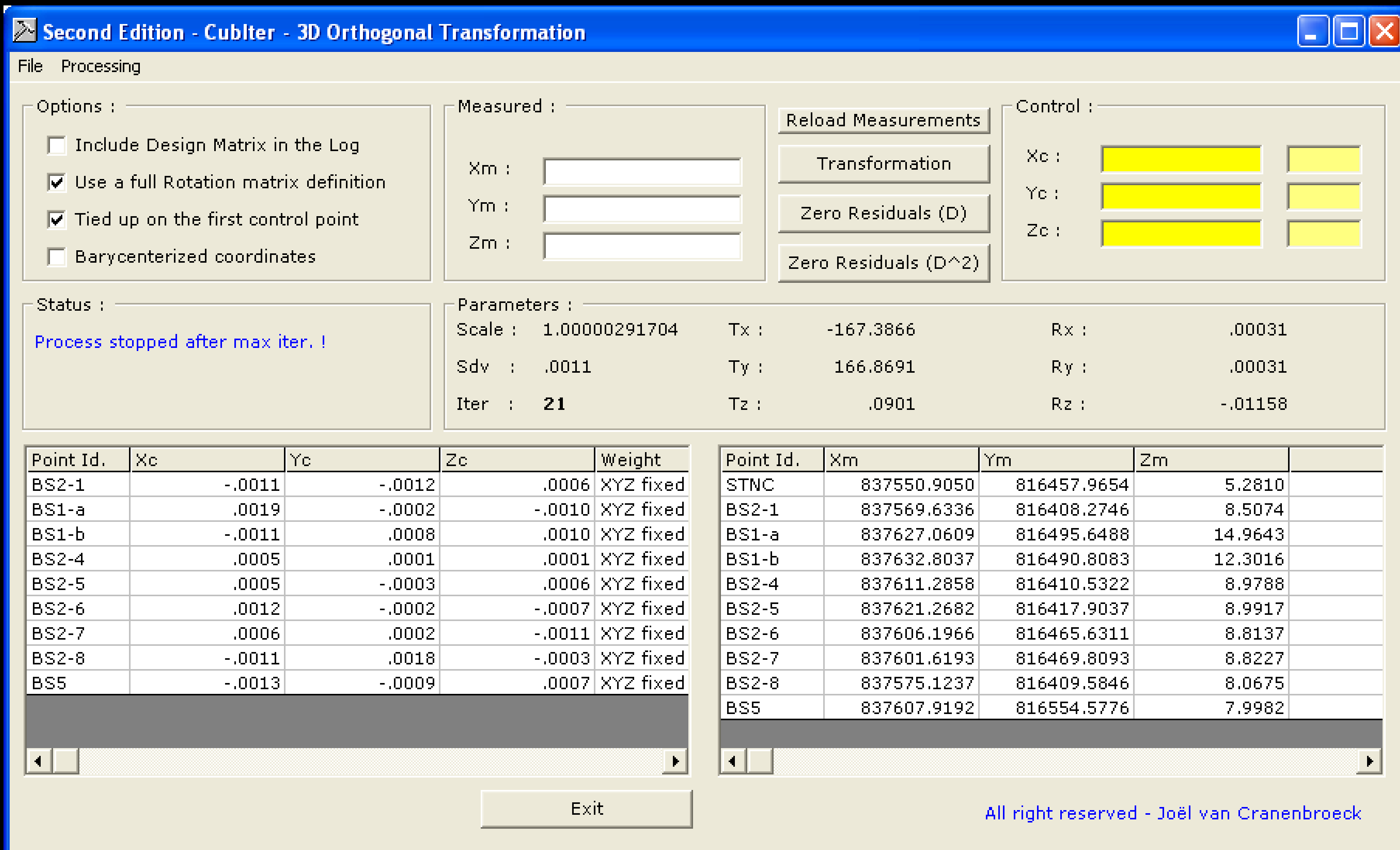
Second Edition - CubIter - 3D Orthogonal Transformation
File
Processing
Options :
Include Design Matrix in the Log
Use a full Rotation matrix definition
Tied up on the first control point
Barycenterized coordinates
Measured :
Xm :
Ym :
Zm :
Reload Measurements
Transformation
Zero Residuals (D)
Zero Residuals (D^2)
Control :
Xc :
Yc :
Zc :
Status :
Process stopped after max iter. !
Parameters :
Scale : 1.00000291704
Sdv : .0011
Iter : 21
Tx : -167.3866
Ty : 166.8691
Tz : .0901
Rx : .00031
Ry : .00031
Rz : -.01158
Point Id. Xc Yc Zc Weight
BS2-1 -.0011 -.0012 .0006 XYZ fixed
BS1-a .0019 -.0002 -.0010 XYZ fixed
BS1-b -.0011 .0008 .0010 XYZ fixed
BS2-4 .0005 .0001 .0001 XYZ fixed
BS2-5 .0005 -.0003 .0006 XYZ fixed
BS2-6 .0012 -.0002 -.0007 XYZ fixed
BS2-7 .0006 .0002 -.0011 XYZ fixed
BS2-8 -.0011 .0018 -.0003 XYZ fixed
BS5 -.0013 -.0009 .0007 XYZ fixed
Point Id. Xm Ym Zm
STNC 837550.9050 816457.9654 5.2810
BS2-1 837569.6336 816408.2746 8.5074
BS1-a 837627.0609 816495.6488 14.9643
BS1-b 837632.8037 816490.8083 12.3016
BS2-4 837611.2858 816410.5322 8.9788
BS2-5 837621.2682 816417.9037 8.9917
BS2-6 837606.1966 816465.6311 8.8137
BS2-7 837601.6193 816469.8093 8.8227
BS2-8 837575.1237 816409.5846 8.0675
BS5 837607.9192 816554.5776 7.9982
Exit
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Corrections on Control Points :

Id.	Vx(m)	Vy(m)	Vz(m)
BS2-1	-.0011	-.0012	.0006
BS1-a	.0019	-.0002	-.0010
BS1-b	-.0011	.0008	.0010
BS2-4	.0005	.0001	.0001
BS2-5	.0005	-.0003	.0006
BS2-6	.0012	-.0002	-.0007
BS2-7	.0006	.0002	-.0011
BS2-8	-.0011	.0018	-.0003
BS5	-.0013	-.0009	.0007

Tx updated : -167.3866
Ty updated : 166.8691
Tz updated : .0901

Scale Factor updated : 1.00000291704

Updated Rotation Matrix

1.0000000	0.0002021	0.0000053
-0.0002021	1.0000000	-0.0000054
-0.0000053	0.0000054	1.0000000

Rotations parameters

Rotation along X axis : .00031
Rotation along Y axis : .00031
Rotation along Z axis : -.01158

Point Identification n° STNC
X(20) = 837550.9050
Y(20) = 816457.9654
Z(20) = 5.2810

27.04.2012 00:07:12.960 Results of free station calculation (Reduced). Solution:ROBUST [GON/M]

27.04.2012 00:07:12.962 Station Coordinates: 837550.9051, 816457.9653, 5.2788

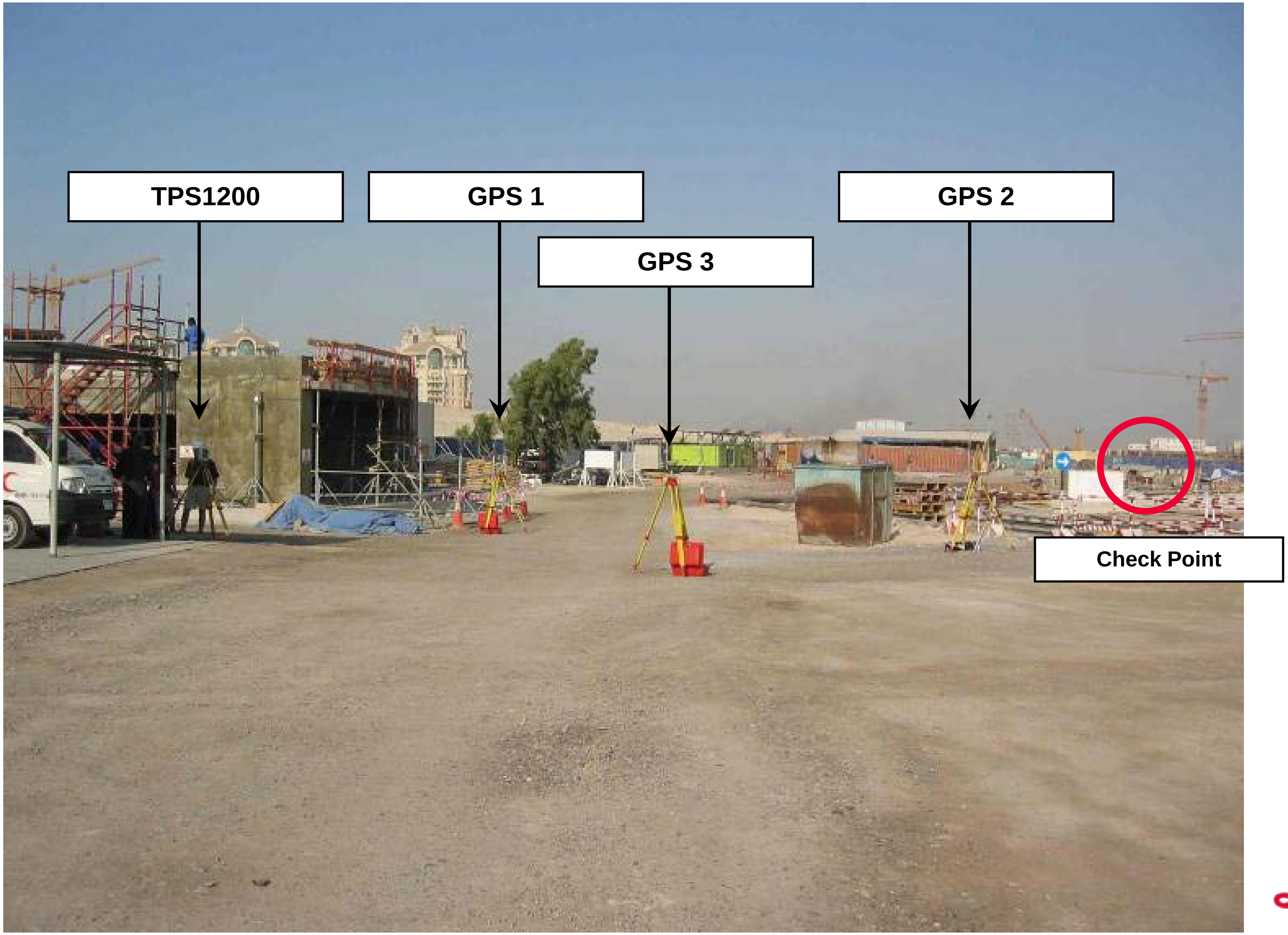
27.04.2012 00:07:12.964 Standard Deviations: 0.0006, 0.0005, 0.0003

27.04.2012 00:07:12.966 Orientation: 0.01264, 0.000285"

27.04.2012 00:07:12.967 Scale: 0.99999609, 0.00000735

STNC	X	Y	Z
LEICA	837550.9051	816457.9653	5.2788
3D	837550.9050	816457.9654	5.2810
Differences	0.0001	-0.0001	-0.0022

Proof of Concept October 2005



Results

SETUP	Absolute Differences			Relative Differences		
	ΔX	ΔY	ΔZ	Δx	Δy	Δz
S1	0.0022	-0.0095	-0.0071			
S2	0.0022	-0.0105	-0.0043	0.0000	-0.0010	0.0028
S3	0.0025	-0.0130	-0.0031	0.0003	-0.0035	0.0040
S4	0.0030	-0.0113	-0.0048	0.0008	-0.0018	0.0023
S5	0.0027	-0.0121	-0.0052	0.0005	-0.0016	-0.0009
S6	0.0028	-0.0108	-0.0026	0.0006	-0.0013	0.0045

Tilted !

