Kaniv HPP | Dniprodzerzhynsk HPP | Dnipro HPP | Dnister HPP

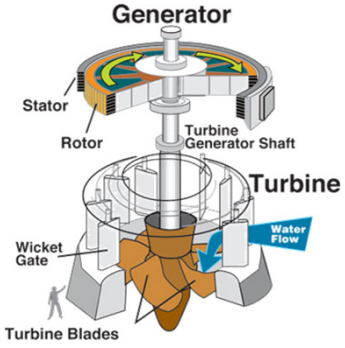
New Design for Hydro Power Plant Structural Geodetic Monitoring Network

Joël van Cranenbroeck, Director of Technology and Projects Development for Geodetic Monitoring Services

GEOMOS AG, Switzerland – Heerbrugg

Hydro Electricity

- **Hydroelectricity** is the term referring to electricity generated by hydropower; the production of electrical power through the use of the gravitational force of falling or flowing water.
- It is the most widely used form of renewable energy.
- Once a hydroelectric complex is constructed, the project produces no direct waste, and has a considerably lower output level of the greenhouse gas carbon dioxide (CO_2) than fossil fuel powered energy plants.
- Worldwide, an installed capacity of 777 **GWe** supplied 2998 TWh of hydroelectricity in 2006.
- This was approximately 20% of the world's electricity, and accounted for about 88% of electricity from renewable sources.



Selected and Placed (design) …

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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)

FIG 2011, Working Week, Marrakech Slide n° 3 /50 Joël van Cranenbroeck / 18.05.2011

Reasons to setup Geodetic Monitoring …

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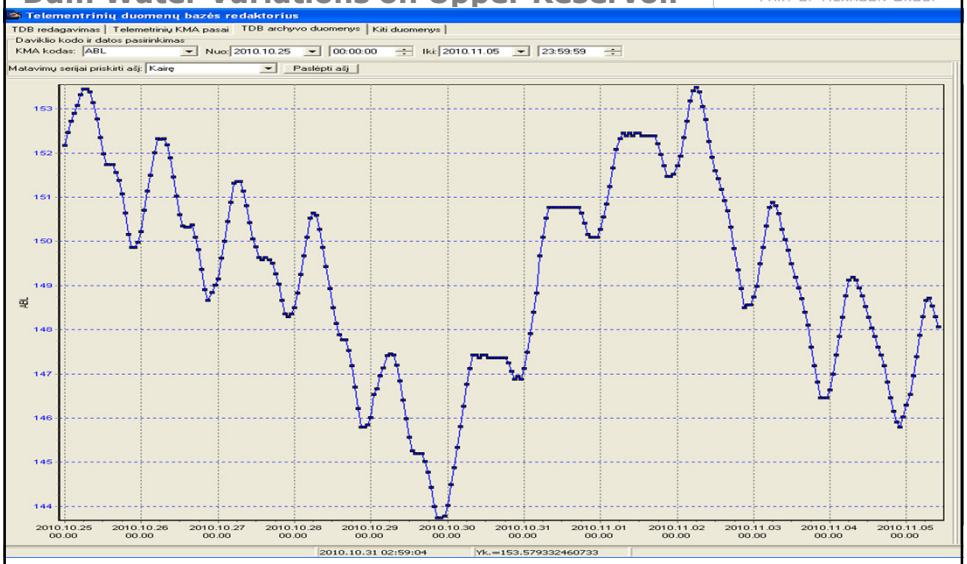
- Hydro PP is a huge investment and must be maintained over years
- There is a large trend to increase the power capacity (renewing the turbines is 15% increase) with an impact of the structure (vibrations)
- Seismicity is a reality (IRAN, CHINA, INDIA…. but also in UKRAINE)
- New Hydro PP infrastructure must be monitored during the filling of the reservoir
- We learnt out of the FUKUSHIMA disaster that a Nuclear PP needs also electricity to work …
- Monitoring must be 24/7 and automatic …
- Geodetic Monitoring can reduce significantly the number of Geotechnical sensors …
- Geodetic Monitoring can be offset by Geotechnical sensors …

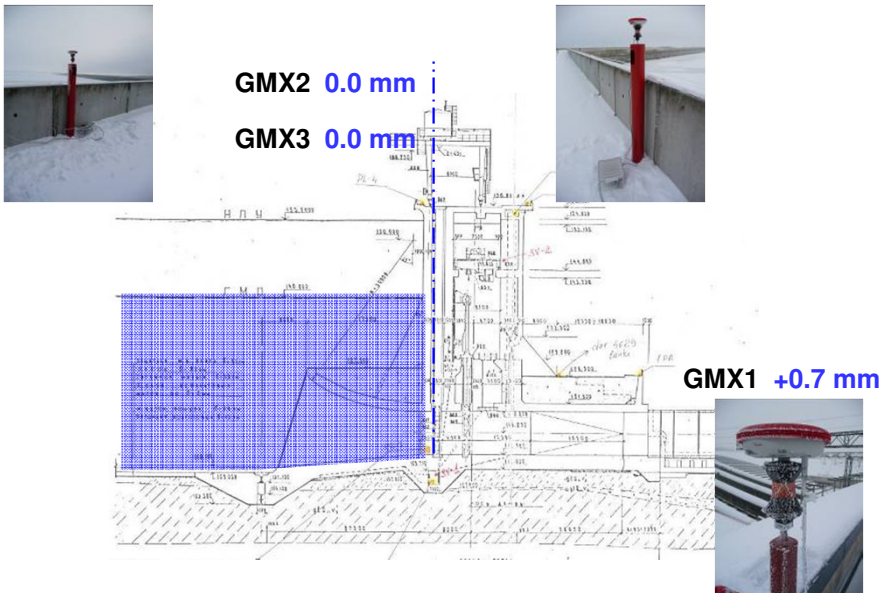
FIG 2011, Working Week, Marrakech Slide n° 4 /50 Joël van Cranenbroeck / 18.05.2011

