geomETH

Networks & Deformation Analysis

10.11.2010 13:45 – 14:30 HIL C 71.3

Contents

- Coordinate Systems & Reference Frames
- Deformation Analysis (epochal) – Epoch Approach
- Deformation Analysis (continuous) – Time Series Analysis

Networks in Engineering Geodesy

- serve as a unique, homogeneous and sufficiently precise geometric reference
- allow simultaneous work at different locations at a large construction site

- network configuration should be....
  - geometrical optimal (in consideration of the site, costs, time etc.)
  - stable over the whole construction period and beyond (reliability of marking)
  - protected against destruction (natural hazards, affect of construction traffic)
  - minimization of refraction impacts
  - observe the law of nearest neighbors

Why is the national trigonometric network not used in Engineering Geodesy?

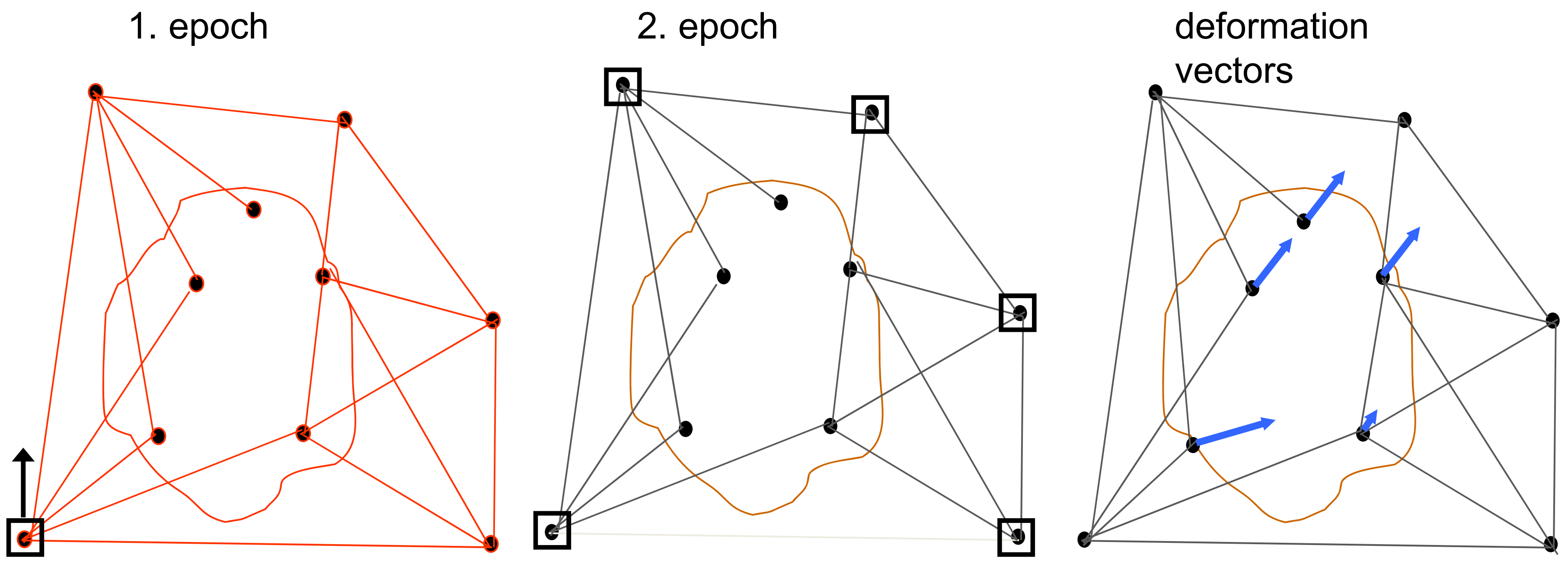
- precision is not sufficiently high e.g. national grid $1.0 \cdot 10^{-4}$ ($1\ \sigma$), industrial requirements are ca. $1.0 \cdot 10^{-5}$ ($1\ \sigma$)
- distortions due to the Gauß-Krüger-mapping function, i.e. scaling factor varies
- point density is not sufficient (1 TP 4th order / km^2)
- trigonometric network is hierarchic; but homogeneous network required
- location of points is driven by requirements in land surveying

establishment of a special control network

- realization simpler than densification of an existing network
- an unconstrained transformation to the national grid is simply achieved
- coordinates obtained in 3D directly

The main objectives are:

- confirm stability of reference points and detect single point movements
- provide deformation vectors
- inform about most recent deformations



Deformation Monitoring: Two-Epoch Analysis

deformation analysis based on geodetic methods:

1. Establishment of an observation scheme.
2. Outlier detection (robust blunder tests). Important step: undetected model errors will be interpreted as deformations!).
3. Free adjustment of individual epochs.
4. Combined adjustment of all epochs. Detection of movements.
5. Description of deformation pattern by a suitable deformation model.

