FIG Working Week 2012
Rome, Italy 6–10 May
Knowing to: Manage the territory Protect the environment Evaluate the cultural heritage

Kaniv HPP *Dniprodzerzhynsk HPP* *Dnipro HPP* *Dnister HPP*

A New Geodetic Network Design for Hydro Power Plants

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Selected and Placed (design) …

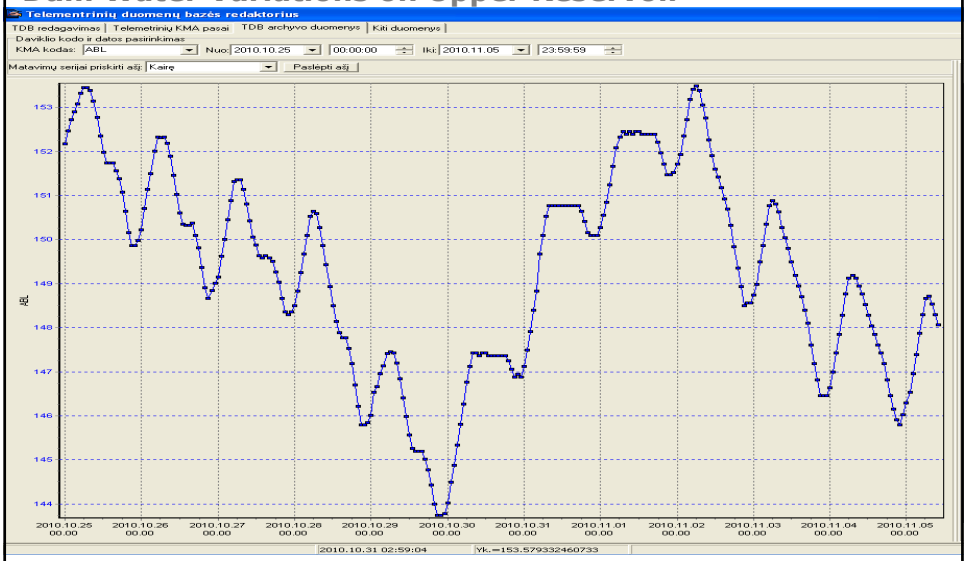
Every instrument on a project should be selected and placed to assist with answering a specific question : if there is no question, there should be no instrumentation.

John Dunnicliff – Geotechnical Instrumentation for Monitoring Field Performance (ISBN 0-471-00546-0 WILEY-INTERSCIENCE)

Reasons to setup Geodetic Monitoring …

- Hydro PP is a huge investment and must be maintained over years to fit with the ROI planning.
- There is a large trend to increase the power capacity (renewing the turbines is 15% power increasing) and/or raise the height with an impact of the structure (vibrations)
- Seismicity is a reality (IRAN, CHINA, INDIA, … but also in UKRAINE)
- New Hydro PP infrastructure must be monitored not only during the filling of the reservoir but after …
- Monitoring must be 24/7 and automatic …
- Geodetic monitoring can reduce significantly the number of Geotechnical sensors …
- Geodetic monitoring instrumentation can be offset by Geotechnical sensors …

Kruonio HAE
Dam Water Variations on Upper Reservoir



Geodetic Monitoring must be 24/7 … or the investment will be lost having no “results” !

Wall Deflection vs Water Level on the upper reservoir

GMX2 0.0 mm

GMX3 0.0 mm

GMX1 +0.7 mm

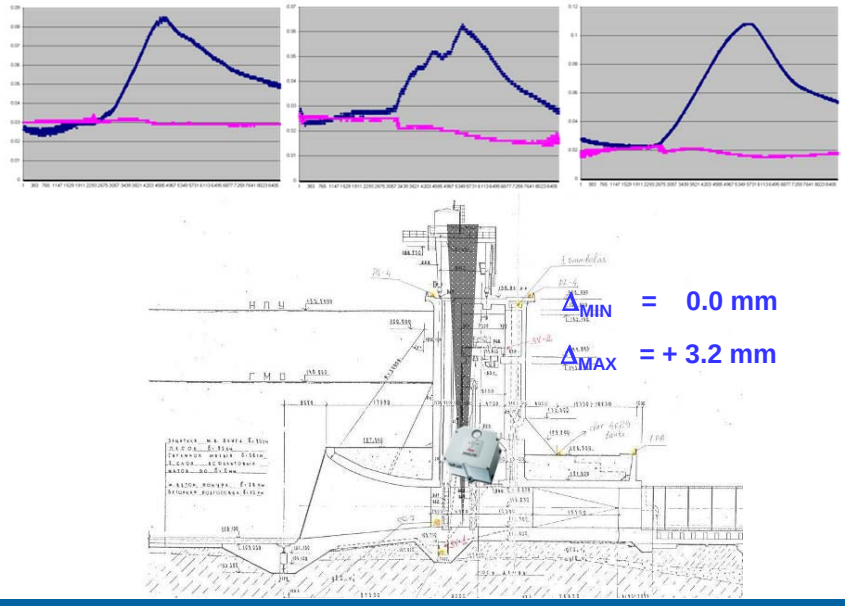
Wall Deflection vs Water Level on the upper reservoir

GMX2 +3.6 mm

GMX3 +3.4 mm

GMX1 0.0 mm

NIVEL210 Long Term Monitoring
Fluctuation on the Dam's wall



Methodology
The 7 seven steps approach …

1. Site visit and meeting with the Director of the HPP, engineers and surveyors
2. Site inspection and final Design
    1. HPP infrastructure, surrounding environment
    2. Selection of GNSS Reference Station location
    3. Selection of TPS location
    4. Location of the GNSS Monitoring stations with 360° reflector
    5. Location of passive control points (360° reflector)
    6. Visit to the control centre, processing facility
    7. Report to partners on communication and accessories
3. Simulation on the final design proposal (Least Squares Adjustment)
4. Report delivered to the authority for approval
5. Planning on instruments and accessories delivering
6. Installation and initialisation (network processing)
7. Fine tuning and acceptance, contractual maintenance and support.