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



Wall Deflection vs Water Level on the upper reservoir

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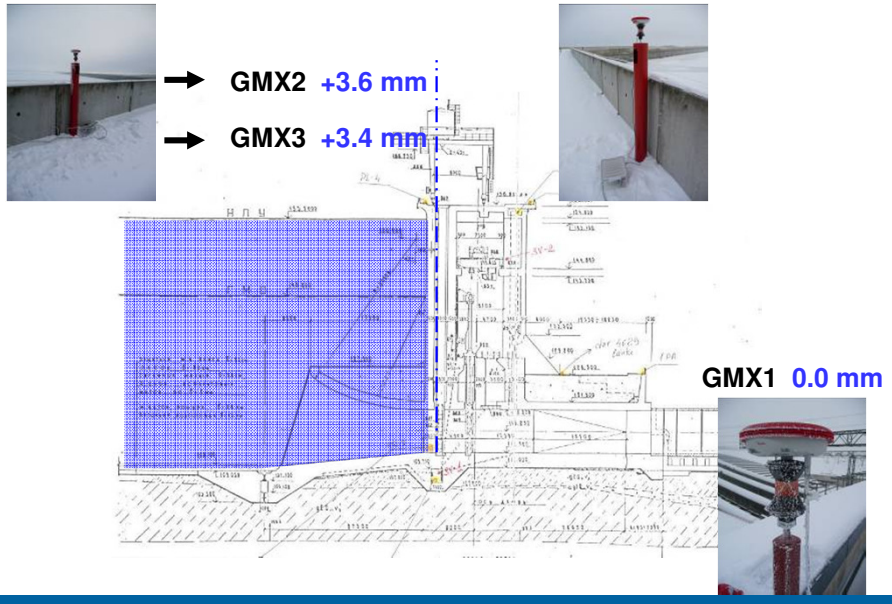

NIVEL210 Long Term Monitoring
Fluctuation on the Dam's wall

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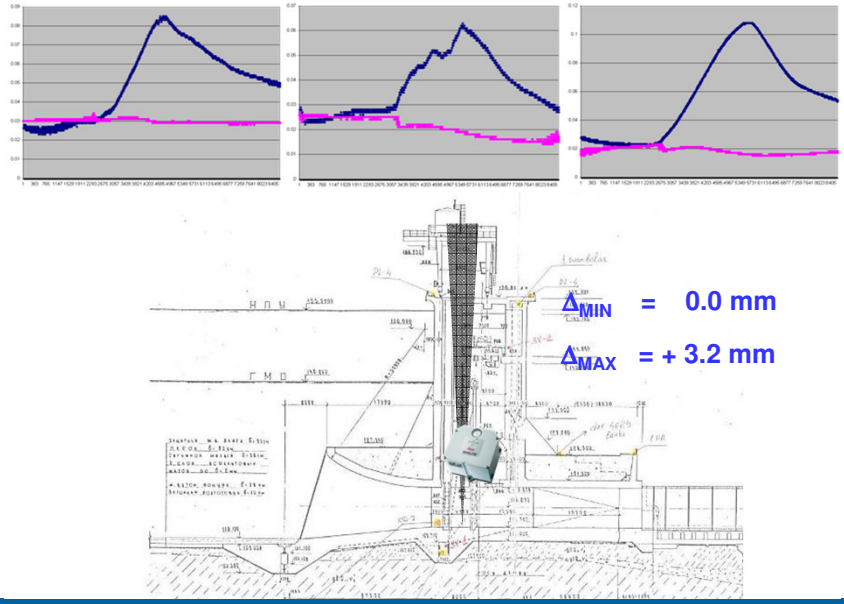
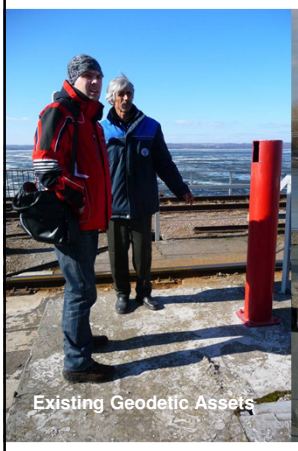


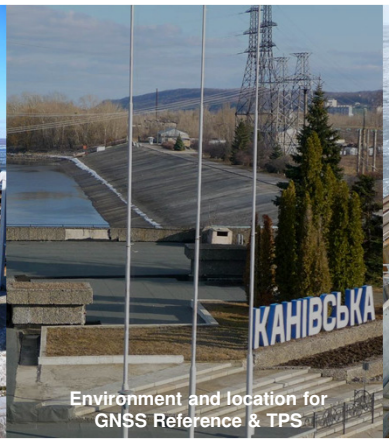
Methodology
The 7 seven steps approach …

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.

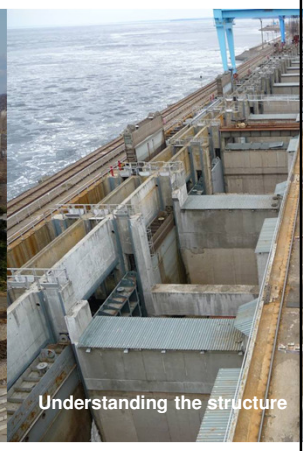
1. Site Visit and Meeting with HPP authority

Understanding the site and infrastructure


Existing Geodetic Assets



Environment and location for GNSS Reference & TPS


Understanding the structure

1. Site Visit and Meeting with HPP authority

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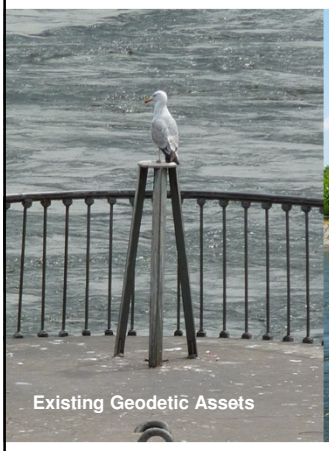
Understanding the site and infrastructure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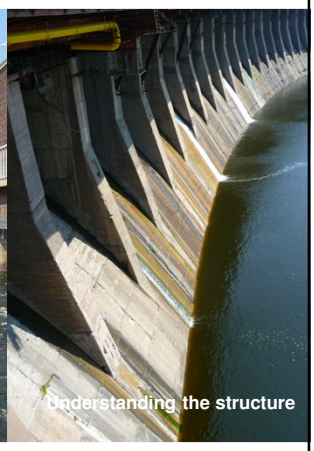
Understanding the structure

1. Site Visit and Meeting with HPP authority

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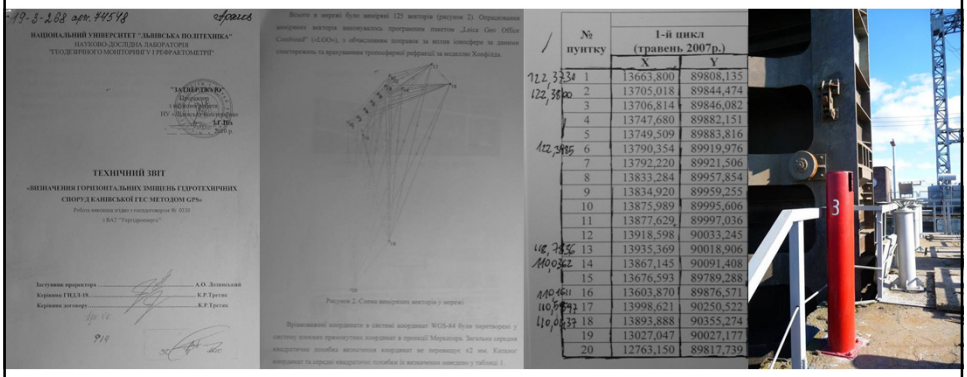
Understanding the past Geodetic history (X,Y)