"Classical Deformation Analyses" informs about correlations between epochs and significance of movements, based on hypothesis testing

- Congruency Test – did a point group stay stable?
- Single Point Diagnosis – is there a significant displacement of one point?
- Rigid Body Displacement – significant movement of point groups?

Requirements for Networks in Engineering Geodesy

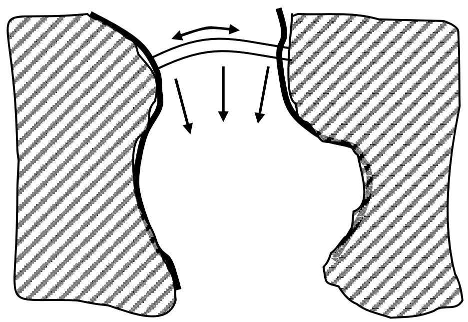
network planning – key task in deformation analyses

obtain information about:

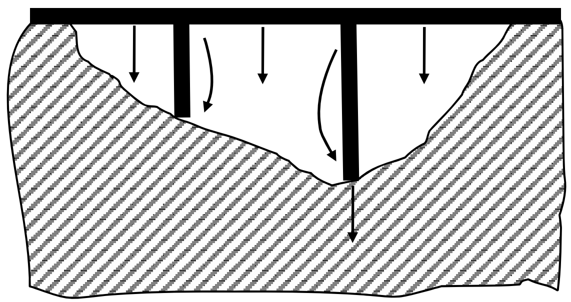
- position and geometry of the network stations – high sensitivity of network, high reliability, detection of movements with significance
- limits of the deformation zone

1. direction
2. magnitude
3. temporal characteristic

} of the expected movements – sensitivity along deformation



horizontal movements of a dam



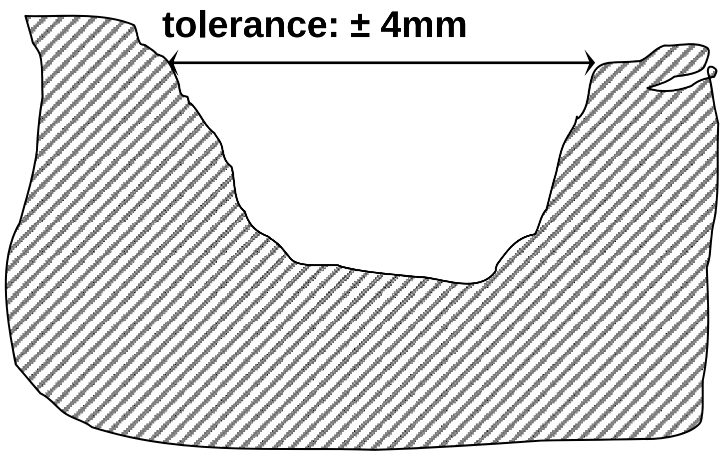
vertical movements of a bridge

Requirements for Networks in Engineering Geodesy

Specification from client: observe deformation across a valley

What is the required coordinate standard deviation?

- coordinates not directly observable



- The accuracy of the coordinate determination of one point is required better than 1 σ = **0.8 mm** !
- blunders and systematic errors not included!

- surveying tolerance $\neq$ standard deviation

  tolerance = 99%-confidence interval

  = 2.5 σ

  => 1 σ = **4 mm** / 2.5 = 1.6 mm

- Deformation means: coordinate differences....