Site Visit and Meeting with HPP authority

Understanding the site and infrastructure

Existing Geodetic Assets

Environment and location for GNSS Reference & TPS

Understanding the structure

Site Visit and Meeting with HPP authority

Understanding the past Geodetic history (X,Y)

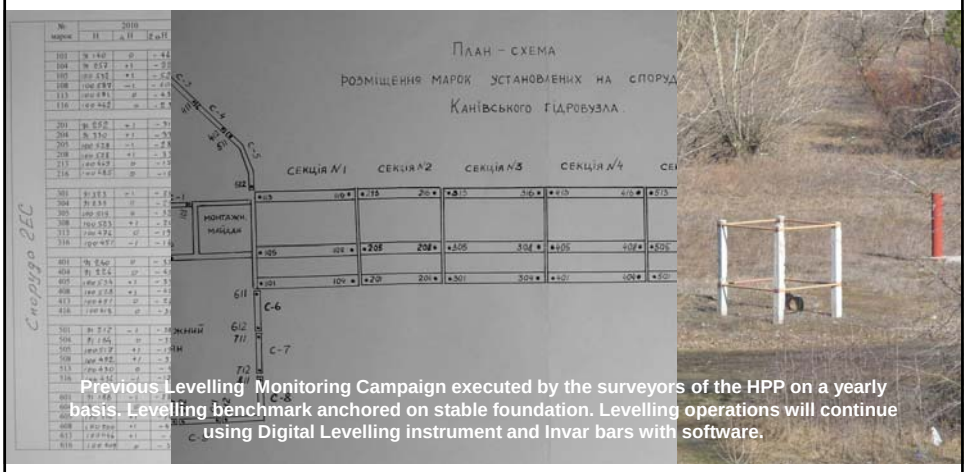
NN п-в	I цикл июнь - июль 1997 г X	Y
b 5	5933.0577	29723.8766
b 8	5928.6630	29772.7443
b 12	5914.5845	29837.1189
b 15	5901.2442	29882.8017
b 16	5896.4080	29898.7920
b 17	5889.4132	29913.5271
b 20	5868.6521	29957.9785
b 23	5845.0293	30000.7189
b 26	5817.5905	30040.9319
b 29	5787.5190	30079.1721

Ведомость составил:

Previous Geodetic Monitoring Campaign executed by University, Geodesy Department using GPS on pillars. Control points and monitoring points on steel pillars anchored on massive concrete foundations.

Site Visit and Meeting with HPP authority

Understanding the past Levelling (H) history



Previous Levelling Monitoring Campaign executed by the surveyors of the HPP on a yearly basis. Levelling benchmark anchored on stable foundation. Levelling operations will continue using Digital Levelling instrument and Invar bars with software.

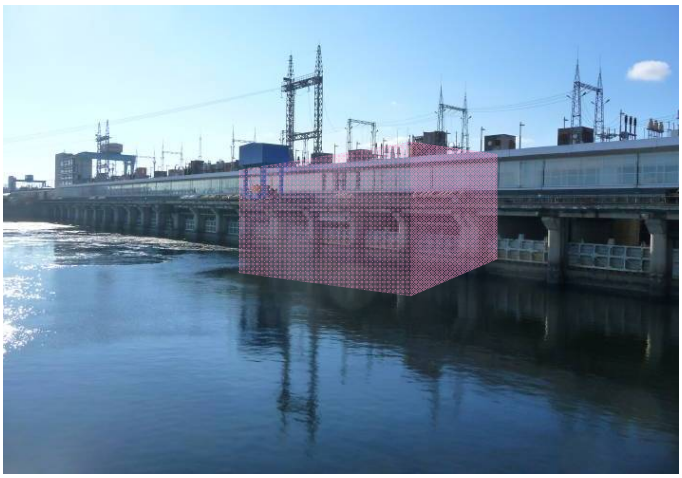
Site Visit and Meeting with HPP authority

Understanding the infrastructure

The original design of the structure and the construction are important elements to understand the HPP structure and how it is supposed to behave under water load. The turbines and electro-mechanical parts management for electricity production planning are influencing the way the structure will react as well.