Tx updated : 12381.3842

Ty updated : 10804.8800

Tz updated : 1.1048

Scale Factor updated : .99999999929

Updated Rotation Matrix

-0.6980183 -0.7160799 -0.0001290

0.7160799 -0.6980183 -0.0000045

-0.0000868 -0.0000955 1.0000000

Rotations parameters

Rotation along X axis : -.00547

Rotation along Y axis : .00497

Rotation along Z axis : -45.73177

Tx updated : 12352.6160

Ty updated : 10807.7507

Tz updated : -683.3258

Scale Factor updated : .99999999929

Updated Rotation Matrix

-0.6991354 -0.7119652 0.0656903

0.7148607 -0.6977957 0.0453364

0.0135605 0.0786557 0.9968096

Rotations parameters

Rotation along X axis : 4.51172

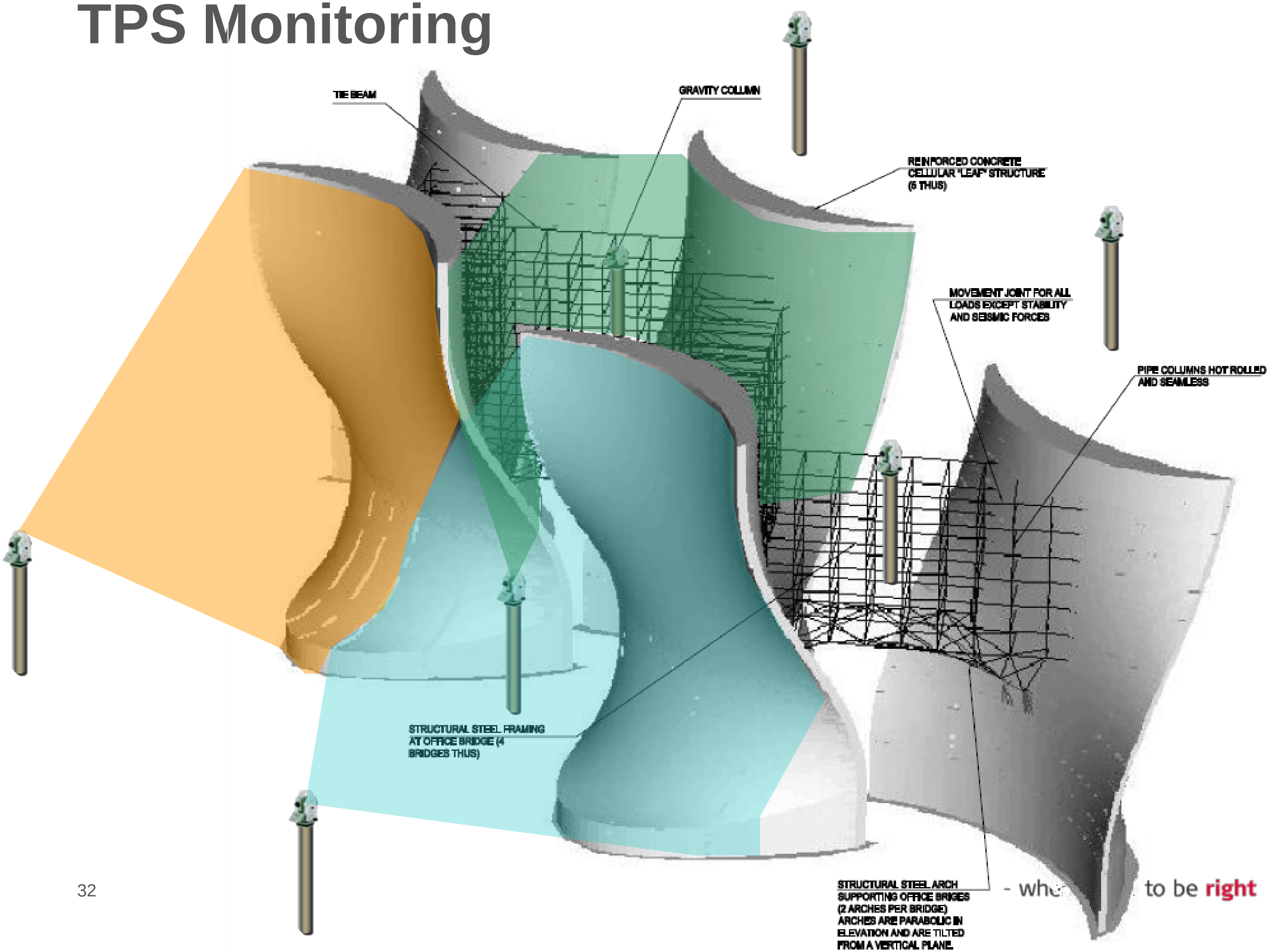
Rotation along Y axis : -.77698

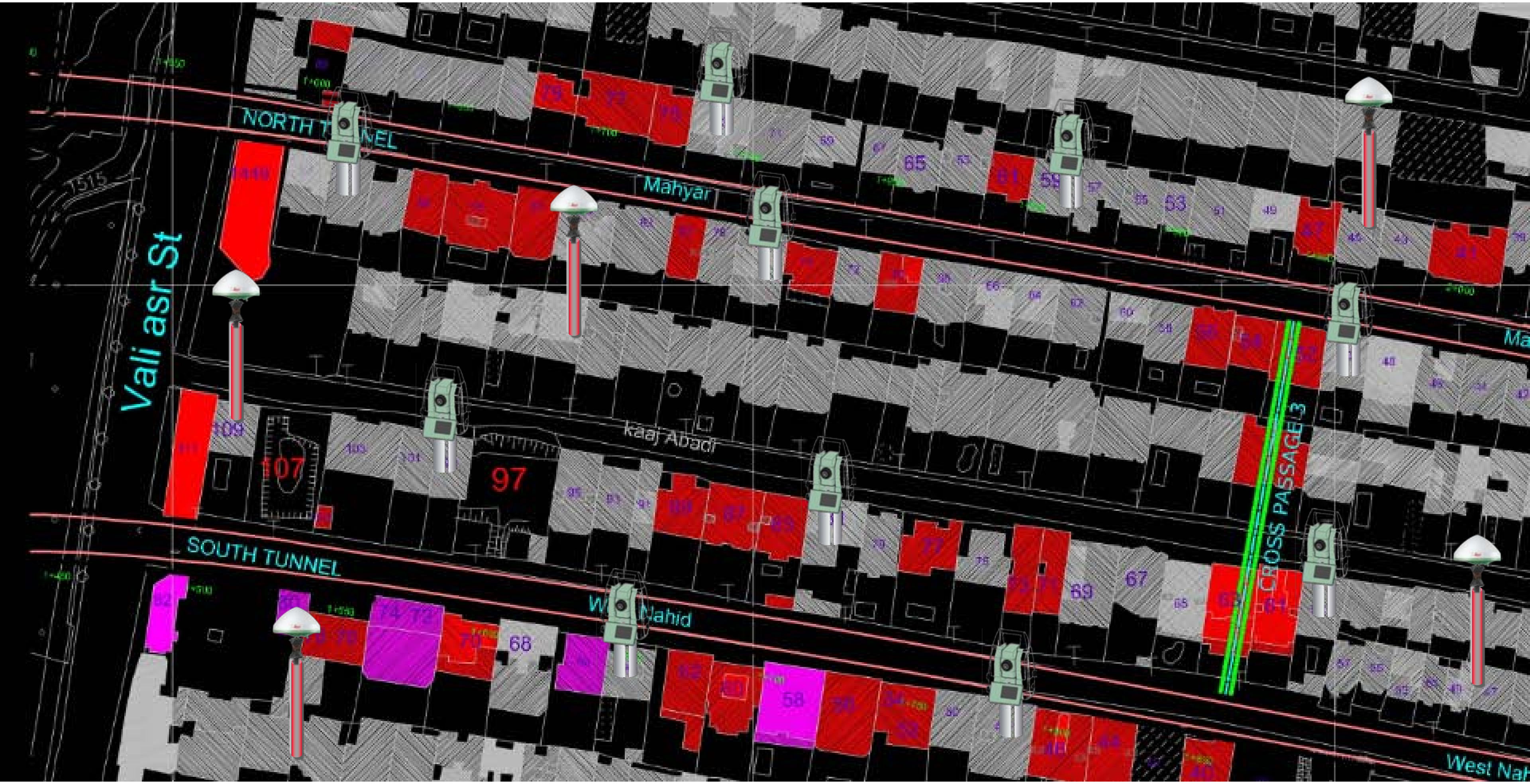
Rotation along Z axis : -45.63717

Considerations …

- The way to design a solution is to first try to derive the calculations needed to provide the results.
- ***What can be computed by using the observables to derive the coordinates, can be computed by using directly the coordinates derived from the observations (Joel's Principle) and by considering the associated variance-covariance matrices.***
- To provide « extreme » results we have to revisit the way we are calculating our coordinates
- Functional models developed for **Photogrammetric applications** have always been a source of inspiration.
- Active Control Point Concept can be extended to a network.
- **GNSS Network corrections** has demonstrated successful capacity to support monitoring operations.
- Much closed integration between GNSS measurements and TPS into a global computing scheme (mutual benefit) …