  => 1 $\sigma_{\Delta t}$ = 1.6 mm

  => 1 σ_{ti} = 1.6 mm / $\sqrt{2}$ = 1.13 mm

  ... between 2 epochs

  => 1 $\sigma_{ti,\,\Delta(Y,X,H)}$ = 1.13 mm

  => 1 $\sigma_{ti,\,(Y,X,H)}$ = 1.13 mm / $\sqrt{2}$ = 0.8 mm

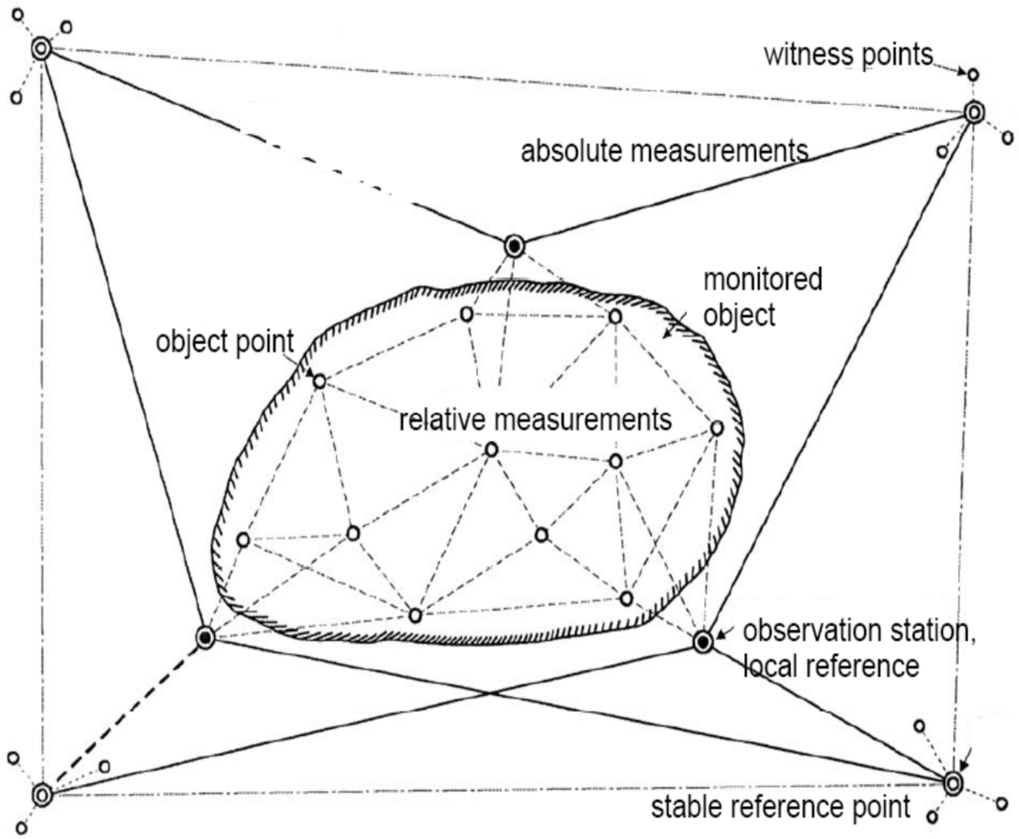
Networks for Deformation Monitoring

<u>Two main types of points in the network</u>

a) object points for detection of relative displacements

note: discretisation of the object by a suitable number of object points that represent the deformations well

b) statistically stable reference points for detection of absolute displacements



relative displacements – changes in the geometry of the object

absolute displacements – movements of the whole object

problematic: stability of the so-called "stable" points

In-Stability of Reference Points

<u>reasons</u> for movements of reference points:

- pressure changes of the subsoil: additional weight of buildings, less weight due to excavations
- dynamic pressure impacts due to traffic, in particular near bridges and transportation routes
- hydrological changes in the soil, oftentimes periodic (ground water table, moistness of the soil)
- impact of ground frost (some millimetre uplift while freezing, subsidence while defrost)
- above ground temperature changes to pillars and markers connected to a building

typical order of <u>magnitude</u>:

- long term horizontal pillar translation: 1 cm up to multiple cm
- short term horizontal pillar translation: 1 mm
- vertical movement of cohesive soil: 2...3 mm/year
- vertical movement of markers at buildings: 0.8 mm/year

Reactions of objects to outer forces

types of deformations:

geometric changes of monitored object

rigid body motion

- translation
- rotation

deformation

- bending
- torsion
- distortion

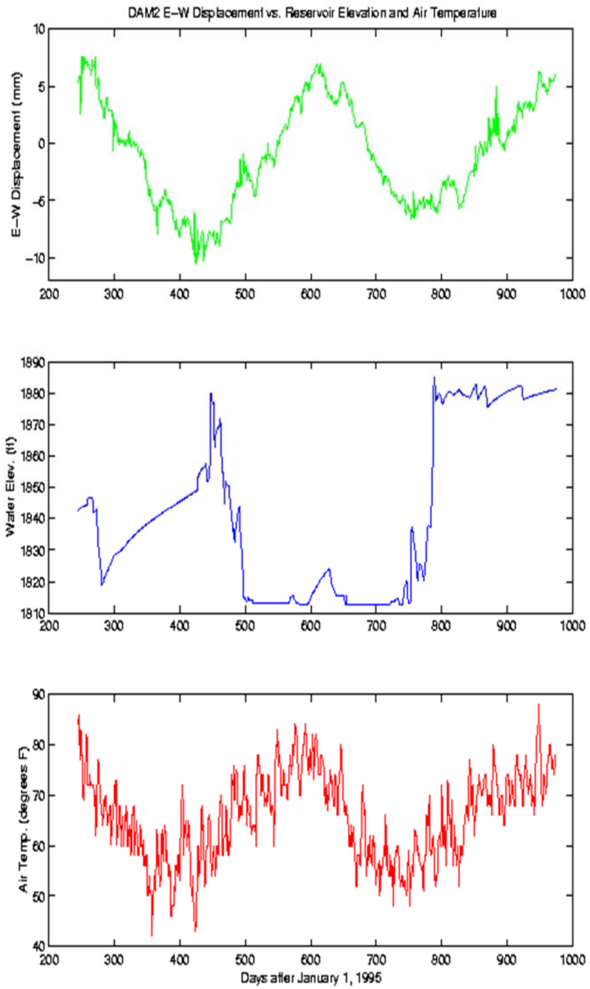
reasons for deformations:

important factor: temperature

natural: daily, yearly, sun & shade
man made: artificial heat sources in industry

important factor: water level

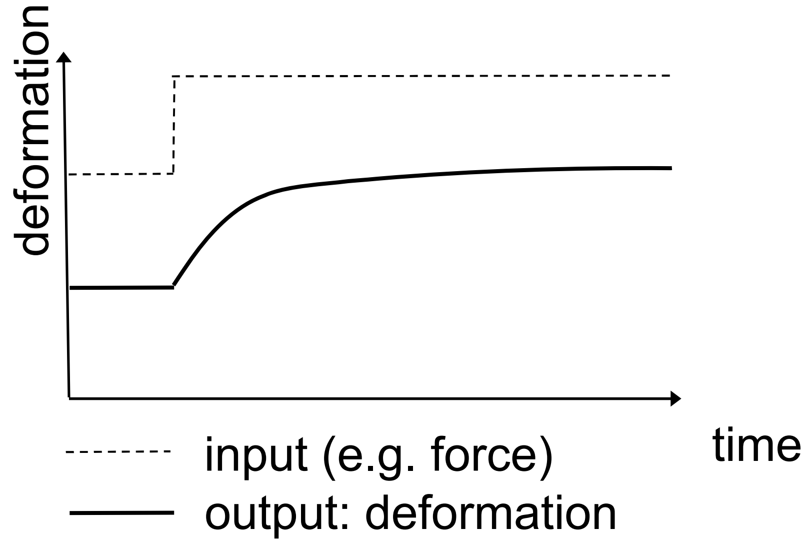
natural: daily, yearly, participation
man made: reservoirs, mining, excavation