ТЕХНІЧНИЙ ЗВІТ

№ пункту	1-й цикл (травень 2007р.) X	Y
1	13663,800	89808,135
2	13705,018	89844,474
3	13706,814	89846,082
4	13747,680	89882,151
5	13749,509	89883,816
6	13790,354	89919,976
7	13792,220	89921,506
8	13833,284	89957,854
9	13834,920	89959,255
10	13875,989	89995,606
11	13877,629	89997,036
12	13918,598	90033,245
13	13935,369	90018,906
14	13867,145	90091,408
15	13676,593	89789,288
16	13603,870	89876,571
17	13998,621	90250,522
18	13893,888	90355,274
19	13027,047	90027,177
20	12763,150	89817,739

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

1. Site Visit and Meeting with HPP authority

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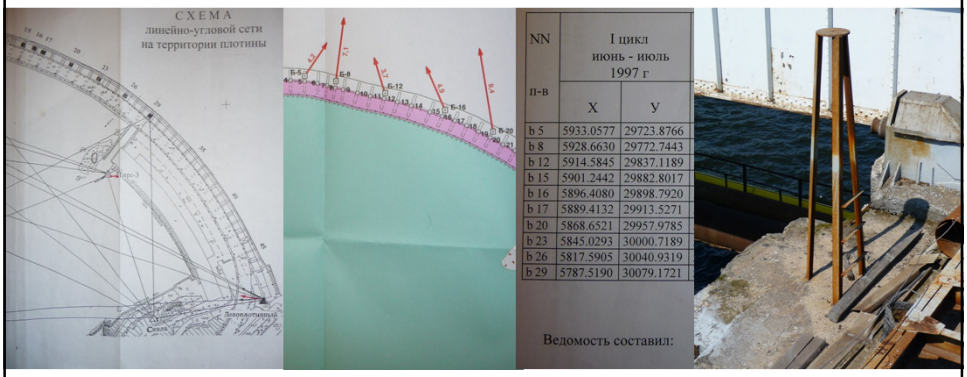
Understanding the past Geodetic history (X,Y)



NN п-в	I цикл июнь - июль 1997 г X	У
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.

1. Site Visit and Meeting with HPP authority

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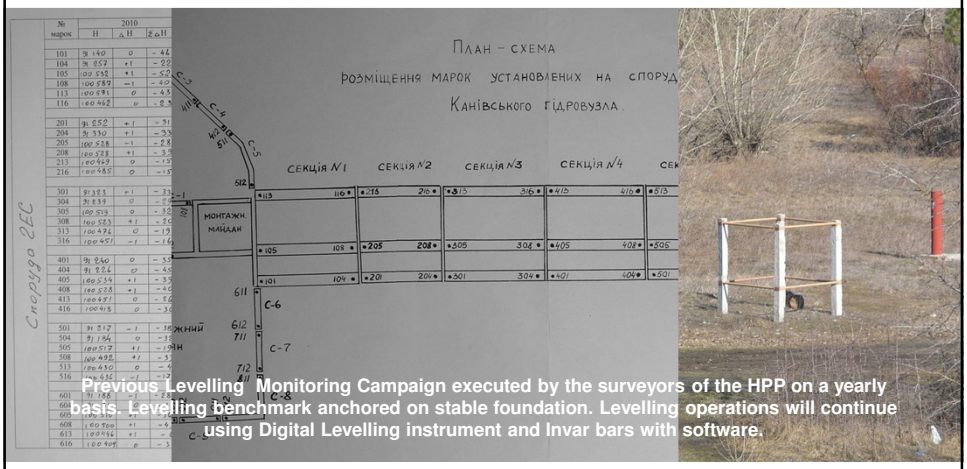
Understanding the past Levelling (H) history



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.

1. Site Visit and Meeting with HPP authority

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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.

1. Site Visit and Meeting with HPP authority

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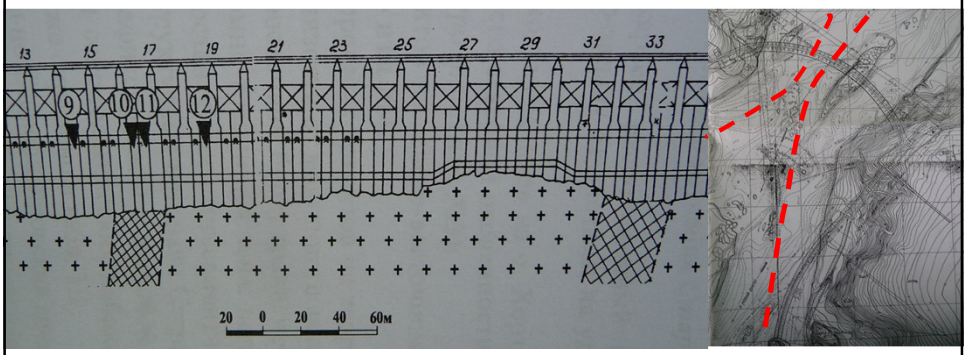
Understanding the infrastructure



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1. Site Visit and Meeting with HPP authority

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Understanding the HPP Structural Behaviour

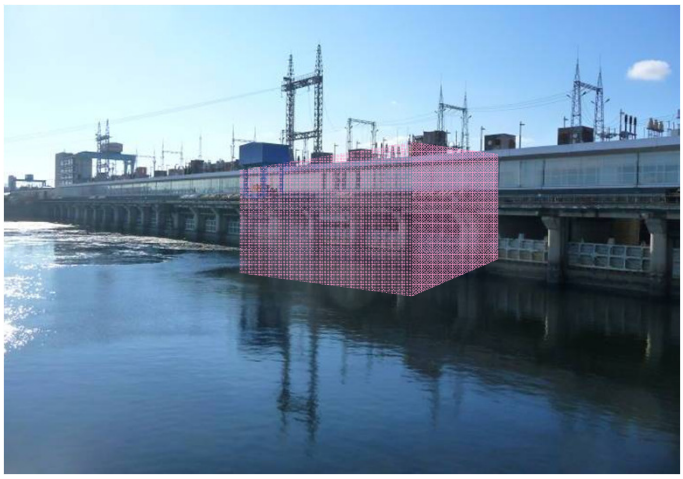

FIG 2011, Working Week, Marrakech Slide n° 17 /50 Joël van Cranenbroeck / 18.05.2011