Building B, C and D
TPS Monitoring

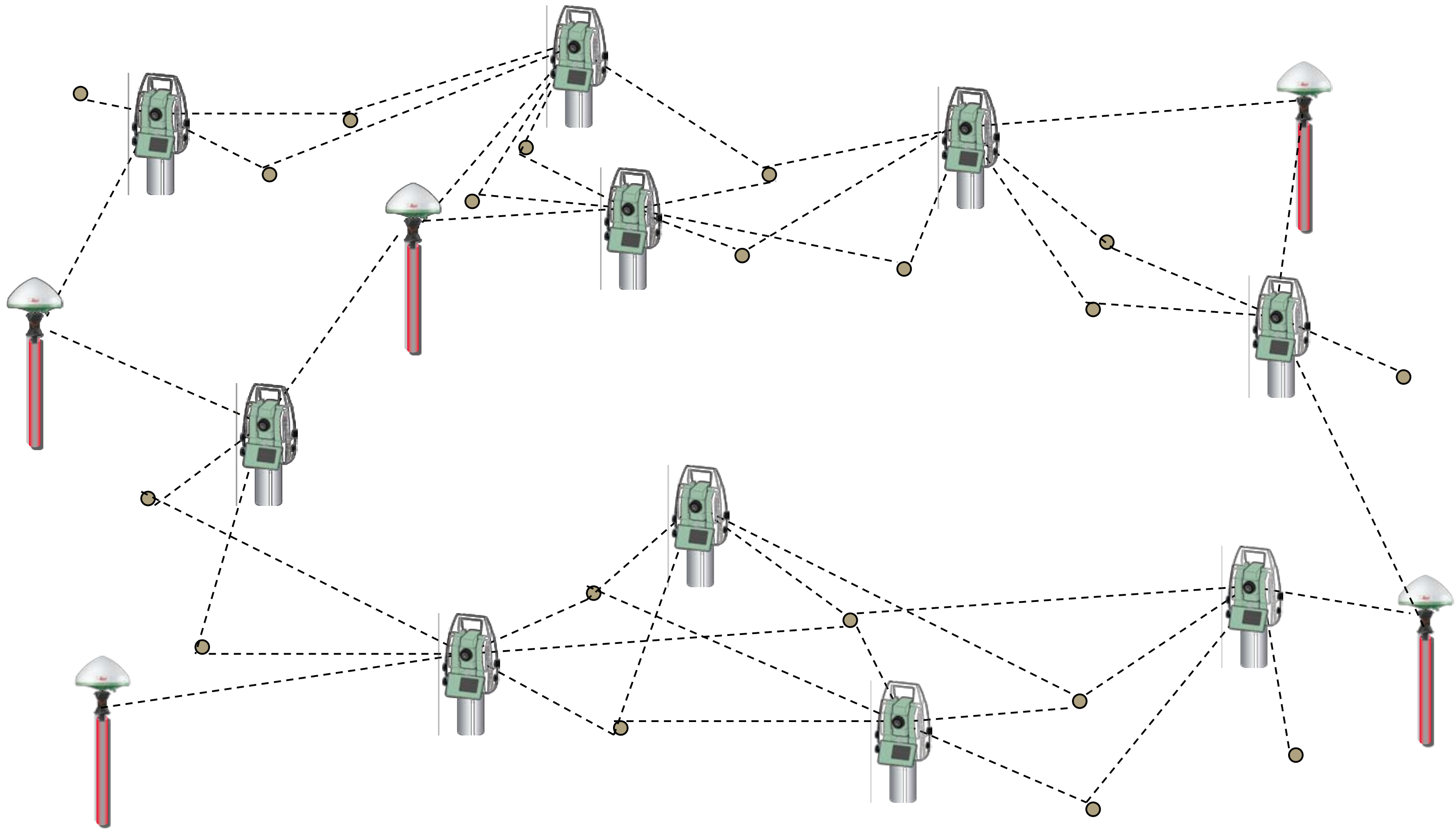




- when it has to be **right**

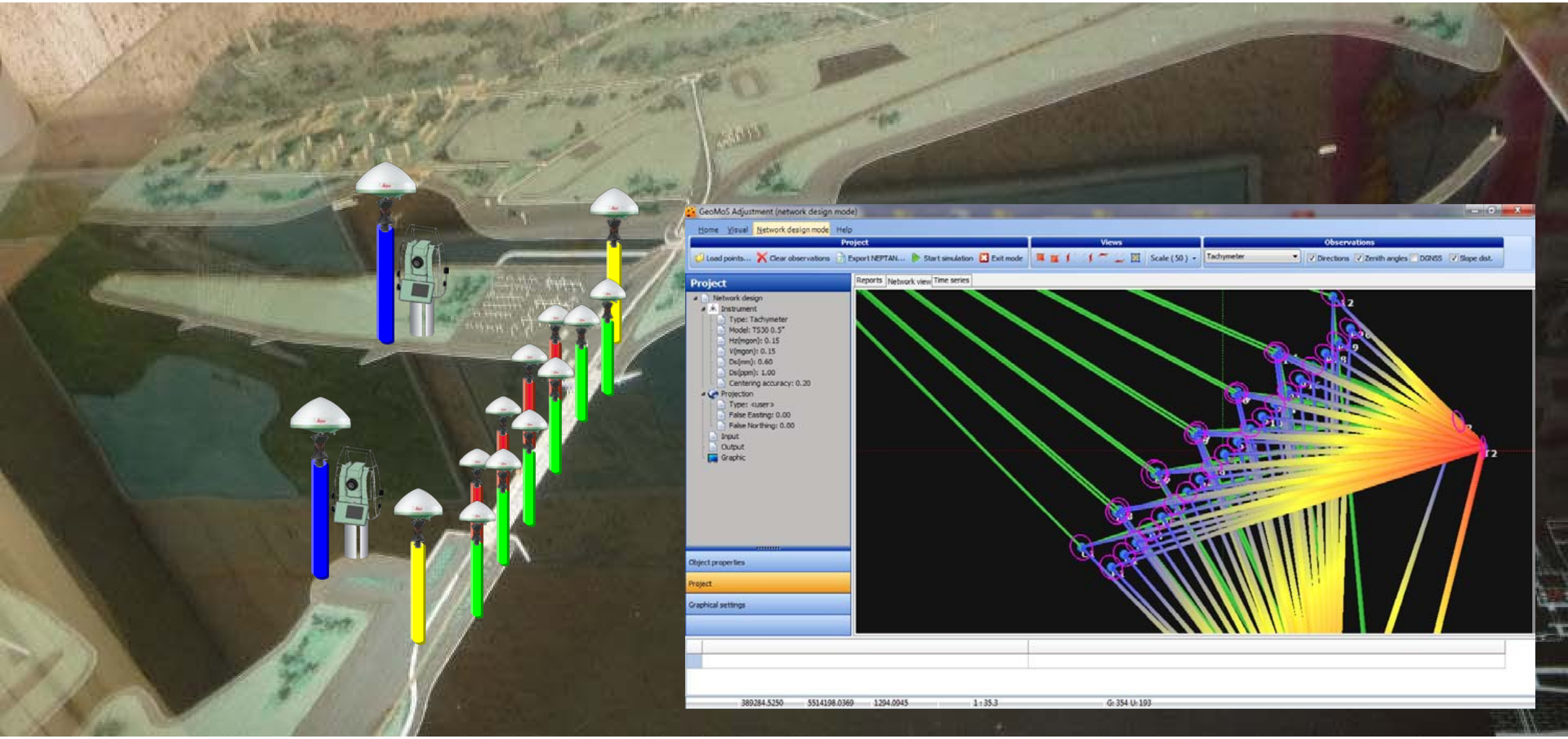
Leica Geosystems

Networked Total Stations Concept (patented)



Automatic Total Stations are networked using common points (pass points) that must be only considered as “stable” during the measurement cycles. GPS antenna’s collocated with 360 degree reflectors are providing control points on the spot.

4 Hydro Power Stations World Bank Project
UHE Ukraine



- when it has to be **right**

Leica Geosystems

WORKFLOW Post-Processing

TPS

GNSS Base

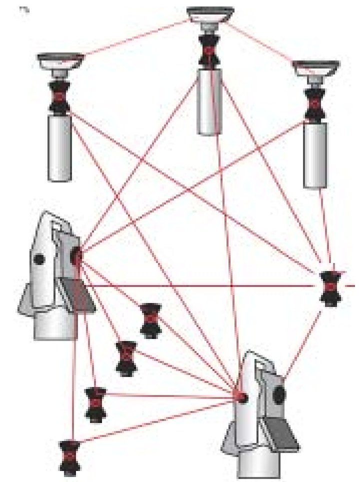
GNSS Control

Hz, Vz, Ds

Data Reduction T°, ppm

$\Delta X, \Delta Y, \Delta Z$

Least Squares Adjust.
Minimum Constraints



Quality Analysis
Data Snooping, Filtering

Epoch of Reference ?