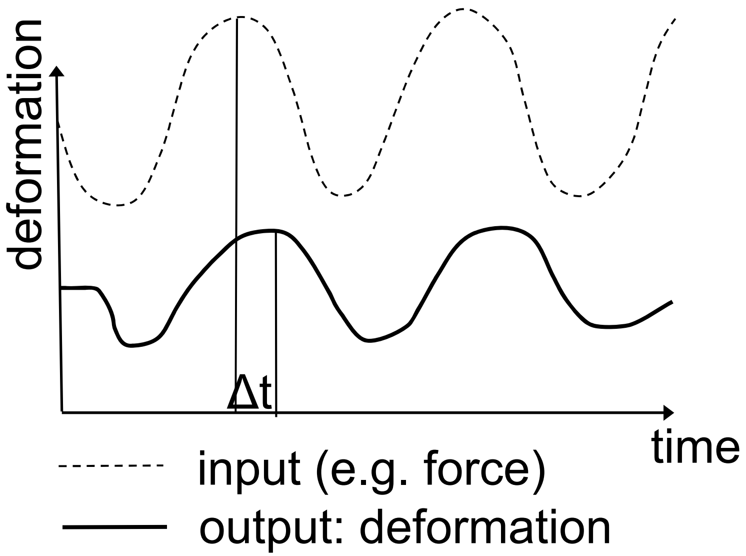


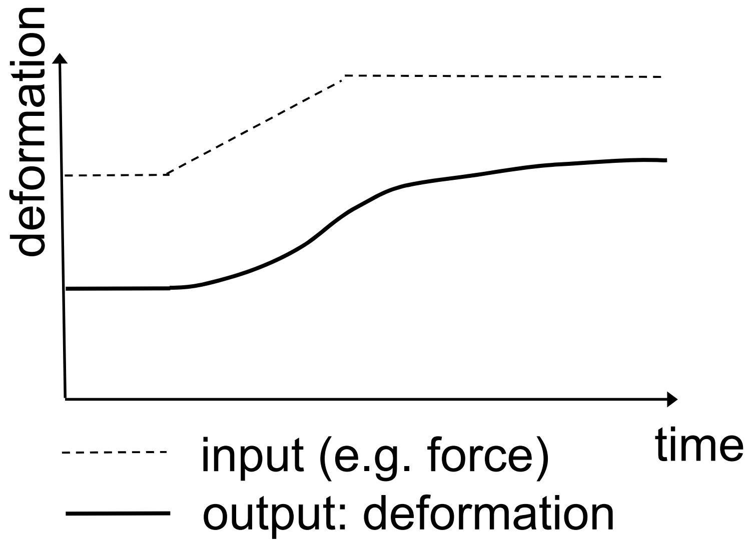
Reactions of objects to outer forces

<u>single input single output model (SISO)</u>

- different changes in the system input (sudden, gradual & periodic)
- different time delays of system reaction
- periodic events show a phase shift







Reactions of objects to outer forces

<u>displacements</u>

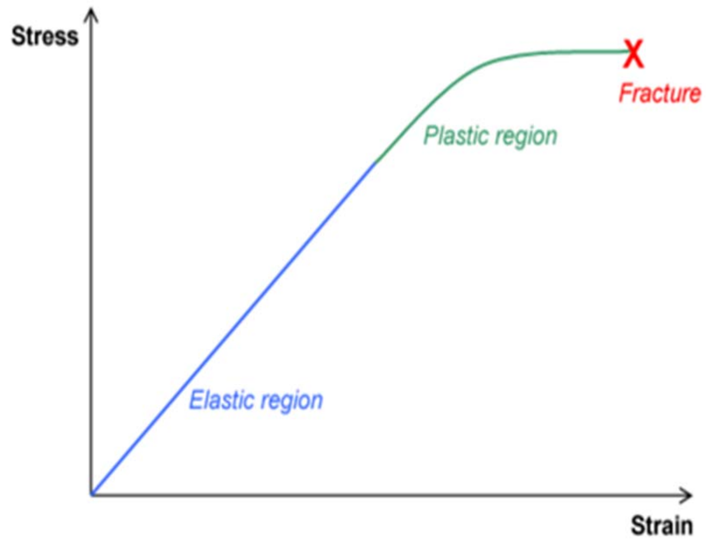
absolute = the whole object
↕
relative = part of the object