1. Site Visit and Meeting with HPP authority

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Understanding the HPP Structural Behaviour

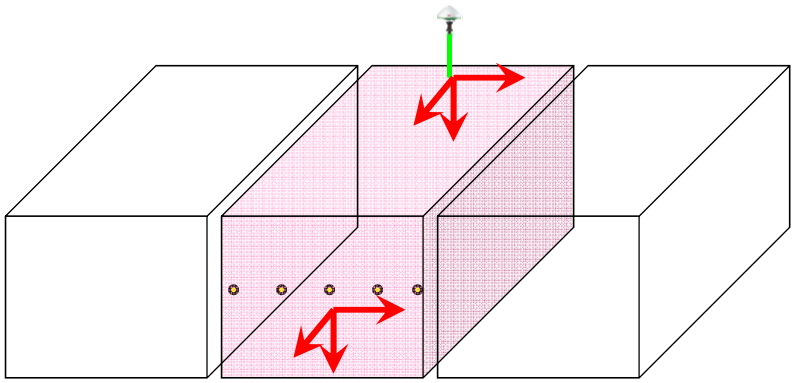

FIG 2011, Working Week, Marrakech Slide n° 18 /50 Joël van Cranenbroeck / 18.05.2011

1. Site Visit and Meeting with HPP authority

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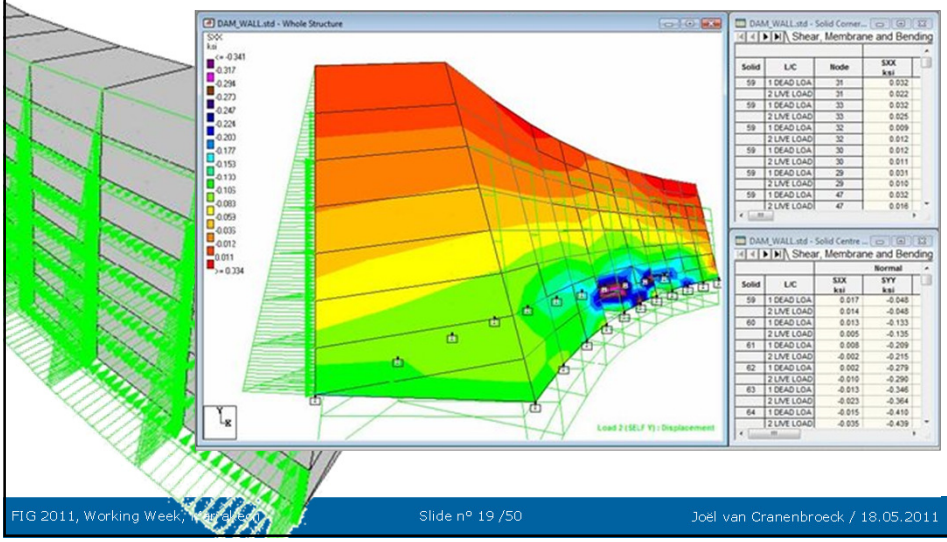
Understanding the HPP Structural Behaviour



1. Site Visit and Meeting with HPP authority

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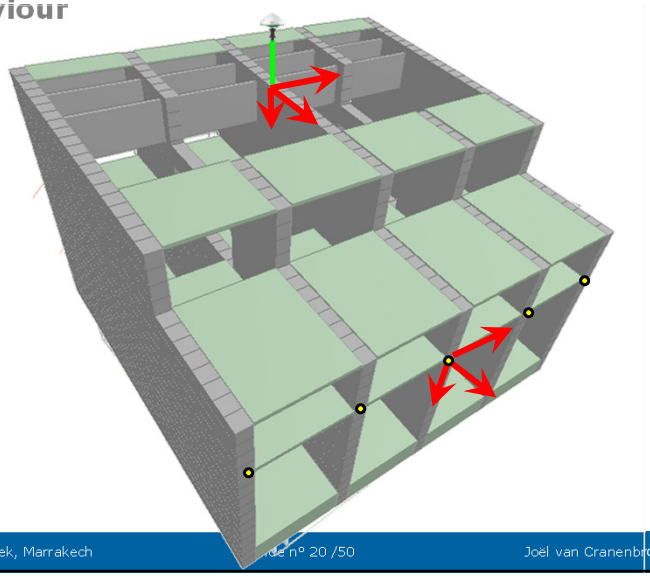
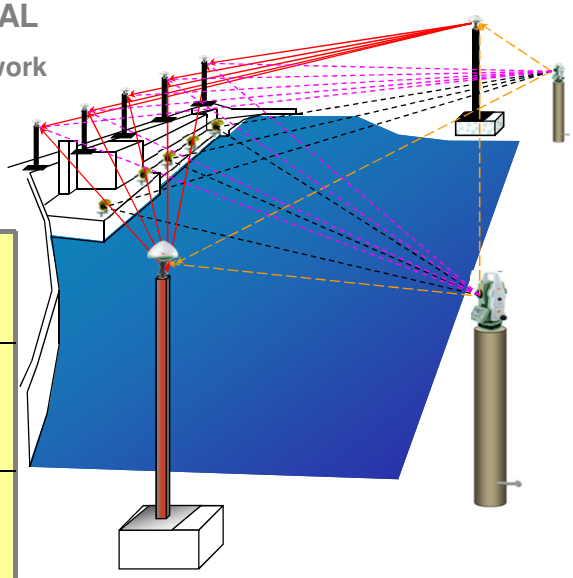
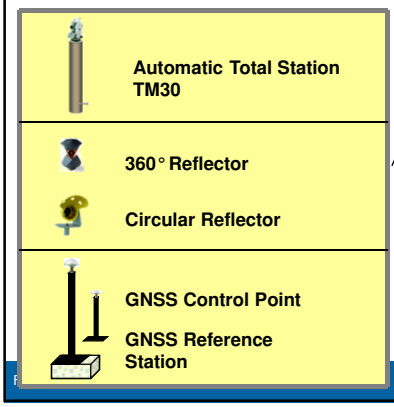
Understanding the HPP Structural Behaviour



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).

Leica GNSS AR10 Antenna (24 cm x 14 cm)

Antenna cable will be protected by a resistant coating against vandalism.

GRZ121 360° Reflector PRO. Reflector with 5/8" thread adapter for mounting of GNSS antenna

Stub to screw 5/8" adaptor or stub support from the mast top.