Yes

Store Epoch of Reference

No

S-Transformation

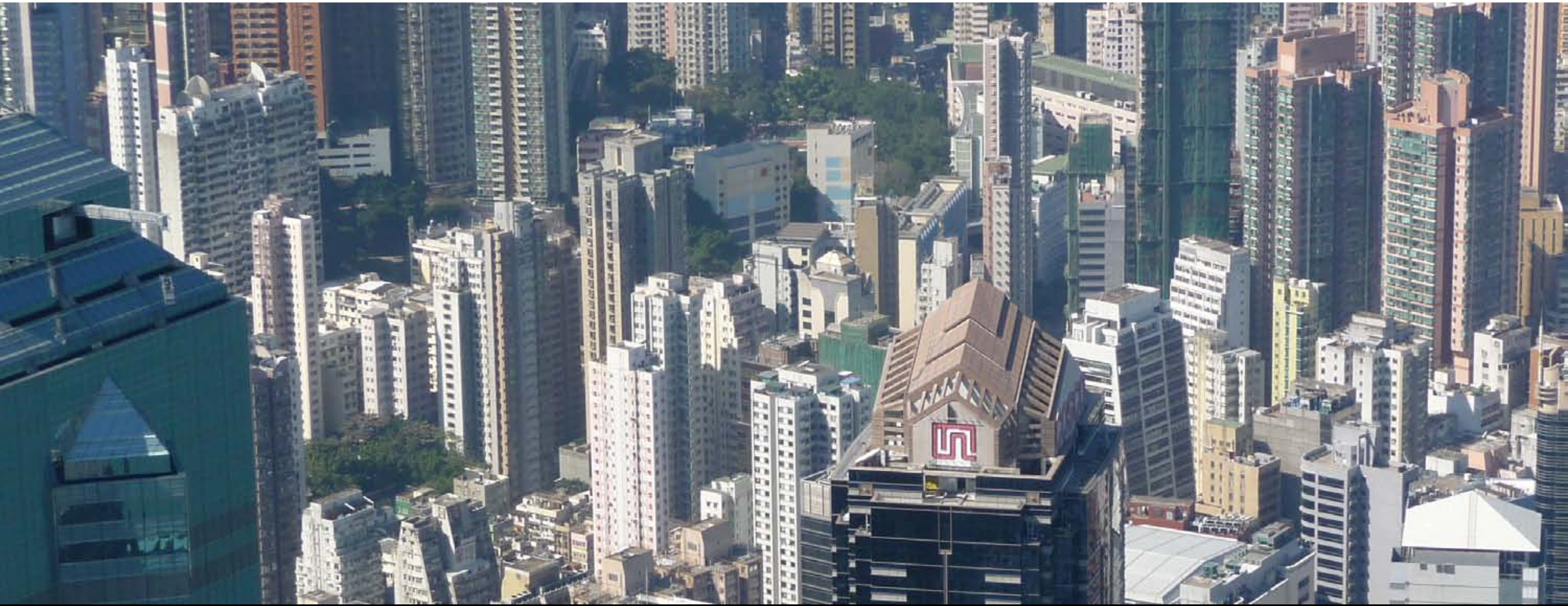
Reporting, Archiving

Visualisation

Deformation Analysis

Statistical Analysis

High Rise Buildings Monitoring & GNSS

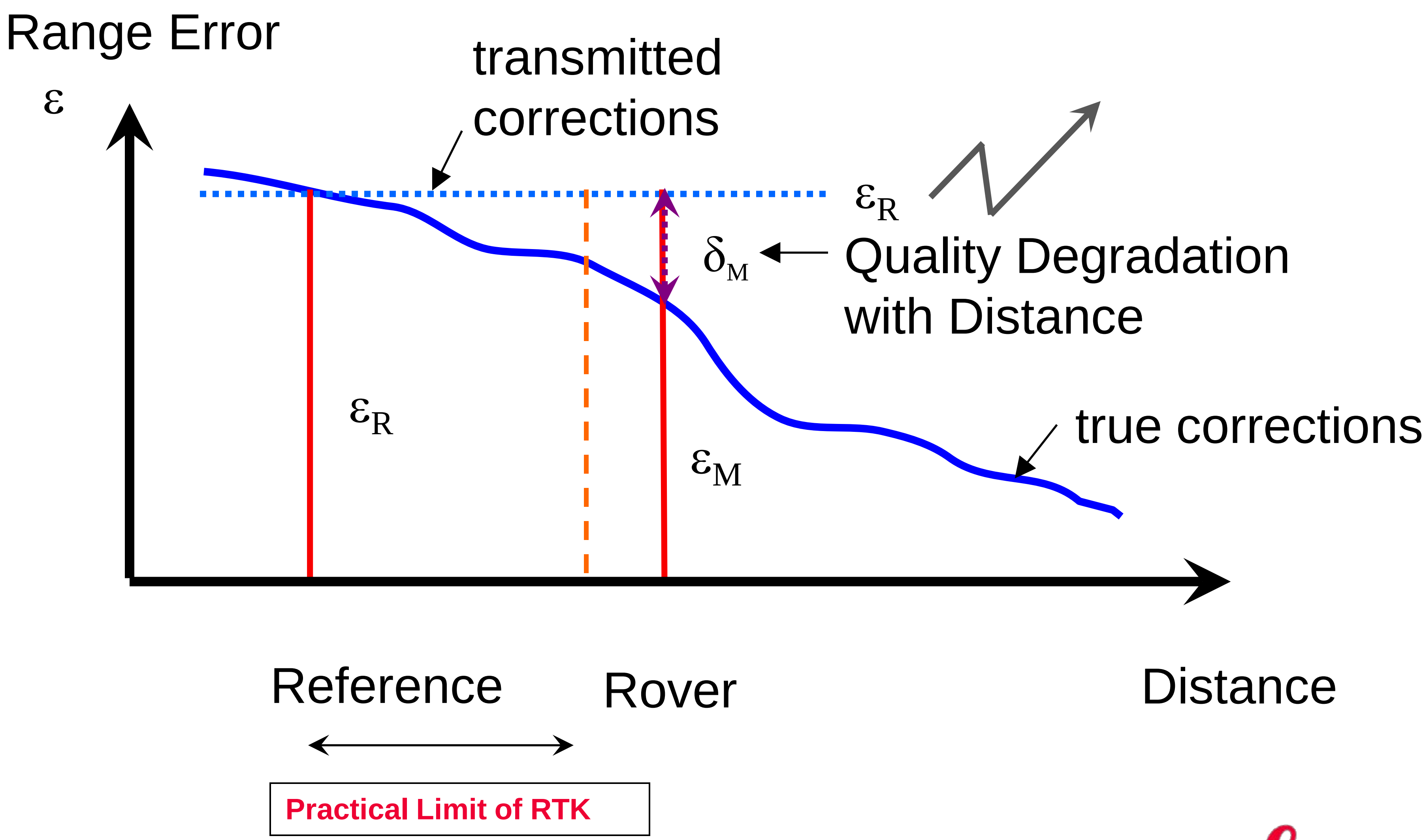


Obstructions will remain a serious limitation on the use of GNSS Technology. But even for setting up GNSS Reference Stations to assist GNSS monitoring

- when it has to be **right**

Leica Geosystems

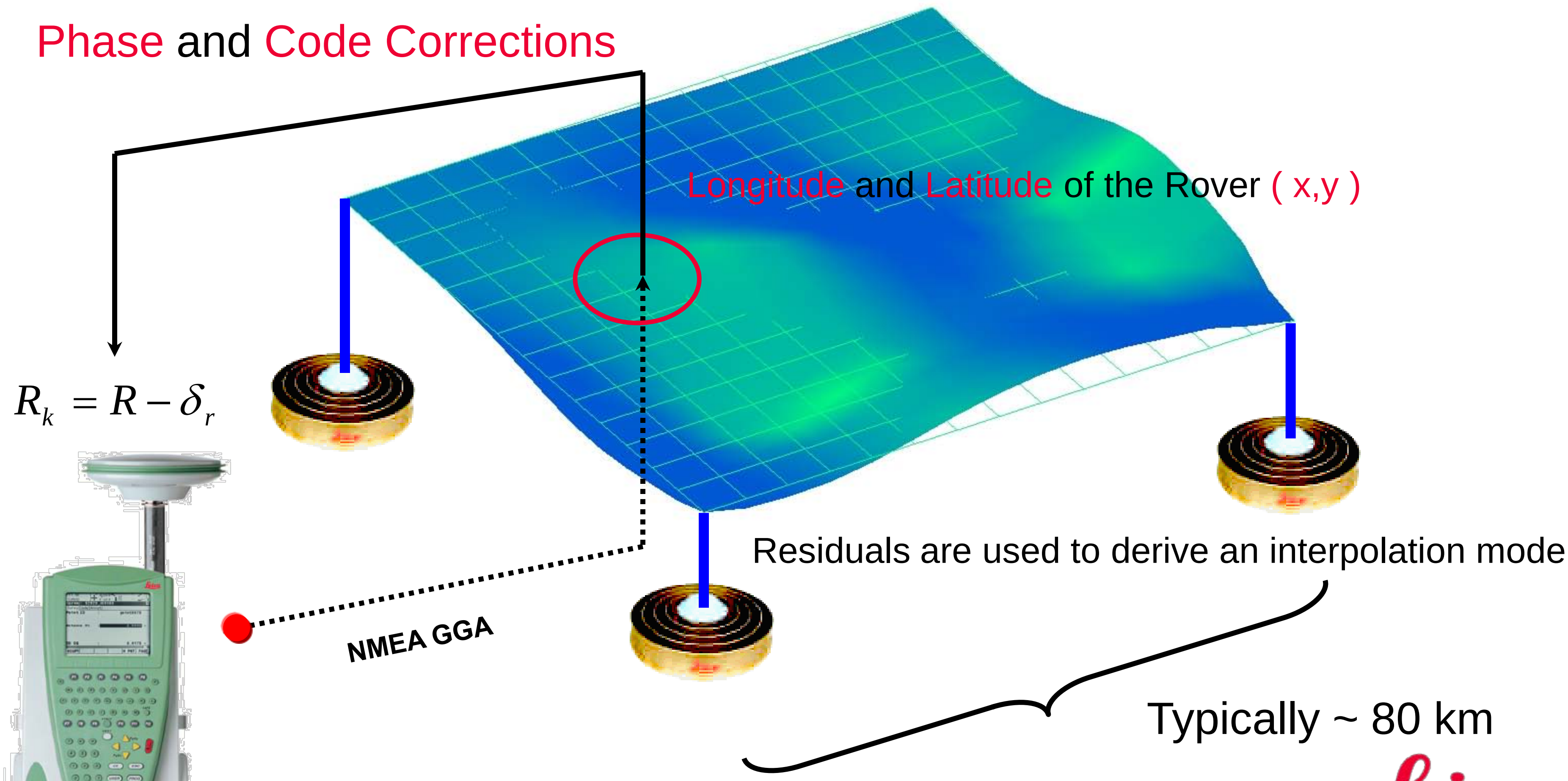
Distance Dependency



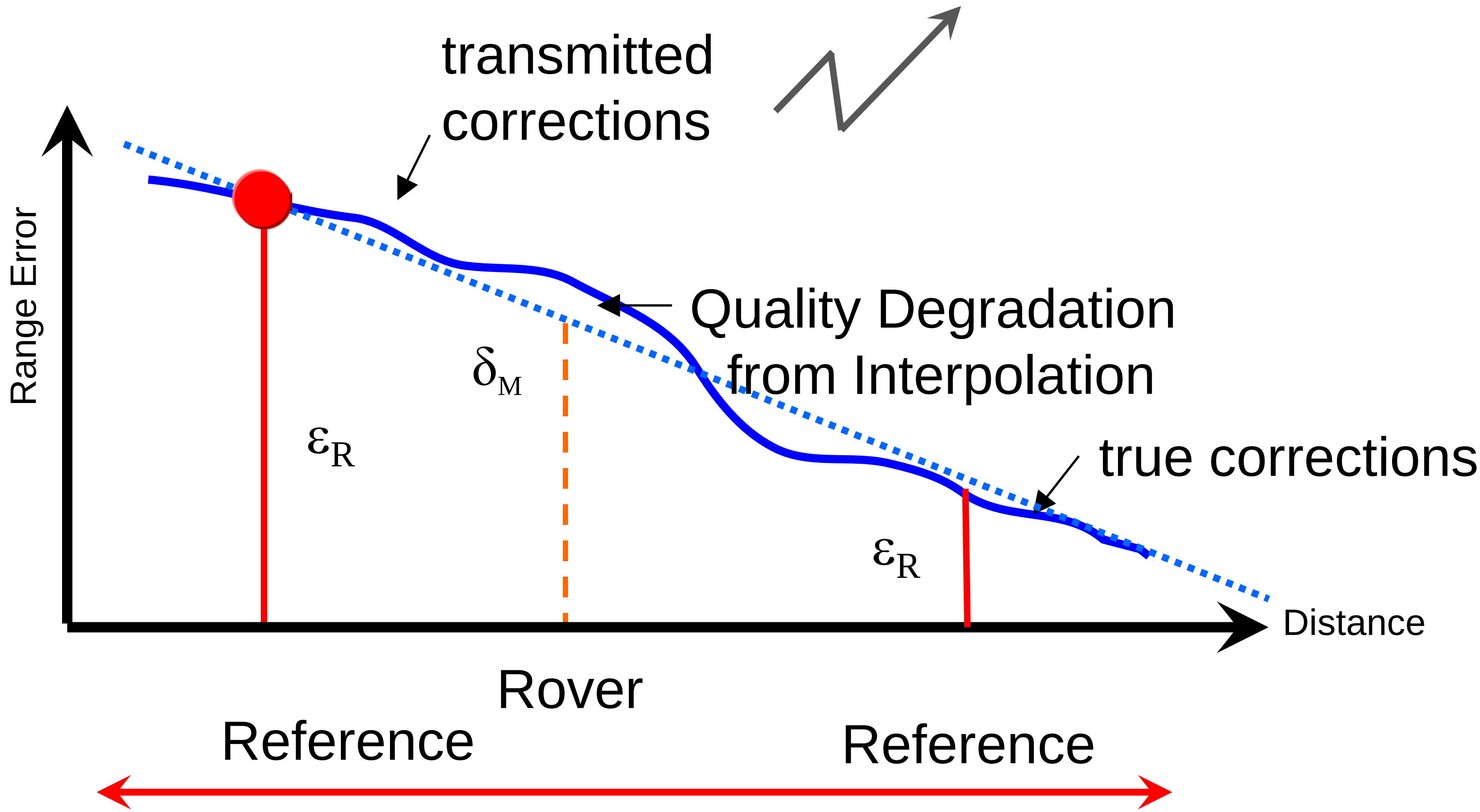
GNSS N-RTK : Derived Observation Corrections

$$\delta_{r0} = \alpha\left(N_0(\varphi-\varphi_R)+E_0(\lambda-\lambda_R)\cos(\varphi_R)\right)$$