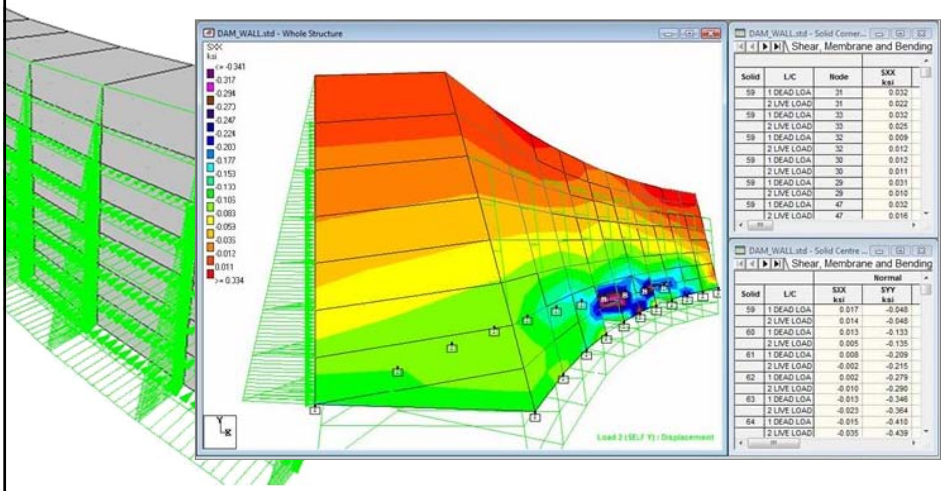
Site Visit and Meeting with HPP authority

Understanding the HPP Structural Behaviour



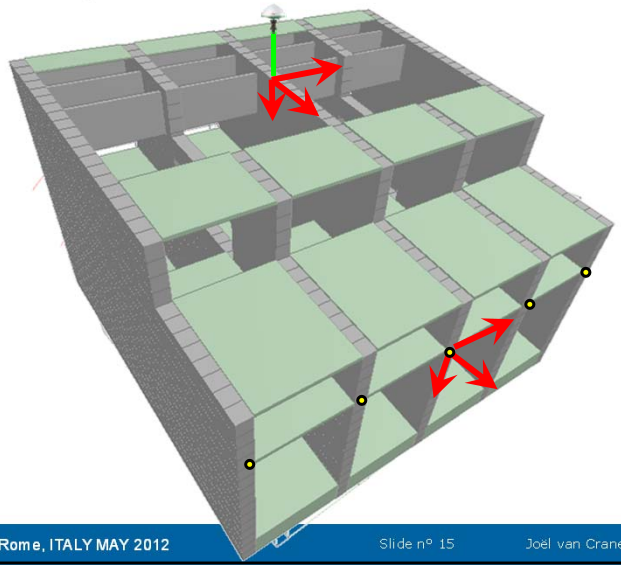
Site Visit and Meeting with HPP authority

Understanding the HPP Structural Behaviour



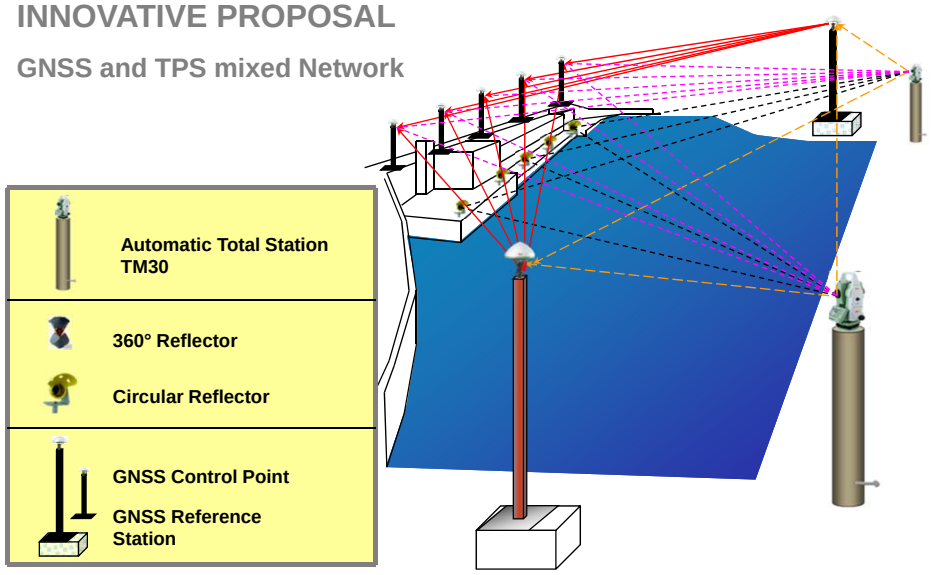
Site Visit and Meeting with HPP authority