Monitoring Leica Total Station TM30

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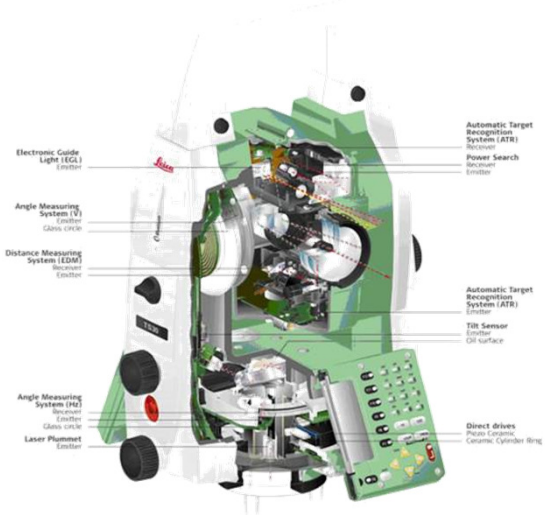
Automatic Target Recognition of Angle, Distance



Circular Prisms and location

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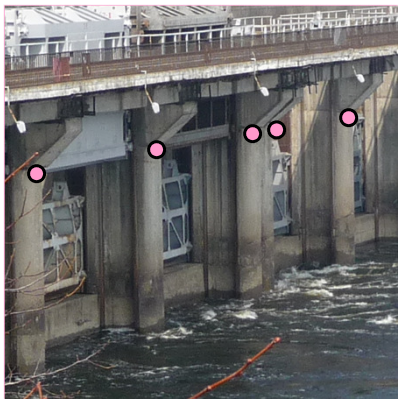

WORKFLOW Post-Processing

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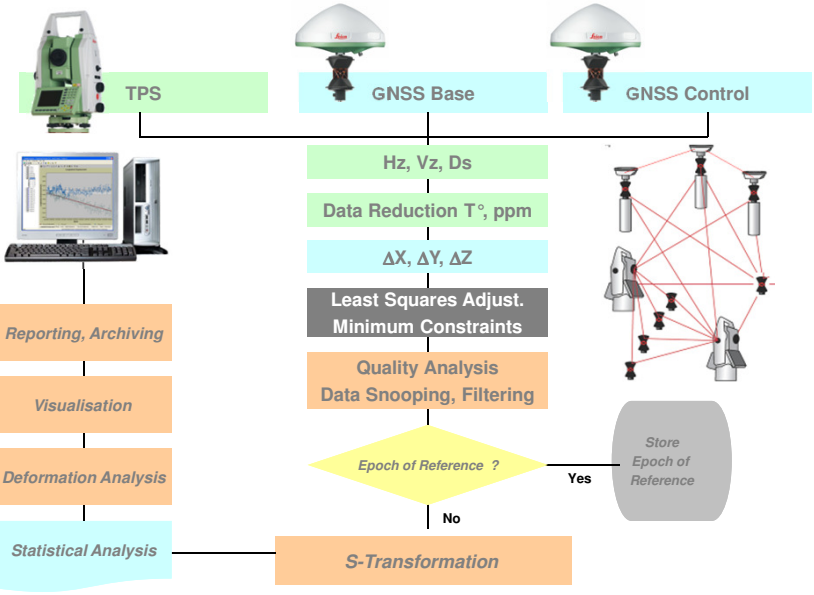

2. Site Inspection and Final Design

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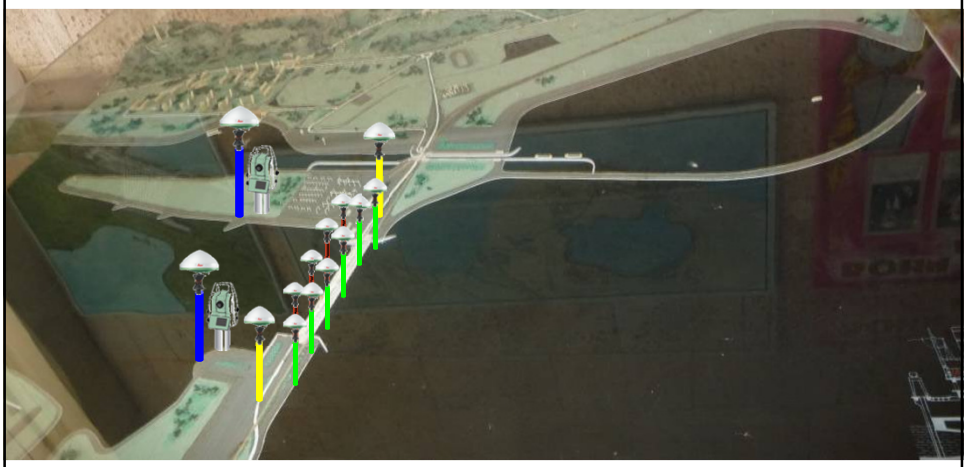
The design must fit with structural analysis



2. Site Inspection and Final Design

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The design must fit with structural analysis

2. Site Inspection and Final Design

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GNSS and TPS location to insure accuracy

2. Site Inspection and Final Design

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GNSS and TPS location to insure accuracy

2. Site Inspection and Final Design

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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.

2. Site Inspection and Final Design

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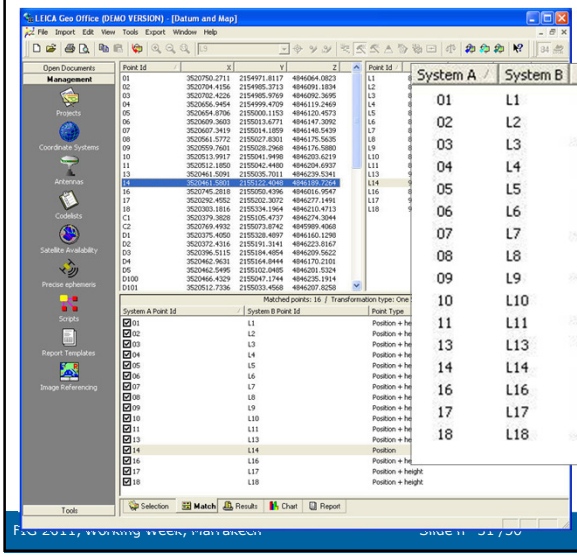
Comparison and DatumTransformation



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

2. Site Inspection and Final Design

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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.