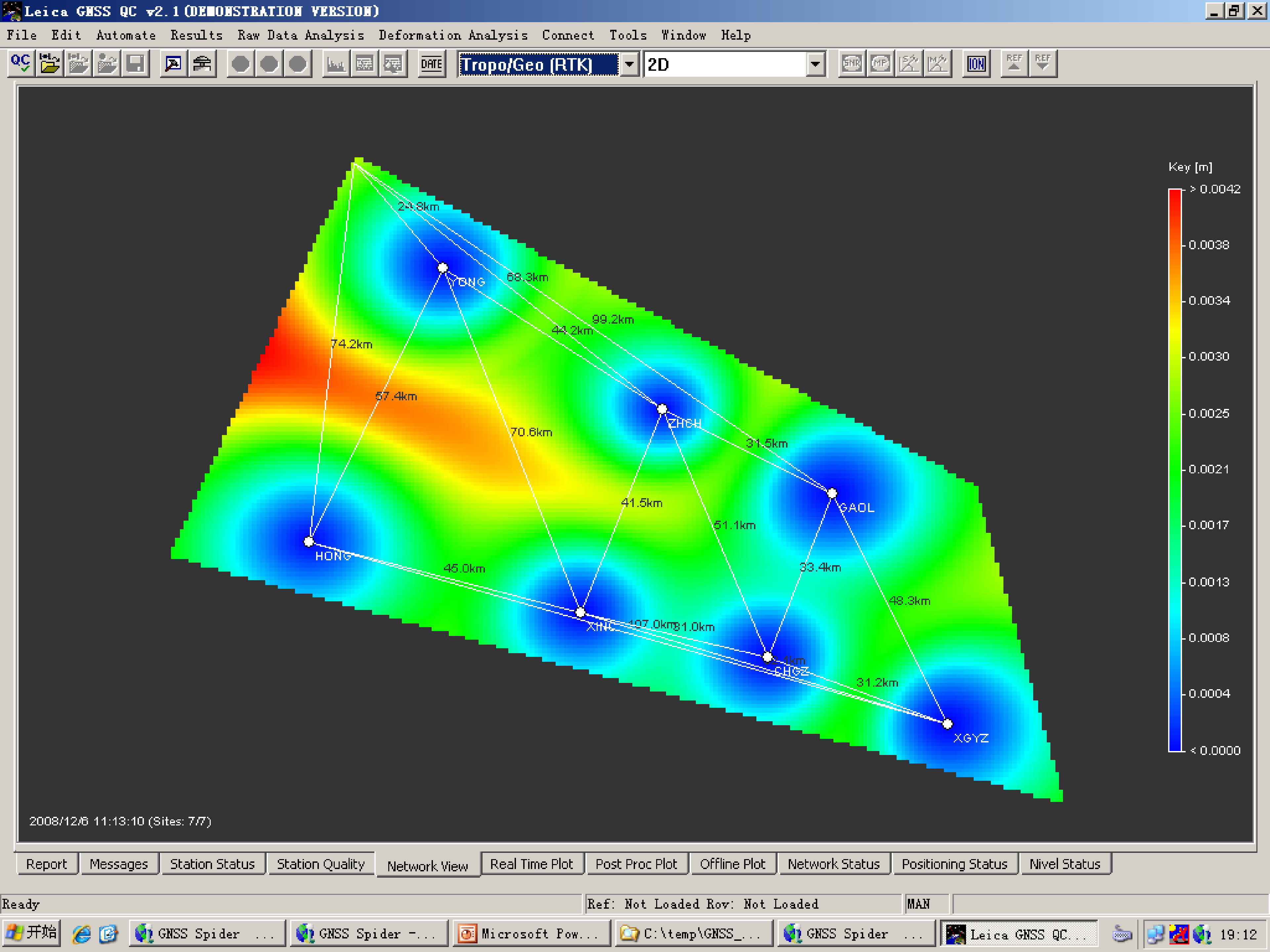
$$\delta_{r1} = \beta \cdot H\left(N_1(\varphi-\varphi_R)+E_1(\lambda-\lambda_R)\cos(\varphi_R)\right)$$

