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.

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

GMX2  +3.6 mm
GMX3  +3.4 mm
GMX1  0.0 mm
NIVEL210 Long Term Monitoring
Fluctuation on the Dam’s wall

\[ \Delta_{\text{MIN}} = 0.0 \text{ mm} \]
\[ \Delta_{\text{MAX}} = +3.2 \text{ mm} \]

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

Site Visit and Meeting with HPP authority

Understanding the past Geodetic history (X,Y)

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 electromechanical 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

Automatic Total Station
TM30

360° Reflector
Circular Reflector

GNSS Control Point
GNSS Reference Station
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).

![Image of 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.

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WORKFLOW Post-Processing

- TPS
- GNSS Base
- GNSS Control

- Data Snooping, Filtering
- Least Squares Adjust. Minimum Constraints
- Quality Analysis
- Visualisation
- Deformation Analysis
- Statistical Analysis
- Reporting, Archiving

- ΔX, ΔY, ΔZ
- ΔX, ΔY, ΔZ
- Data Reduction T°, ppm
- Hz, Vz, Ds

- Store Epoch of Reference
- Epoch of Reference?
- Yes
- No

- S-Transformation

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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 verifying 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.

Comparison and Datum Transformation

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Site Inspection and Final Design

Comparison and Datum Transformation

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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

Validation of EDM performances over water

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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

![Diagram of sensors and data fusion process]

Web distributor

SQL DB's

Results per epoch

Final Report

Least Squares Adjustment – Work Flow

GNSS + TPS Best Linear Unbiased Estimates

Free Network Adj.  Weighted Constraint  Fully Constraint

Data Snooping  Identify Fixed Control Points

Blunder Detection

NO FIXED POINTS !  MINIMUM FIXED POINTS !
Least Squares Adjustment – Work Flow

Automatic Deformation Analysis

Epoch Reference (any)

S-Transformation

\[ \Delta x, \Delta y, \Delta z, r_x, r_y, r_z \]

Residuals Analysis

\[ t = \frac{X - \mu}{s / \sqrt{N}} \]

Least Squares Adjustment

The “Mock-up” proof of concept
**Design of GNSS Reference Station and TPS Station monumentation**

![Diagram of GNSS Reference Station and TPS Station](image)

**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 $\sigma = 1 \text{ mm (95\%)}$ 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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