2. Site Inspection and Final Design

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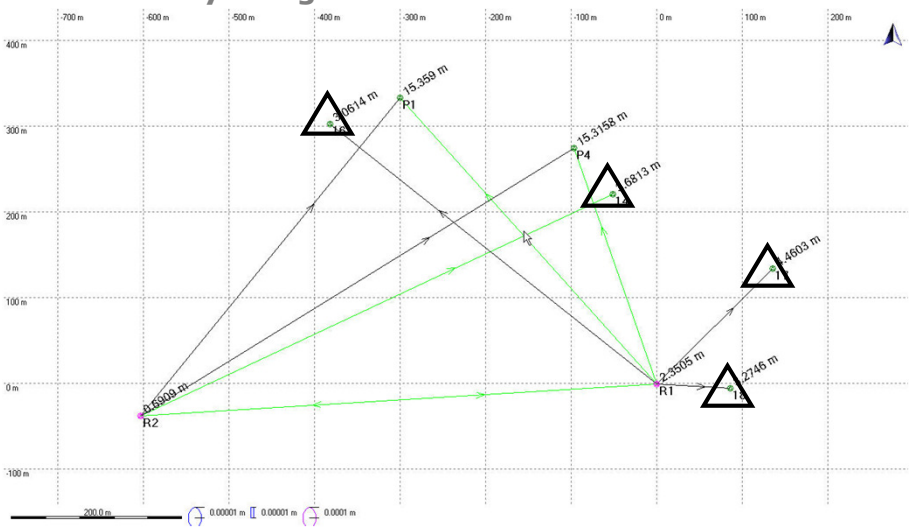
Site survey using TPS



2. Site Inspection and Final Design

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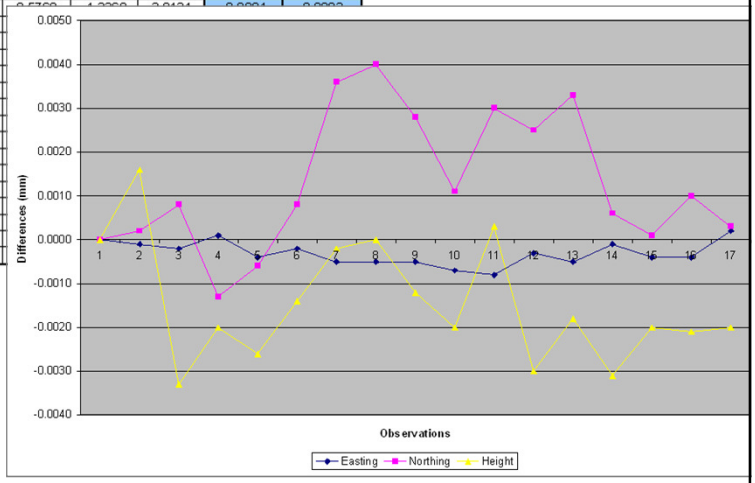
Validation of EDM over Water

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					



3. Simulation of Final Design Proposal

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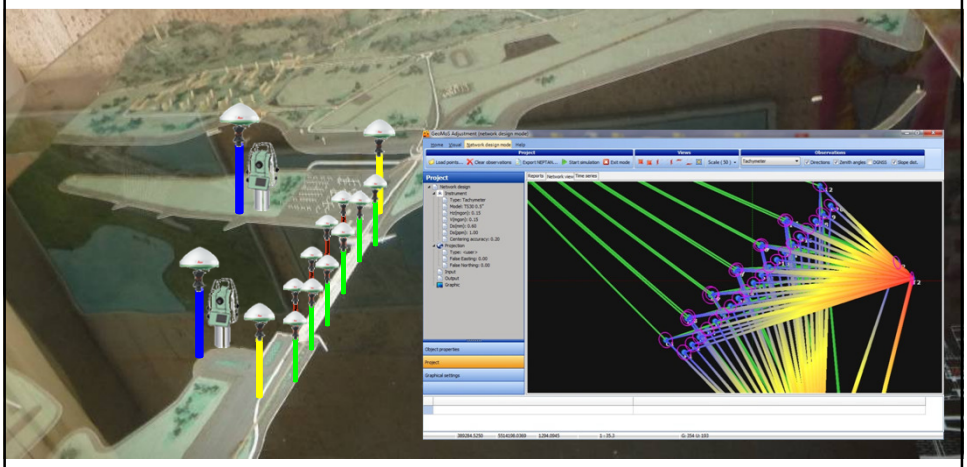
Least Squares Adjustment Simulation



3. Simulation of Final Design Proposal

Least Squares Adjustment Simulation

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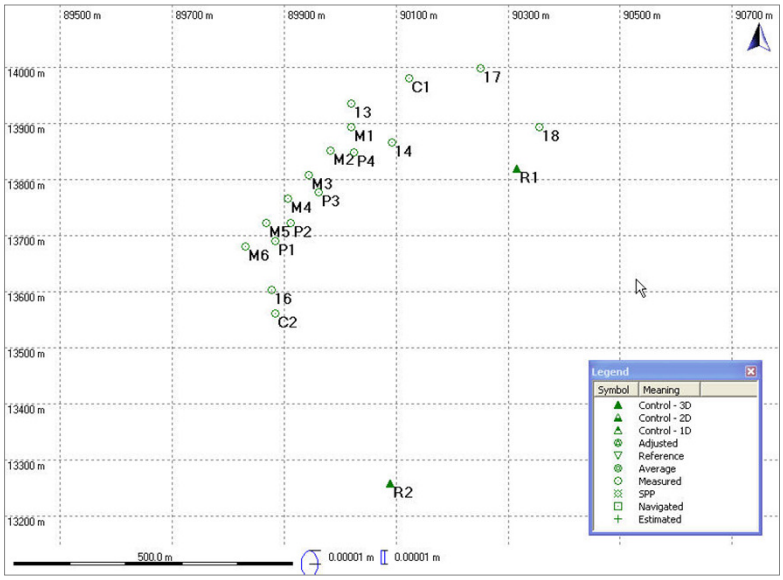

3. Simulation of Final Design Proposal

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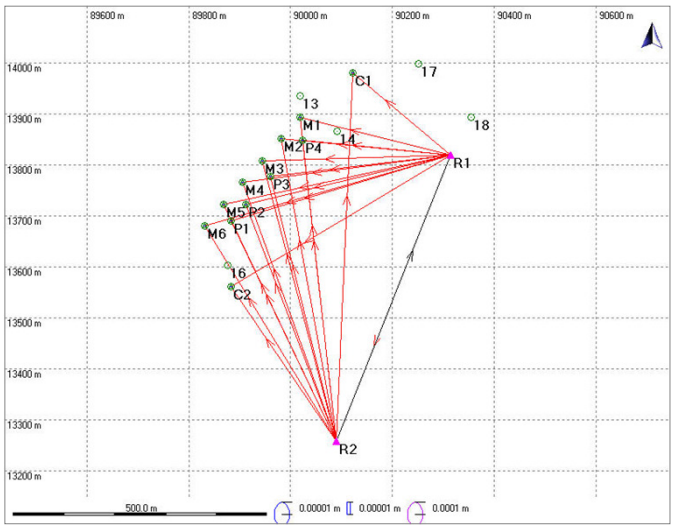
Least Squares Adjustment GNSS Simulation