Understanding the HPP Structural Behaviour



INNOVATIVE PROPOSAL

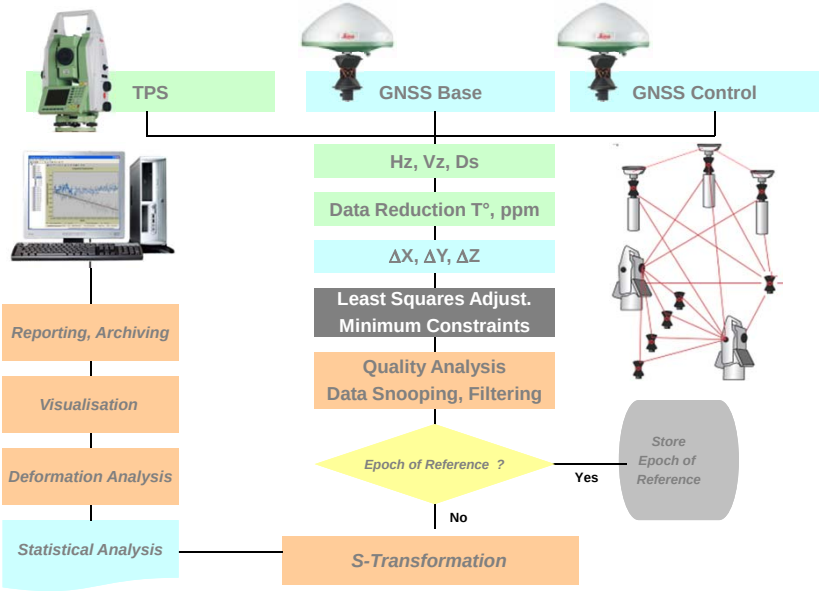
GNSS and TPS mixed Network



Active GNSS Control Points
Concept

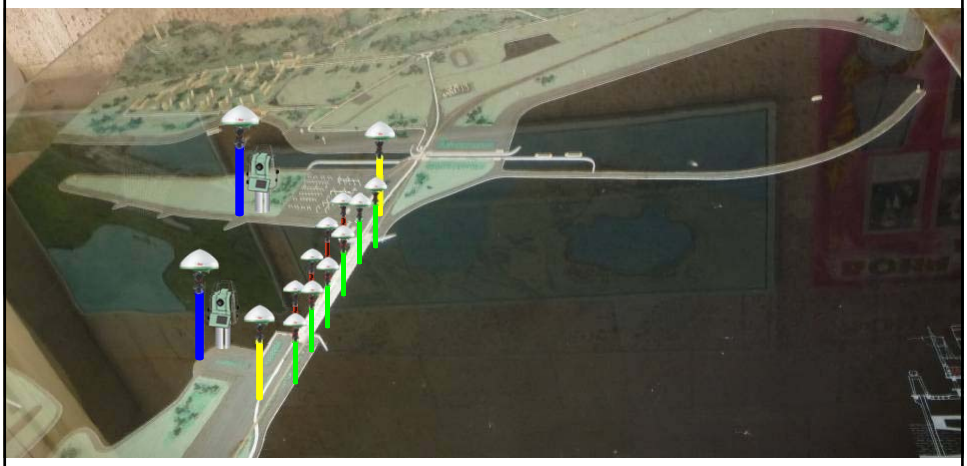
- For each GNSS stations (control points and reference) a 360° reflector will be collocated with the antenna in order to be measured by the Total Stations (Active Control Points).

WORKFLOW Post-Processing



Site Inspection and Final Design

The design must fit with structural analysis



Site Inspection and Final Design

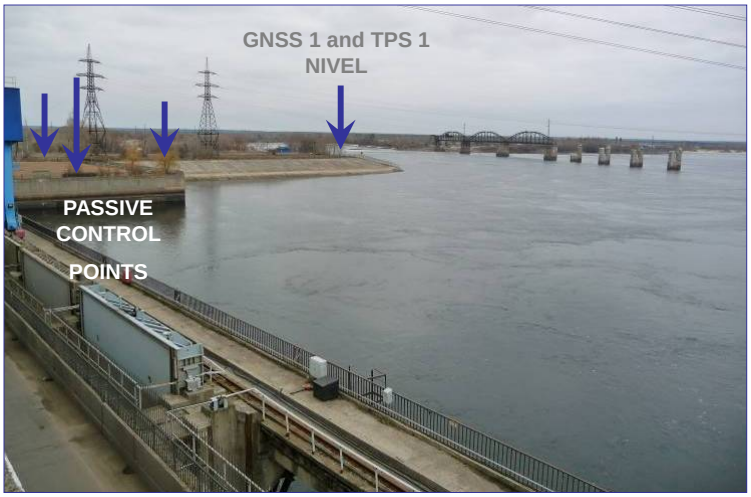
The design must fit with structural analysis

Site Inspection and Final Design

GNSS and TPS location to insure accuracy

Site Inspection and Final Design

GNSS and TPS location to insure accuracy



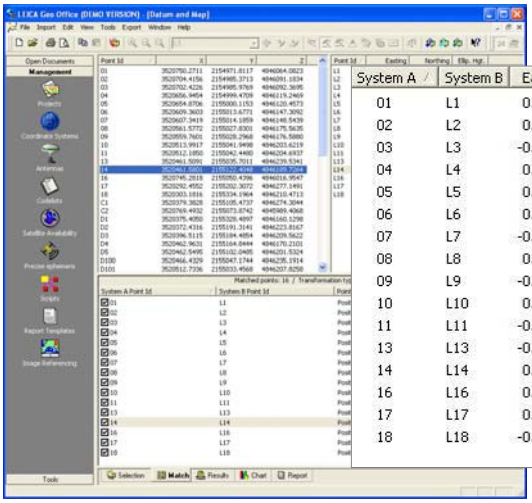
Site Inspection and Final Design

Site survey using GNSS RTK

The site survey is an important operation consisting of validating the existing geodesy (coordinate system), the designed location of instrumentation (GNSS and TPS) and to obtain information for the final design validation using “Least Squares Simulation” processing.