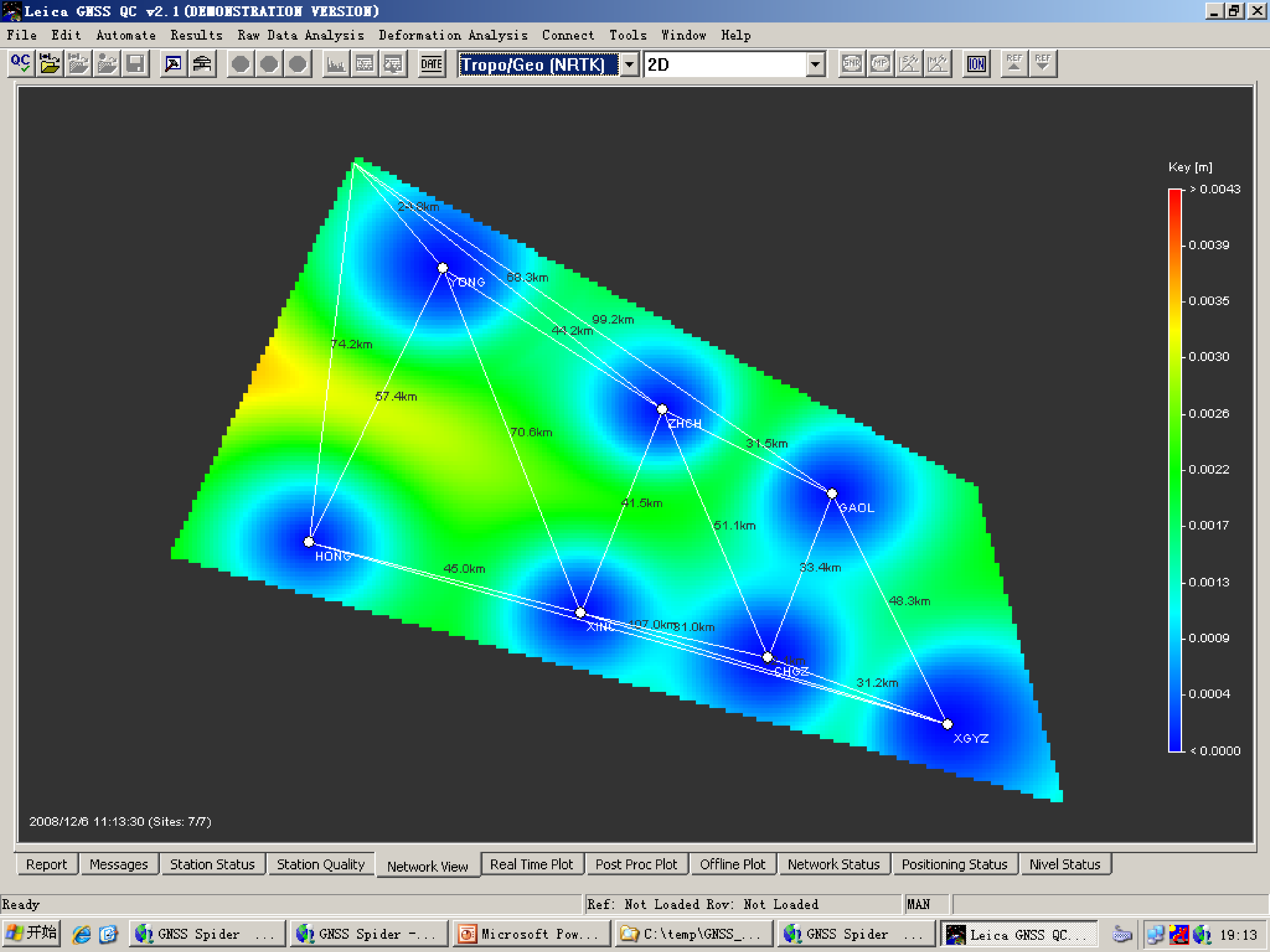


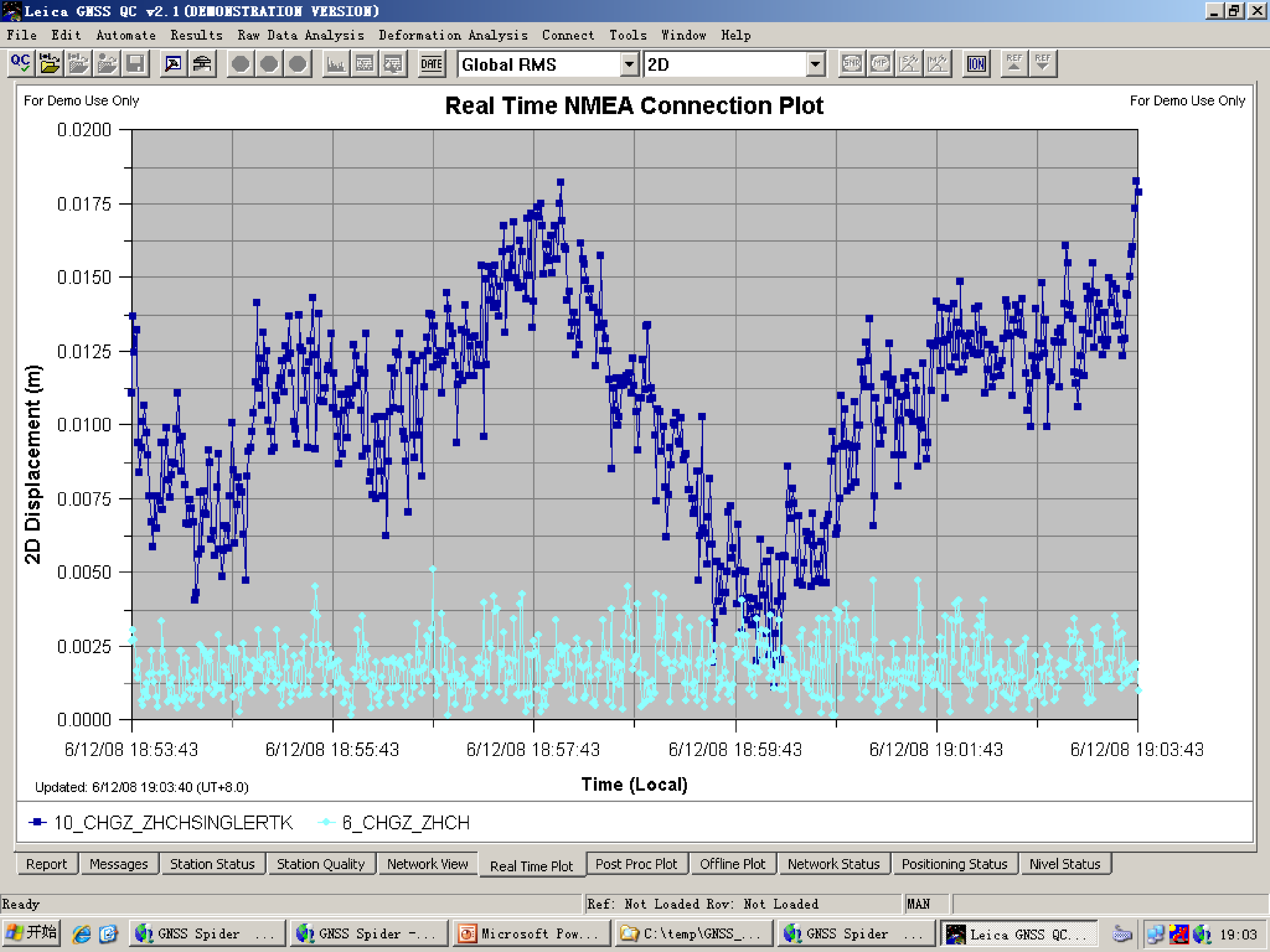
Master Station(s) in N-RTK MAC



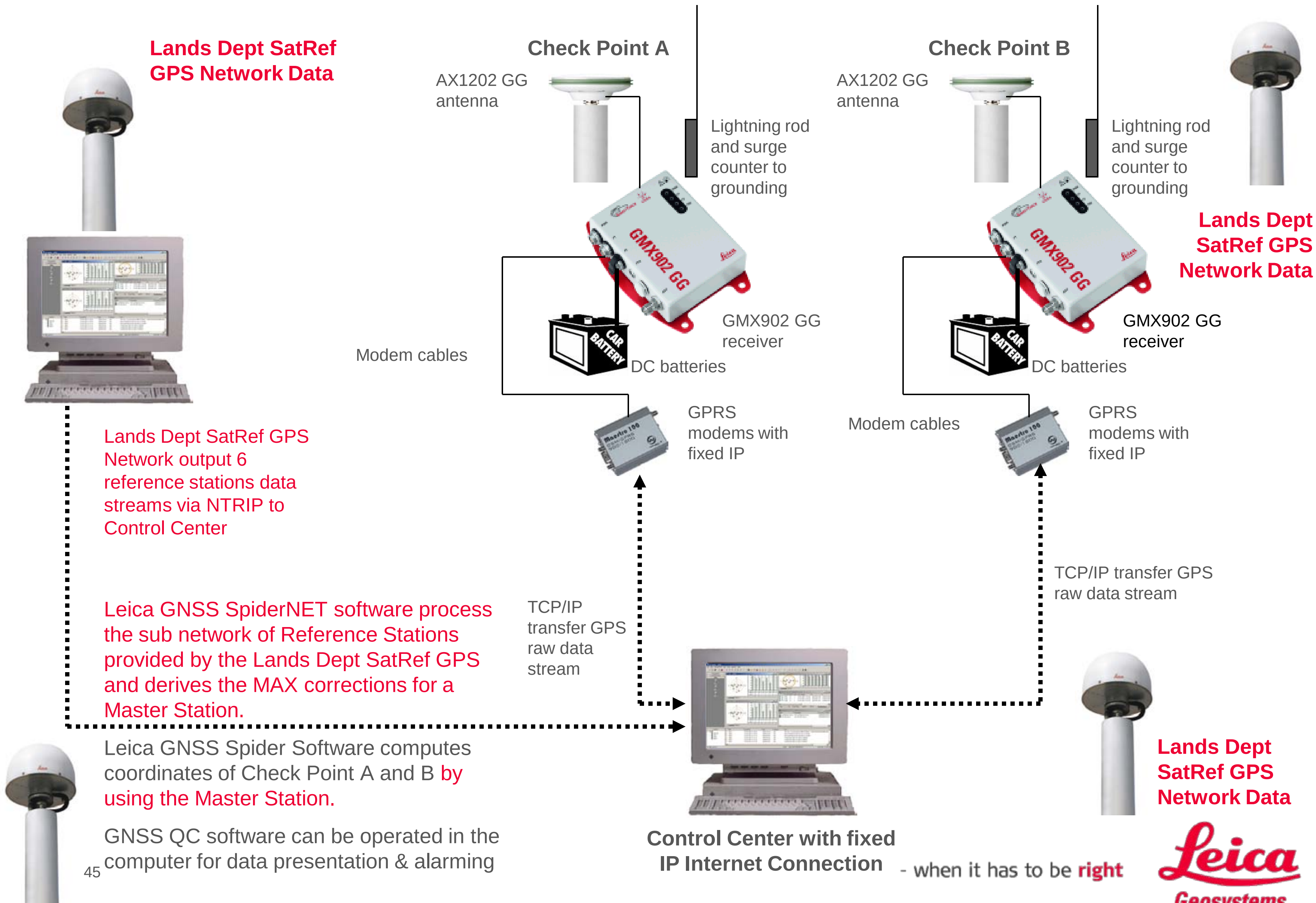
With a GNSS Network RTK (interpolation & extrapolation) no more distance dependency. The choice of the Master Station can be any Reference station selected within the cell.


Leica GNSS QC v2.1 (DEMONSTRATION VERSION)
File Edit Automate Results Raw Data Analysis Deformation Analysis Connect Tools Window Help
Tropo/Geo (RTK)
2D
24.8km
YONG
68.3km
99.2km
44.2km
74.2km
57.4km
70.6km
ZHCH
31.5km
GAOL
41.5km
51.1km
HONG
45.0km
33.4km
48.3km
XING
107.0km
81.0km
CHGZ
31.2km
XGYZ
Key [m]
> 0.0042
0.0038
0.0034
0.0030
0.0025
0.0021
0.0017
0.0013
0.0008
0.0004
< 0.0000
2008/12/6 11:13:10 (Sites: 7/7)
Report
Messages
Station Status
Station Quality
Network View
Real Time Plot
Post Proc Plot
Offline Plot
Network Status
Positioning Status
Nivel Status
Ready
Ref: Not Loaded Rov: Not Loaded
MAN
开始
GNSS Spider
Microsoft Pow...
C:\temp\GNSS_...
Leica GNSS QC...
19:12


Leica GNSS QC v2.1 (DEMONSTRATION VERSION)
File Edit Automate Results Raw Data Analysis Deformation Analysis Connect Tools Window Help
Tropo/Geo (NRTK)
2D
Key [m]
> 0.0043
0.0039
0.0035
0.0030
0.0026
0.0022
0.0017
0.0013
0.0009
0.0004
< 0.0000
YONG
ZHCH
GAOL
HONG
XGYZ
68.3km
99.2km
44.2km
74.2km
57.4km
70.6km
31.5km
41.5km
51.1km
33.4km
45.0km
48.3km
31.0km
31.2km
2008/12/6 11:13:30 (Sites: 7/7)
Report
Messages
Station Status
Station Quality
Network View
Real Time Plot
Post Proc Plot
Offline Plot
Network Status
Positioning Status
Nivel Status
Ready
Ref: Not Loaded Rov: Not Loaded
MAN
开始
GNSS Spider
Microsoft Pow...
Leica GNSS QC...
19:13


Leica GNSS QC v2.1 (DEMONSTRATION VERSION)
File Edit Automate Results Raw Data Analysis Deformation Analysis Connect Tools Window Help
Global RMS
2D
For Demo Use Only
Real Time NMEA Connection Plot
For Demo Use Only
2D Displacement (m)
0.0200
0.0175
0.0150
0.0125
0.0100
0.0075
0.0050
0.0025
0.0000
6/12/08 18:53:43
6/12/08 18:55:43
6/12/08 18:57:43
6/12/08 18:59:43
6/12/08 19:01:43
6/12/08 19:03:43
Updated: 6/12/08 19:03:40 (UT+8.0)
Time (Local)
10_CHGZ_ZHCHSINGLERTK
6_CHGZ_ZHCH
Report
Messages
Station Status
Station Quality
Network View
Real Time Plot
Post Proc Plot
Offline Plot
Network Status
Positioning Status
Nivel Status
Ready
Ref: Not Loaded Rov: Not Loaded
MAN
开始
GNSS Spider ...
GNSS Spider -...
Microsoft Pow...
C:\temp\GNSS_...
GNSS Spider ...
Leica GNSS QC...
19:03