3. Simulation of Final Design Proposal

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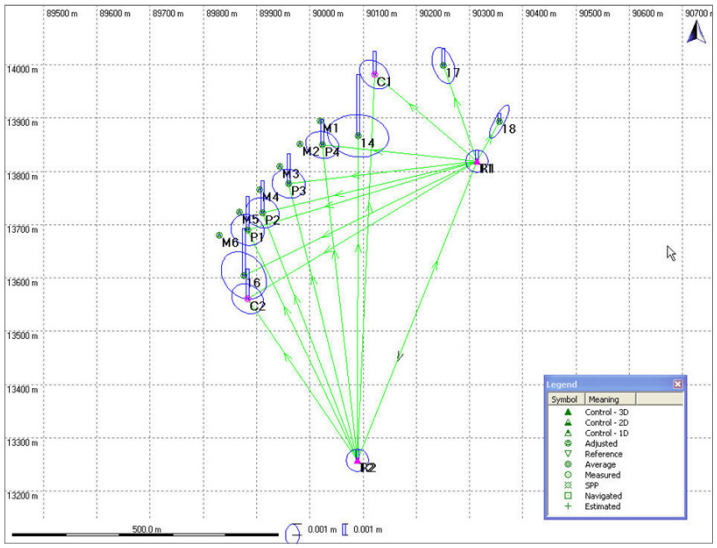
Least Squares Adjustment TPS Simulation



3. Simulation of Final Design Proposal

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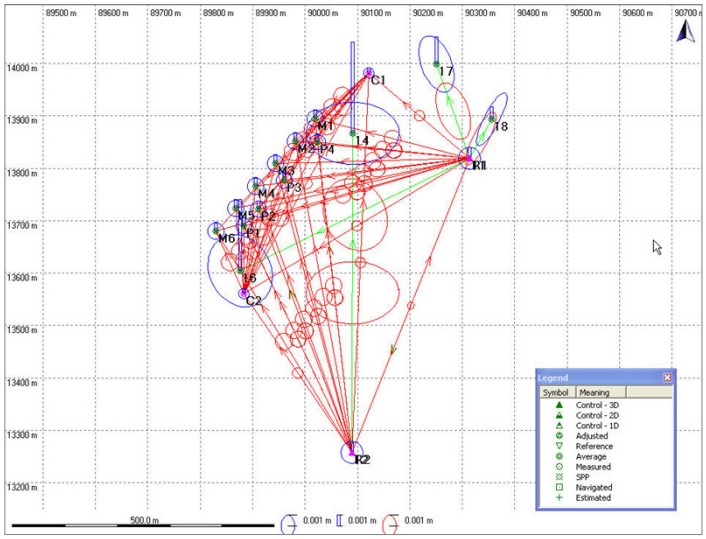
Least Squares Adjustment Mixed Simulation



3. Simulation of Final Design Proposal

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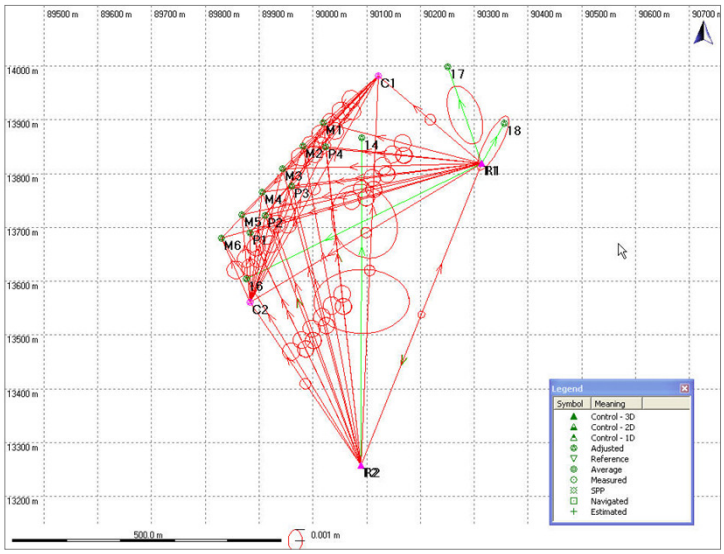
Relative Error Ellipse ~ 1mm



3. Simulation of Final Design Proposal

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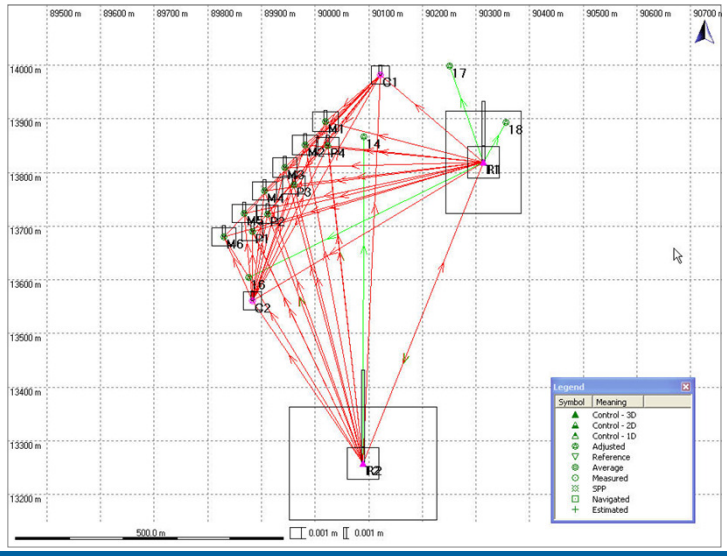
Reliability (marginal detectable error) ~ 1mm



Sensors and Data Fusion

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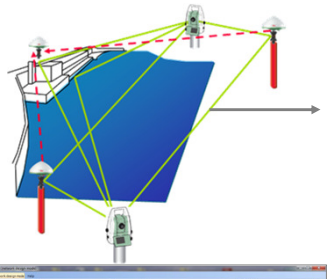
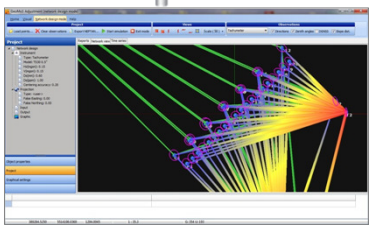
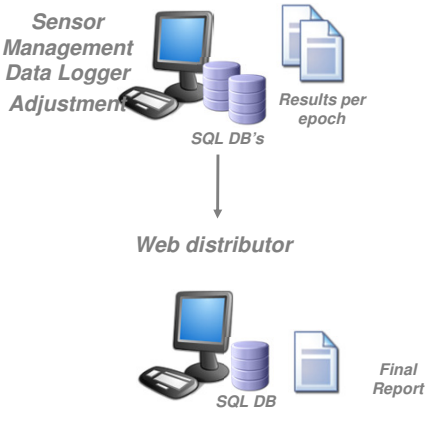
Rigorous Least-Squares Adjustment Analysis