Site Inspection and Final Design

Comparison and Datum Transformation



System A	System B	Easting	Northing	Height	Position	Position+Height
01	L1	0.0002	0.0034	-0.0058	0.0034	0.0067
02	L2	0.0054	0.0008	-0.0135	0.0054	0.0145
03	L3	-0.0114	-0.0054	-0.0017	0.0126	0.0127
04	L4	0.0051	-0.0083	0.0137	0.0097	0.0167
05	L5	0.0052	-0.0035	0.0120	0.0063	0.0135
06	L6	0.0051	-0.0080	-0.0055	0.0095	0.0109
07	L7	-0.0070	-0.0062	0.0152	0.0094	0.0179
08	L8	0.0148	0.0052	0.0324	0.0157	0.0360
09	L9	-0.0124	-0.0051	-0.0291	0.0134	0.0320
10	L10	0.0111	0.0053	0.0004	0.0123	0.0123
11	L11	-0.0164	0.0068	-0.0087	0.0178	0.0198
13	L13	-0.0119	0.0103	-0.0056	0.0157	0.0166
14	L14	0.0051	-0.0075	-	0.0091	0.0091
16	L16	0.0035	0.0153	-0.0036	0.0157	0.0161
17	L17	0.0045	0.0049	-0.0019	0.0066	0.0069
18	L18	-0.0009	-0.0080	0.0016	0.0081	0.0082

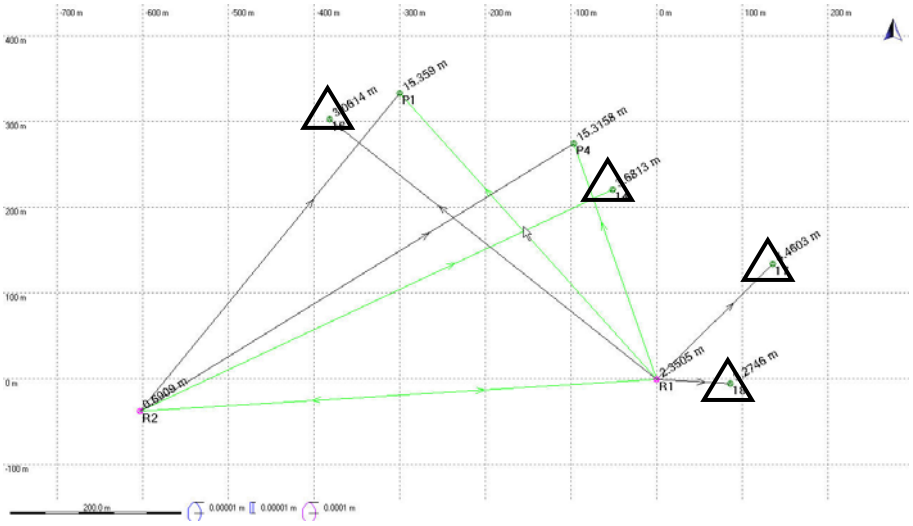
Site Inspection and Final Design

Site survey using TPS

The site survey with TPS is an important operation consisting of validating the designed location of instrumentation (TPS and Reflectors), the performances on site and to obtain information for the final design validation using "Least Squares Simulation" processing.

Site Inspection and Final Design

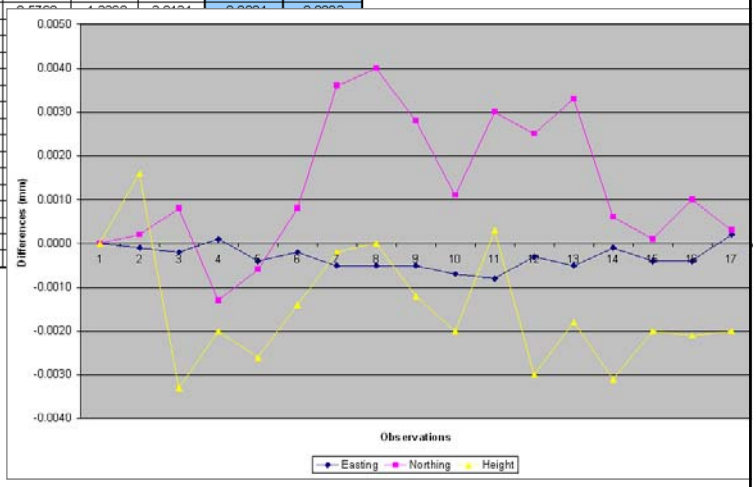
Site survey using TPS



Site Inspection and Final Design

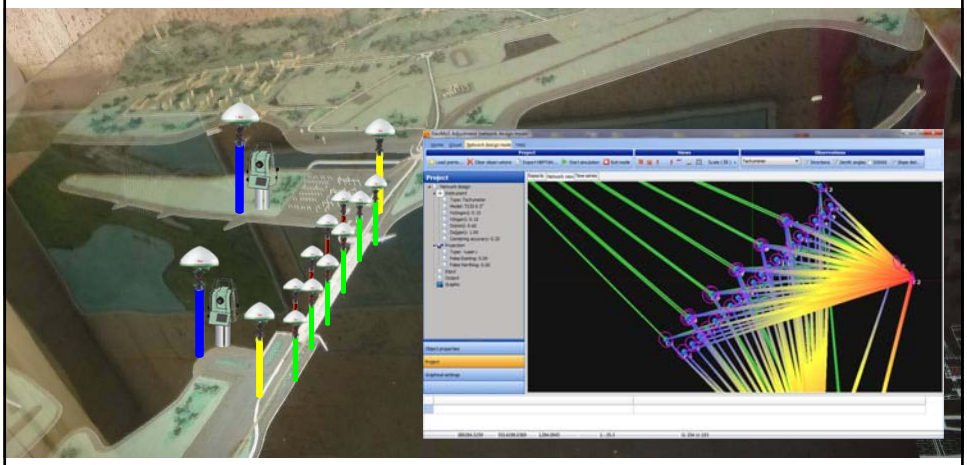
Validation of EDM performances over water