GNSS Network RTK aided Seawall Monitoring System Diagram

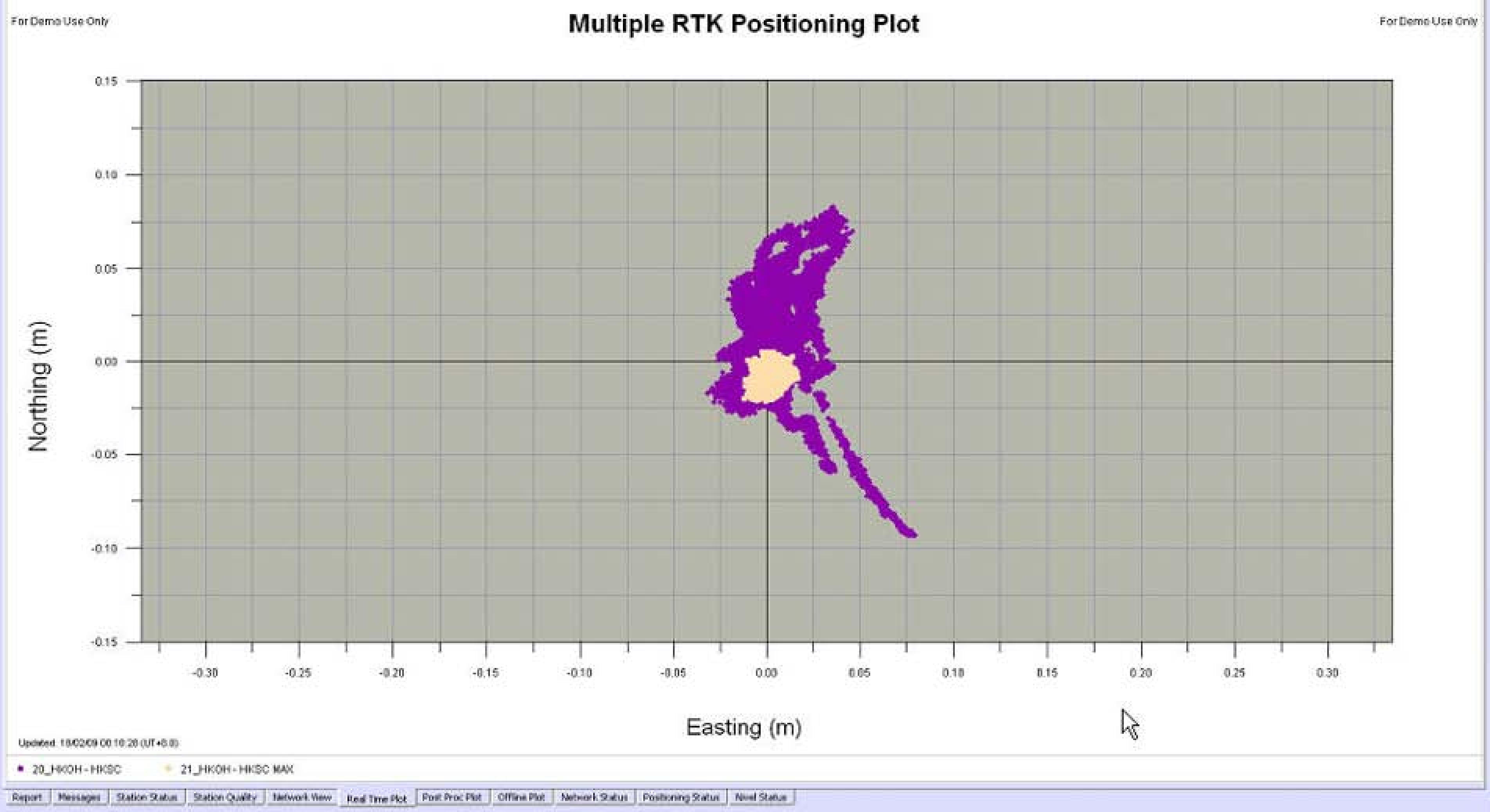


- when it has to be **right**

Leica Geosystems

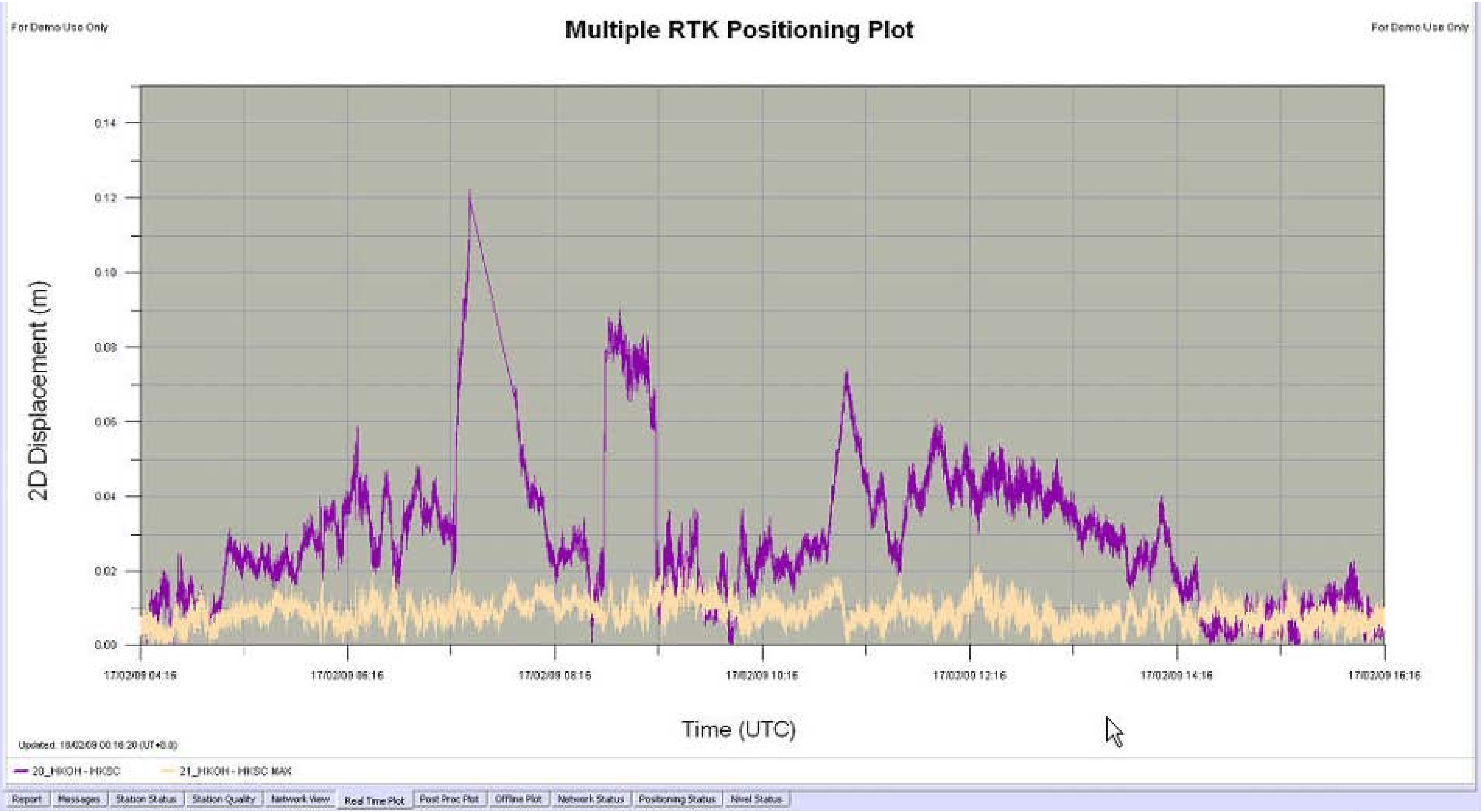
Single GPS RTK vs GPS Network RTK MAX

Processing in Real Time L1 & L2 GPS data



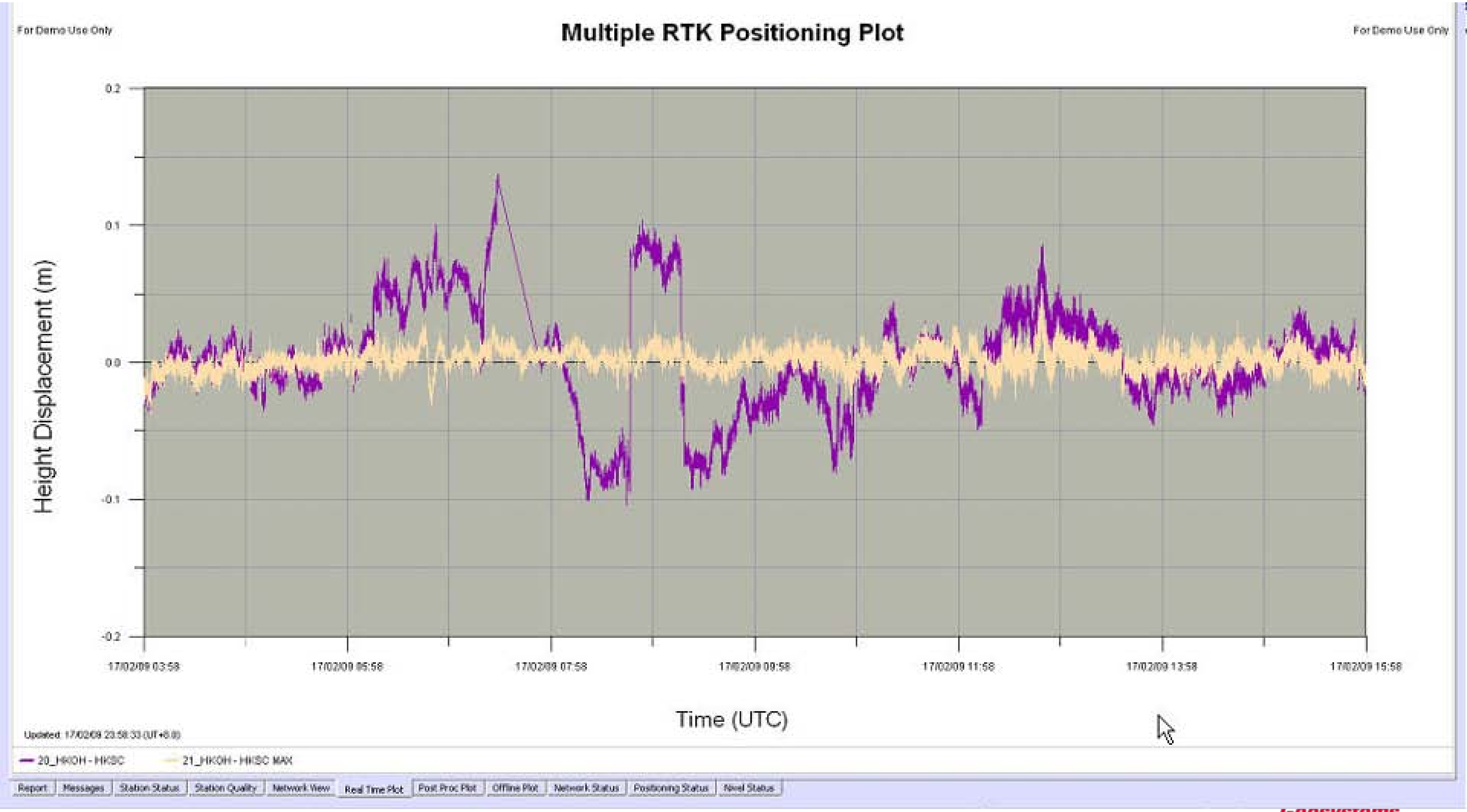
Single GPS RTK vs GPS Network RTK MAX

Processing in Real Time L1 & L2 GPS data



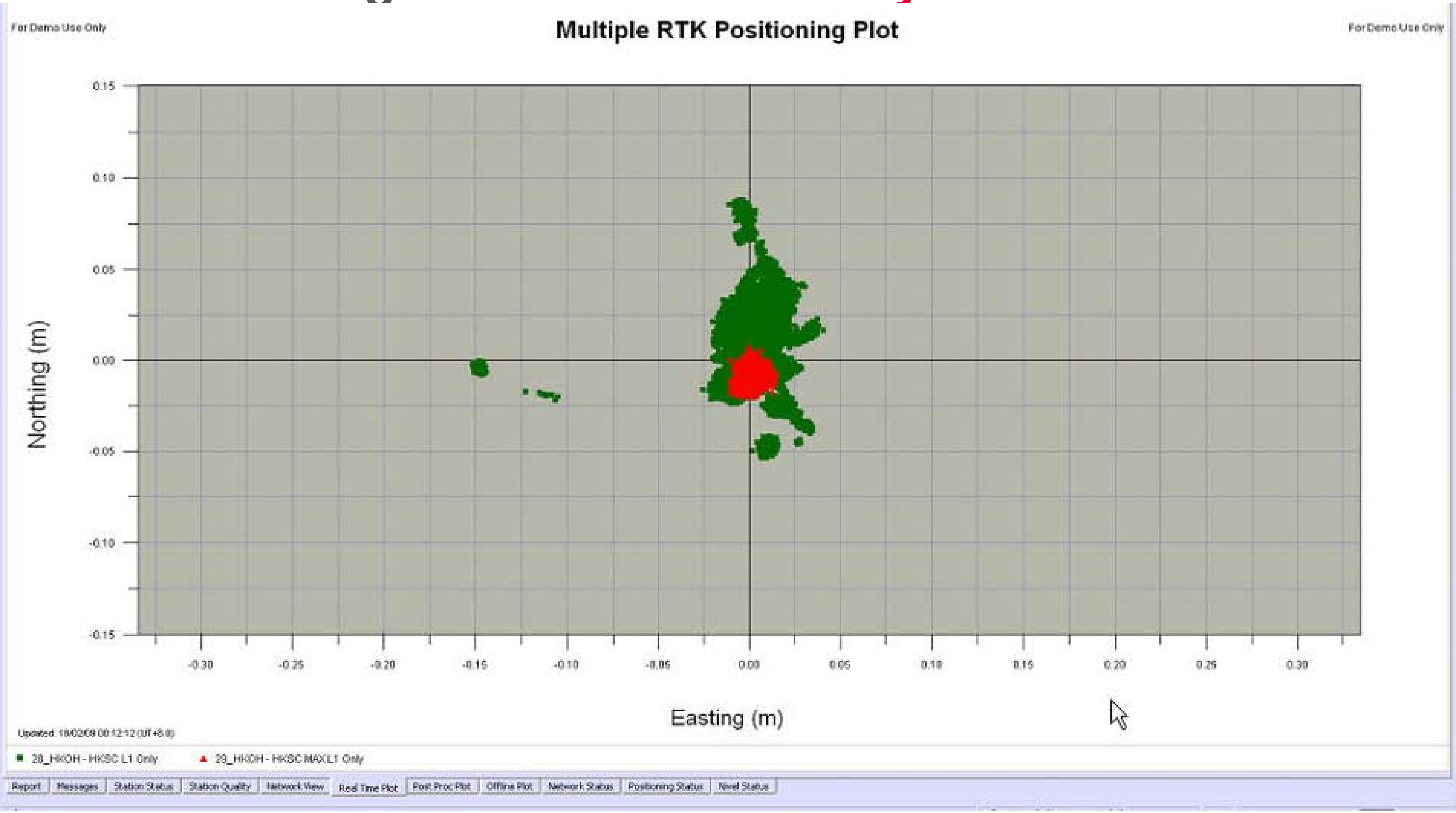
Geosystems