plastic and irreversible
↕
elastic and reversible

→ geometry domain

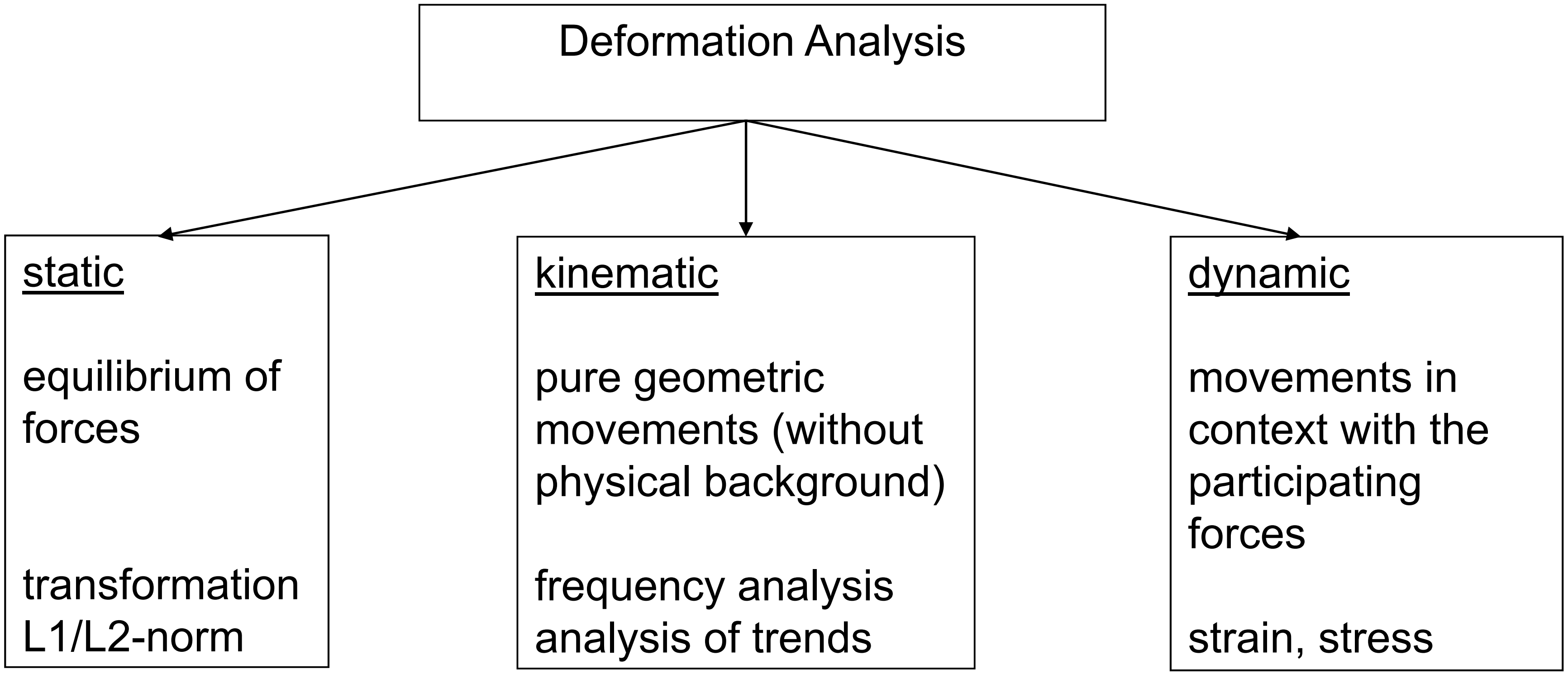
periodical (short or long periods)
↕
following a trend

→ time domain



from: Wikipedia

Tripartite Model in Deformation Analysis



Deformation Monitoring

natural & artificial load

point positions, geometric changes

a priory knowledge of object properties

geodetic measurements

dynamic model:

$G(x, \dot{x}, \ddot{x}) = 0$

displacement functions:

$dx = a_0 + a_1 x + a_2 y + a_3\, xy + a_4\, x^2 + \ldots$

$dy = b_0 + b_1 x + b_2 y + b_3\, xy + b_4\, x^2 + \ldots$

here: polynomials

coefficients: $a_0, b_0, a_1, b_2 \ldots$

adaptation of model-parameters

quantification of inner and outer forces, estimation of strain, refinement of deformation model