ID	TIME	Easting	Northing	Height	ΔEasting	ΔNorthing
501	04/18/2011 12:10:34	0.5770	-1.3271	2.8105	0.0000	0.0000
502	04/18/2011 12:10:34					
503	04/18/2011 12:10:34					
504	04/18/2011 12:10:34					
505	04/18/2011 12:10:34					
506	04/18/2011 12:10:34					
507	04/18/2011 12:10:34					
508	04/18/2011 12:10:34					
509	04/18/2011 12:10:34					
510	04/18/2011 12:10:34					
511	04/18/2011 12:10:34					
512	04/18/2011 12:10:34					
513	04/18/2011 12:10:34					
514	04/18/2011 12:10:34					
515	04/18/2011 12:10:34					
516	04/18/2011 12:10:34					
517	04/18/2011 12:10:34					

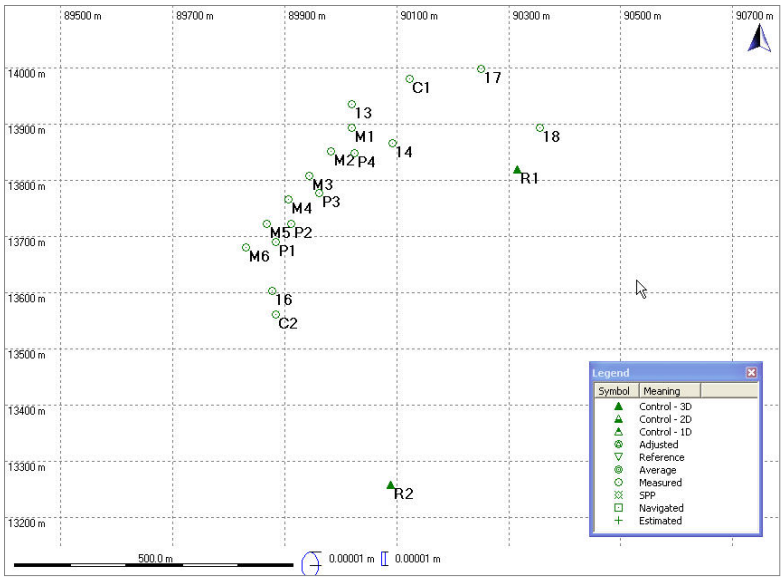


Simulation of Final Design Proposal

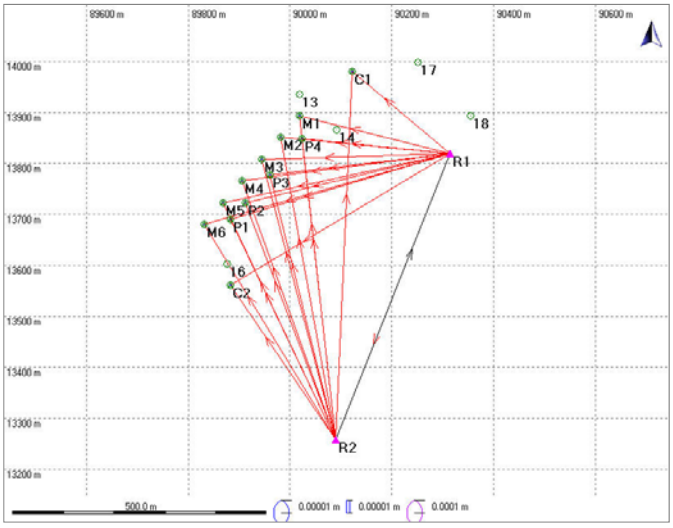
Least Squares Adjustment Simulation