Single GPS RTK vs GPS Network RTK MAX
Processing in Real Time L1 & L2 GPS data

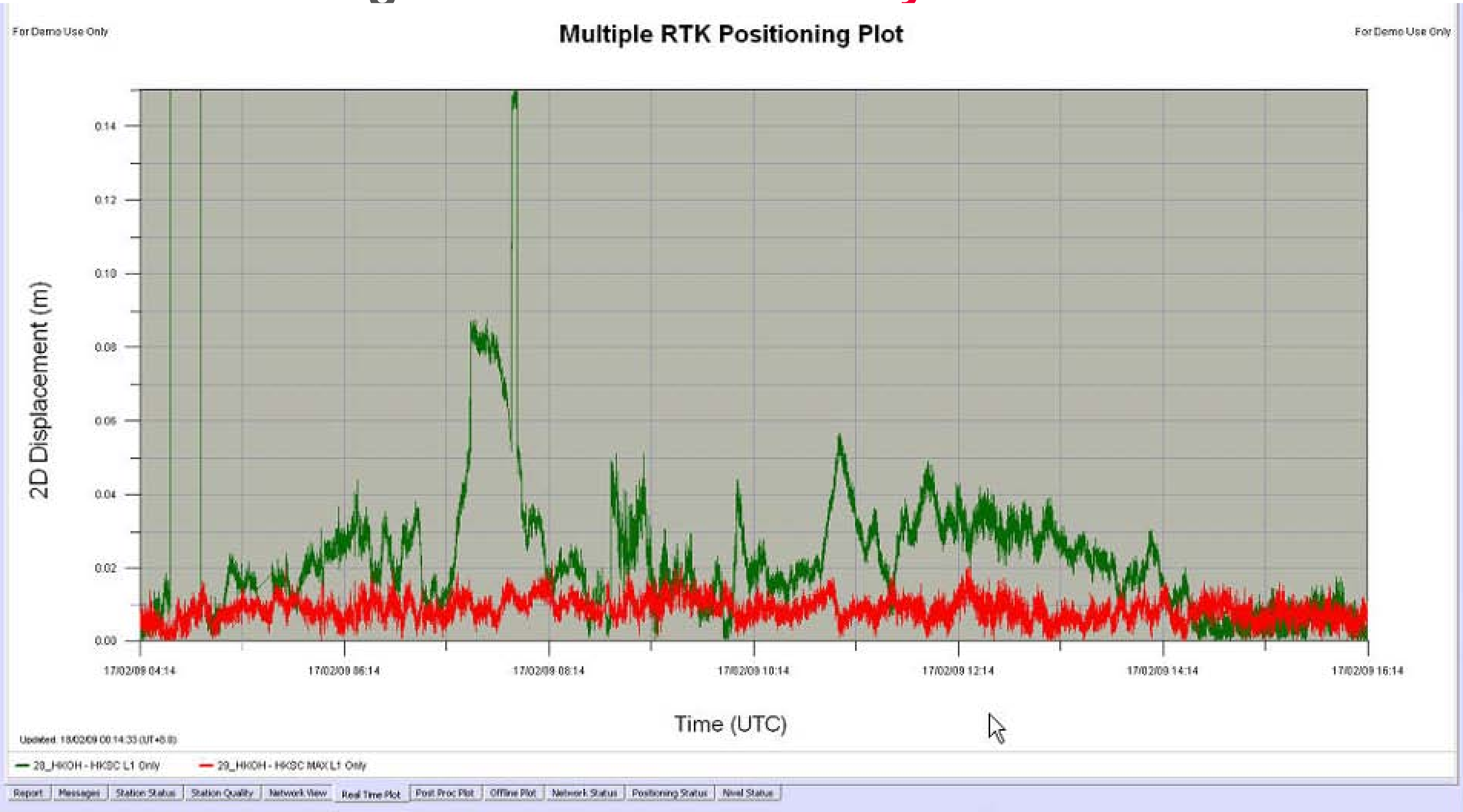


Geosystems

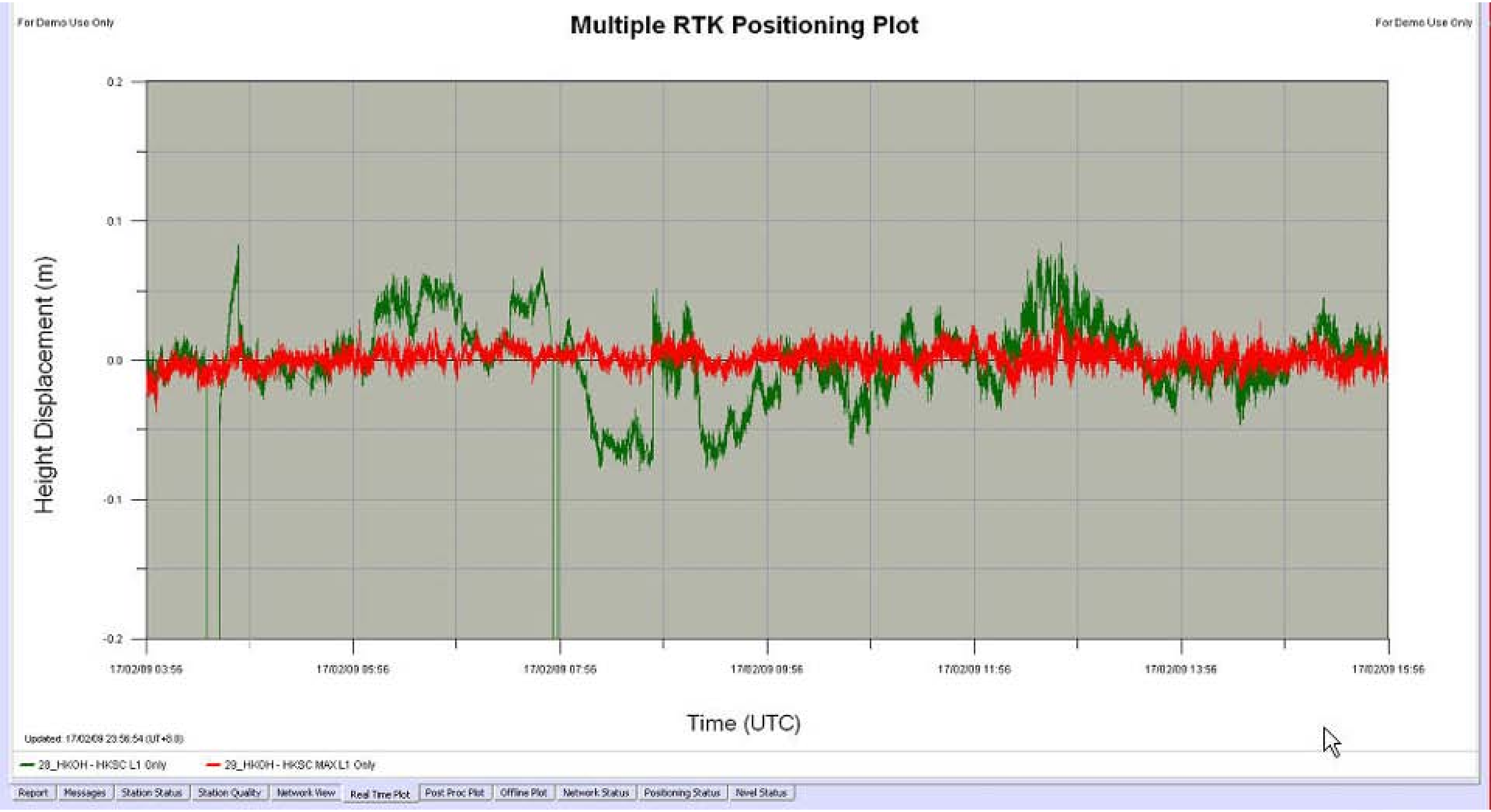
Single GPS RTK vs GPS Network RTK MAX Processing in Real Time L1 only GPS data



Single GPS RTK vs GPS Network RTK MAX
Processing in Real Time L1 only GPS data



Single GPS RTK vs GPS Network RTK MAX Processing in Real Time L1 only GPS data



High Rise Buildings Monitoring Using Virtual RS