comparison of predicted and determined reaction

temporal discretisation

types of temporal discretisation

epochal, periodic
for
slow, predictable and innocuous reactions

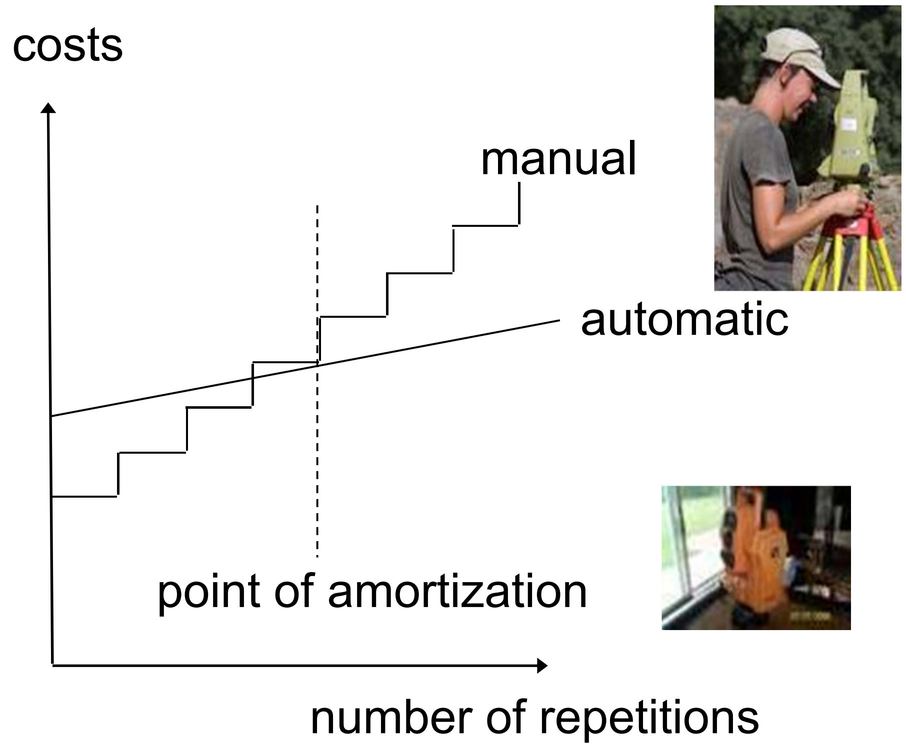
mostly manual

"continuous"
for
uncontrolled, sudden changes, vulnerable structures

mostly automatic

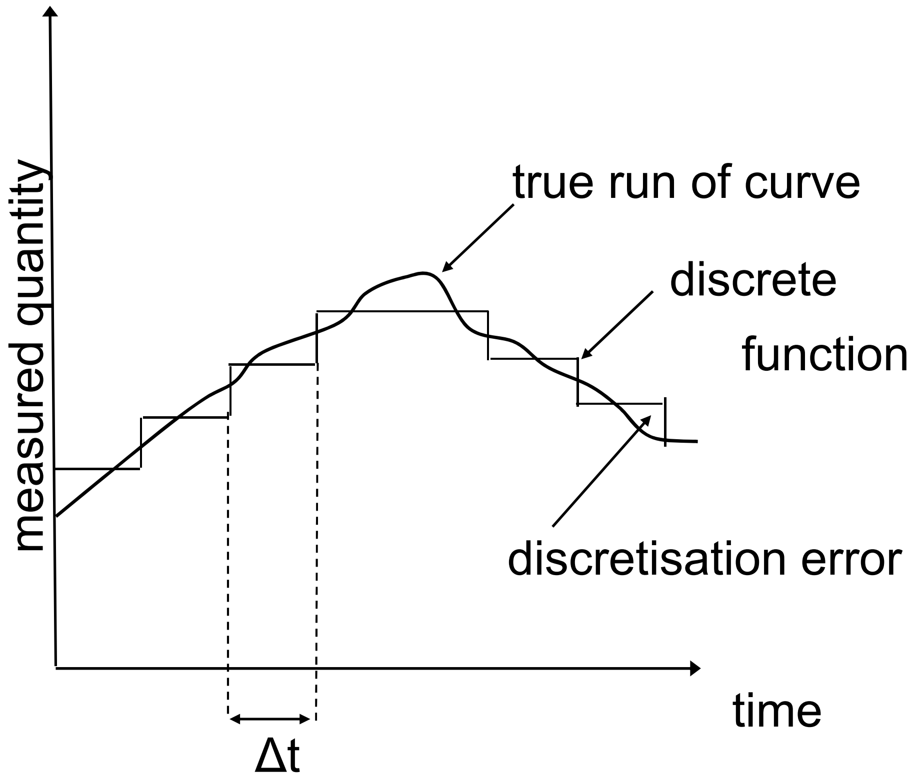
note: so-called "continuous" measurements refer to automatic measurements with small time intervals

automatic or manual observation strategy?