Simulation of Final Design Proposal
Least Squares Adjustment Simulation

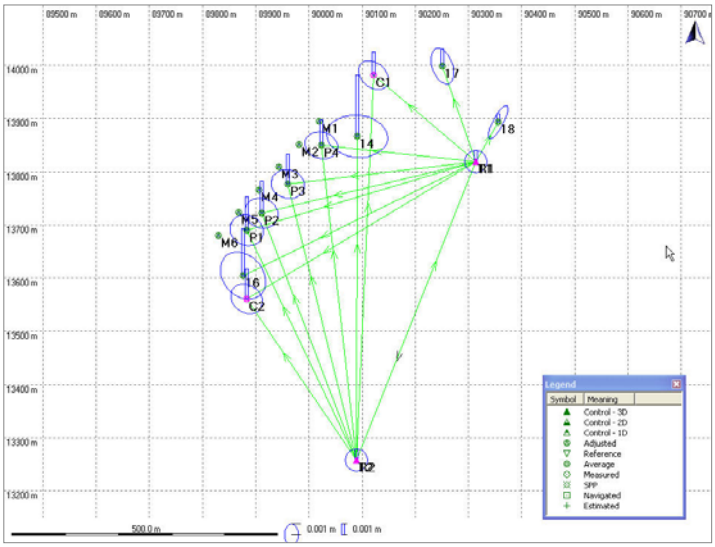


Simulation of Final Design Proposal
Least Squares Adjustment GNSS Simulation



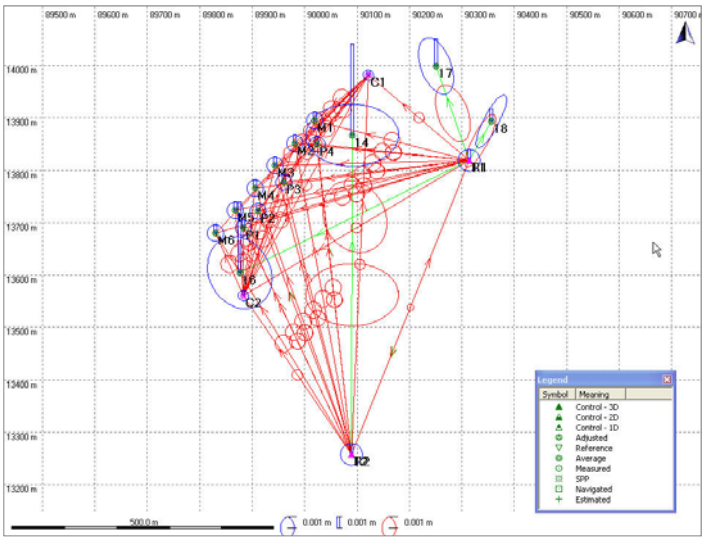
Simulation of Final Design Proposal

Least Squares Adjustment TPS Simulation



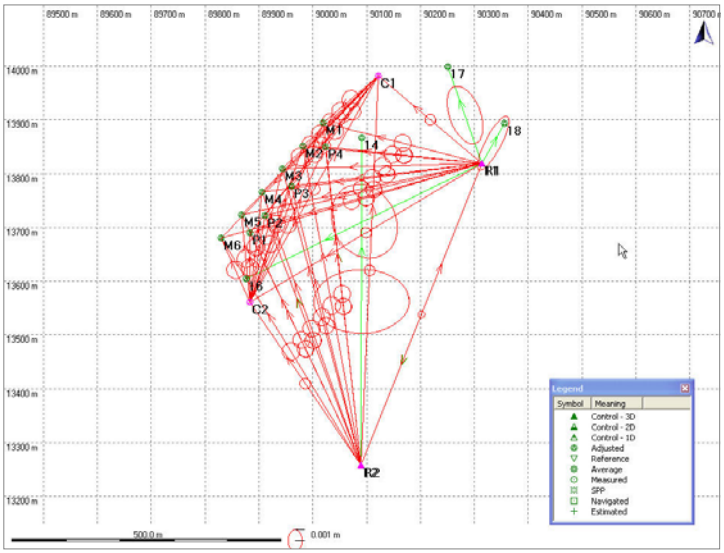
Simulation of Final Design Proposal

Least Squares Adjustment Mixed Simulation



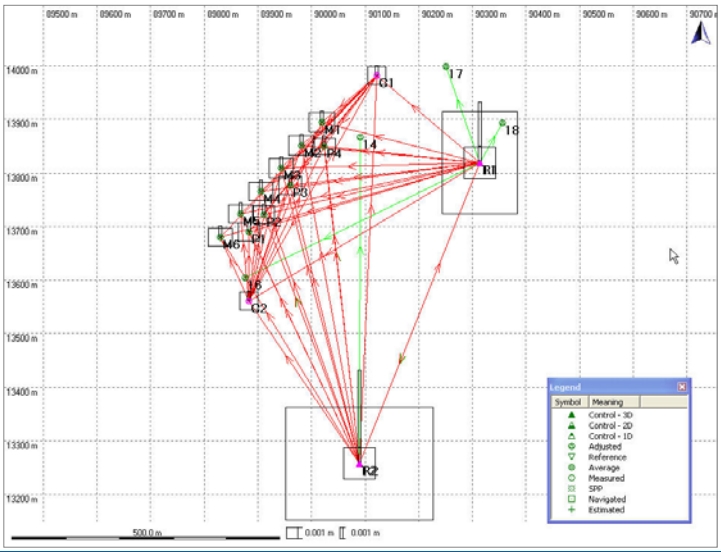
Simulation of Final Design Proposal

Relative Error Ellipse ~ 1mm



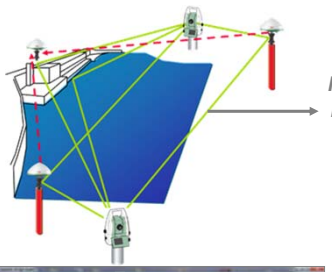
Simulation of Final Design Proposal

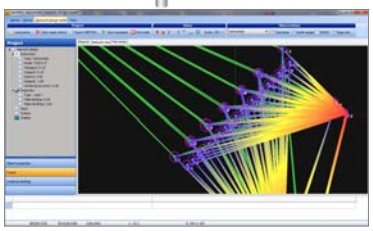
Reliability (marginal detectable error) ~ 1mm