Least Squares Adjustment – Work Flow

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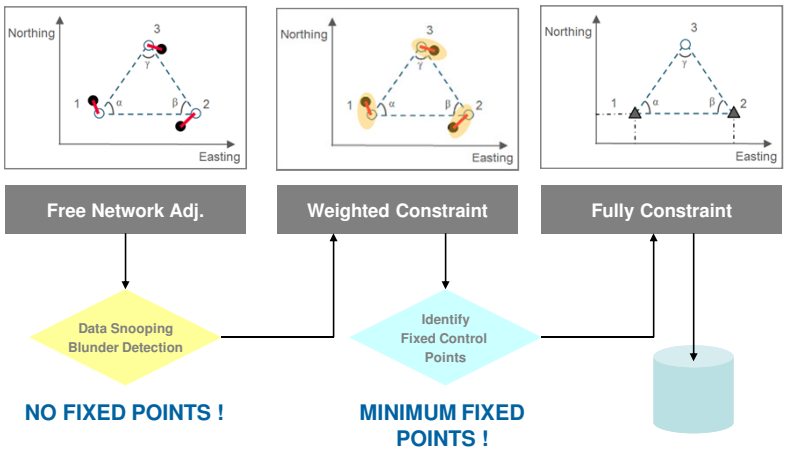
GNSS + TPS Best Linear Unbiased Estimates



Least Squares Adjustment – Work Flow

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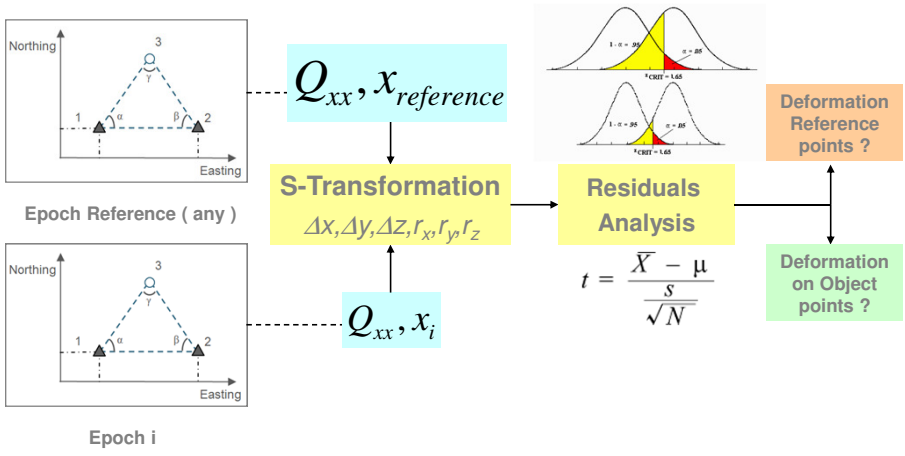
Automatic Deformation Analysis



Methodology
The "Mock-up" approach

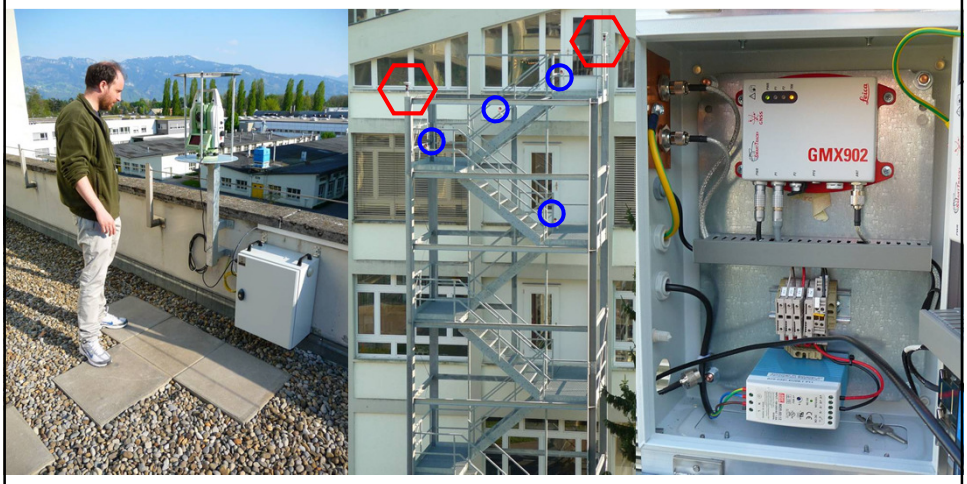


FIG 2011, Working Week, Marrakech Slide n° 45 /50 Joël van Cranenbroeck / 18.05.2011

Sketch of GNSS Reference Station and TPS Station monumentation

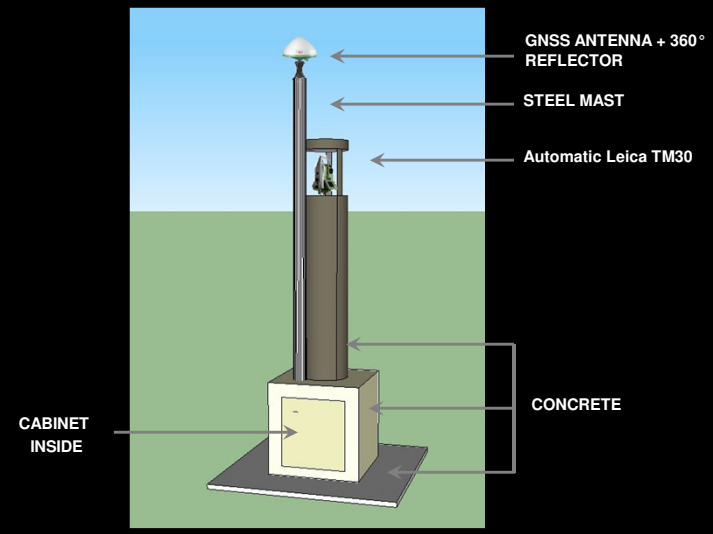


FIG 2011, Working Week, Marrakech Slide n° 46 /50 Joël van Cranenbroeck / 18.05.2011

Conclusion

- Every instrument should be selected to answer a specific question !
- Site reconnaissance and understanding of the structure is fundamental background to design a monitoring network
- Site qualification and 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 !