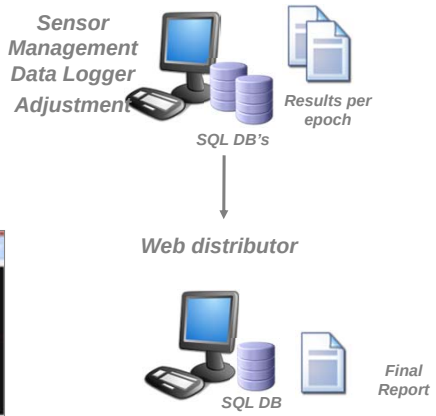


Sensors and Data Fusion

Rigorous Least-Squares Adjustment Analysis

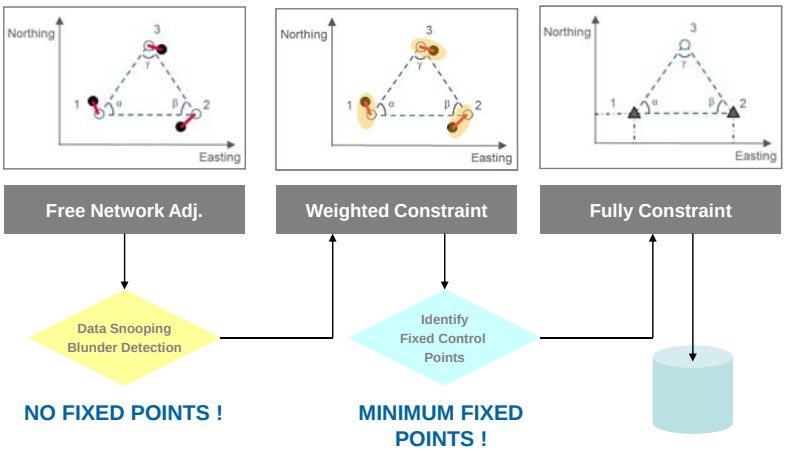






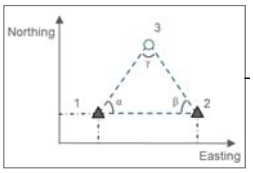
Least Squares Adjustment – Work Flow

GNSS + TPS Best Linear Unbiased Estimates



Least Squares Adjustment – Work Flow

Automatic Deformation Analysis

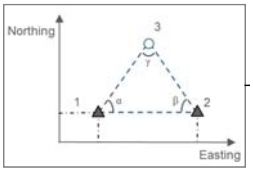


Epoch Reference (any)

$Q_{xx}, x_{reference}$

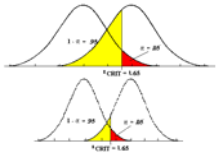
S-Transformation

$\Delta x, \Delta y, \Delta z, r_x, r_y, r_z$



Epoch i

Q_{xx}, x_i



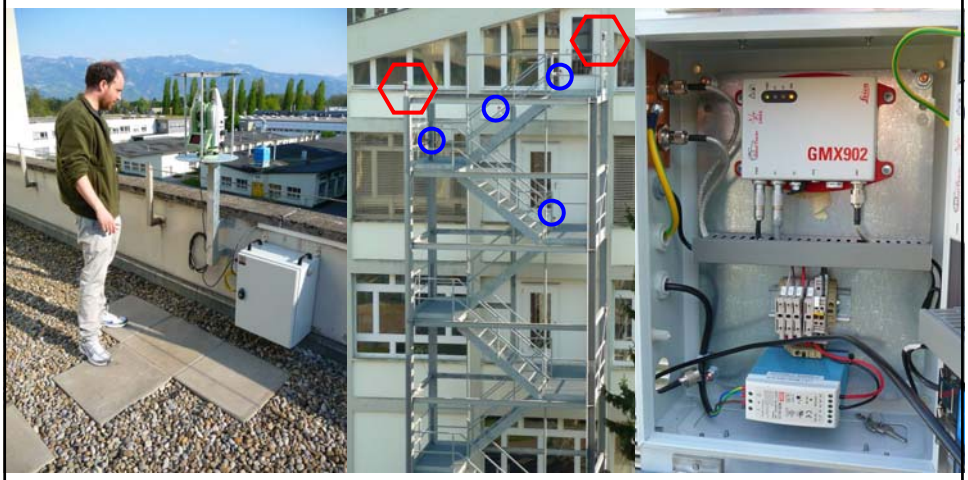
Residuals Analysis

$$t = \frac{\bar{X} - \mu}{\frac{s}{\sqrt{N}}}$$

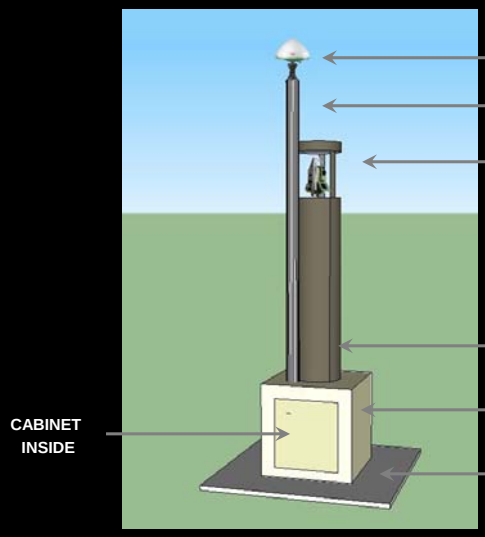
Deformation Reference points ?

Deformation on Object points ?

The "Mock-up" proof of concept



Design of GNSS Reference Station and TPS Station monumentation



Conclusion

- Every instrument should be selected to answer a specific question !
- Site reconnaissance and understanding of the structure is fundamental background to design a geodetic monitoring network
- Site qualification and pre-survey are mandatory
- Least Squares Simulation allows the project engineer to check and improve the design to match the accuracy requirements

- Geodetic Monitoring is the σ = 1 mm (95%) market segment

- “Eine Messung is Keine Messung” (Karl Friedrich GAUSS)
- The Marginal Detectable Error is one of the main criterion
- Precision without Reliability is zero quality

- Geodetic Monitoring is just … more than surveying !

Many thanks for your consideration

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