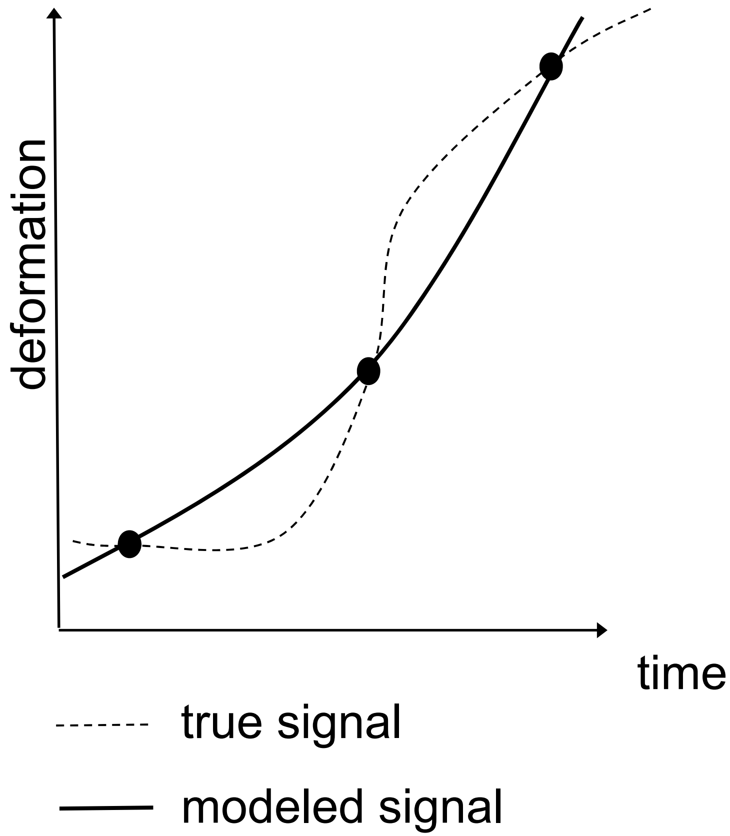


“Continuous” Deformation Monitoring

temporal discretisation



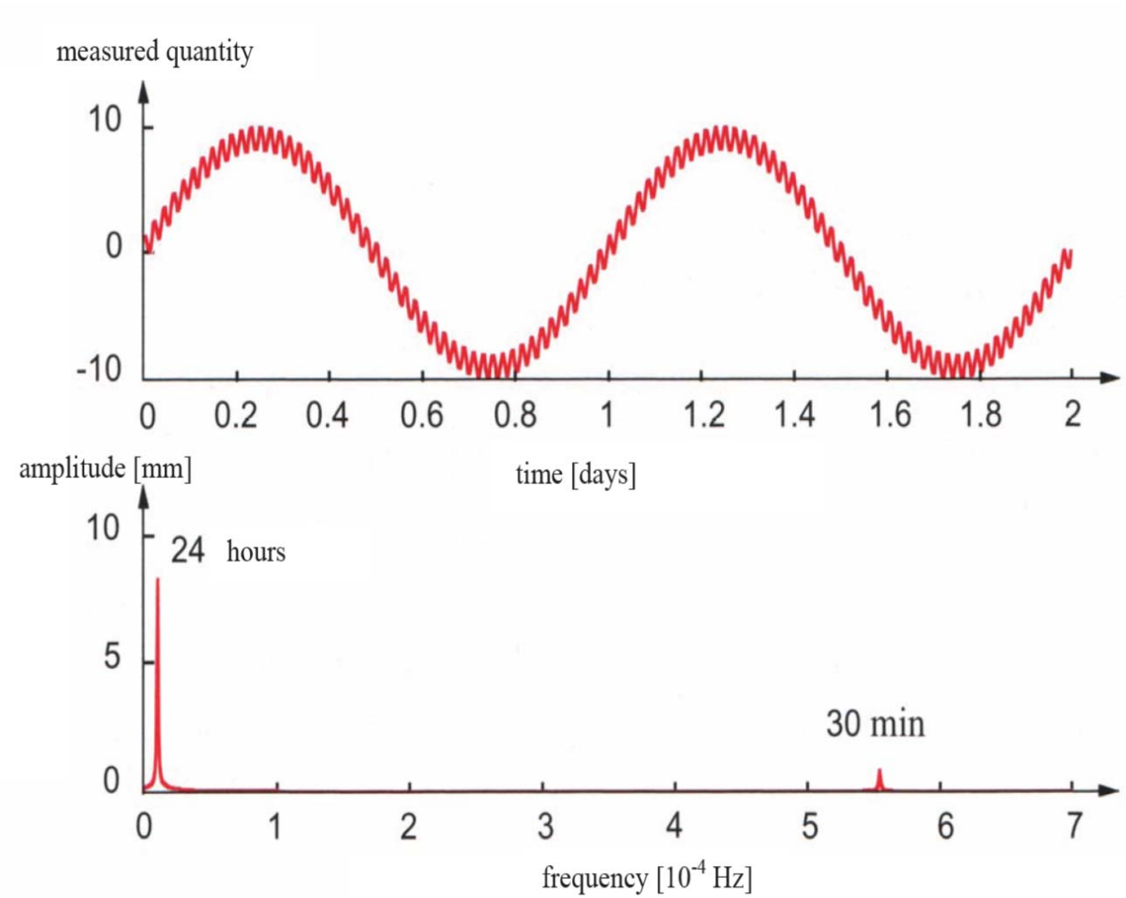
misinterpretation due to disretization



<u>note:</u> some analysis algorithms require equidistant time-intervals, e.g. Fourier analysis

<u>note:</u> data gaps are the normal case (sensor failure, constraints don't allow to collect continuous data)

Own PhD thesis: "*On the Determination of Frequencies in Time Series*", Solving Nonlinear Adjustment Problems

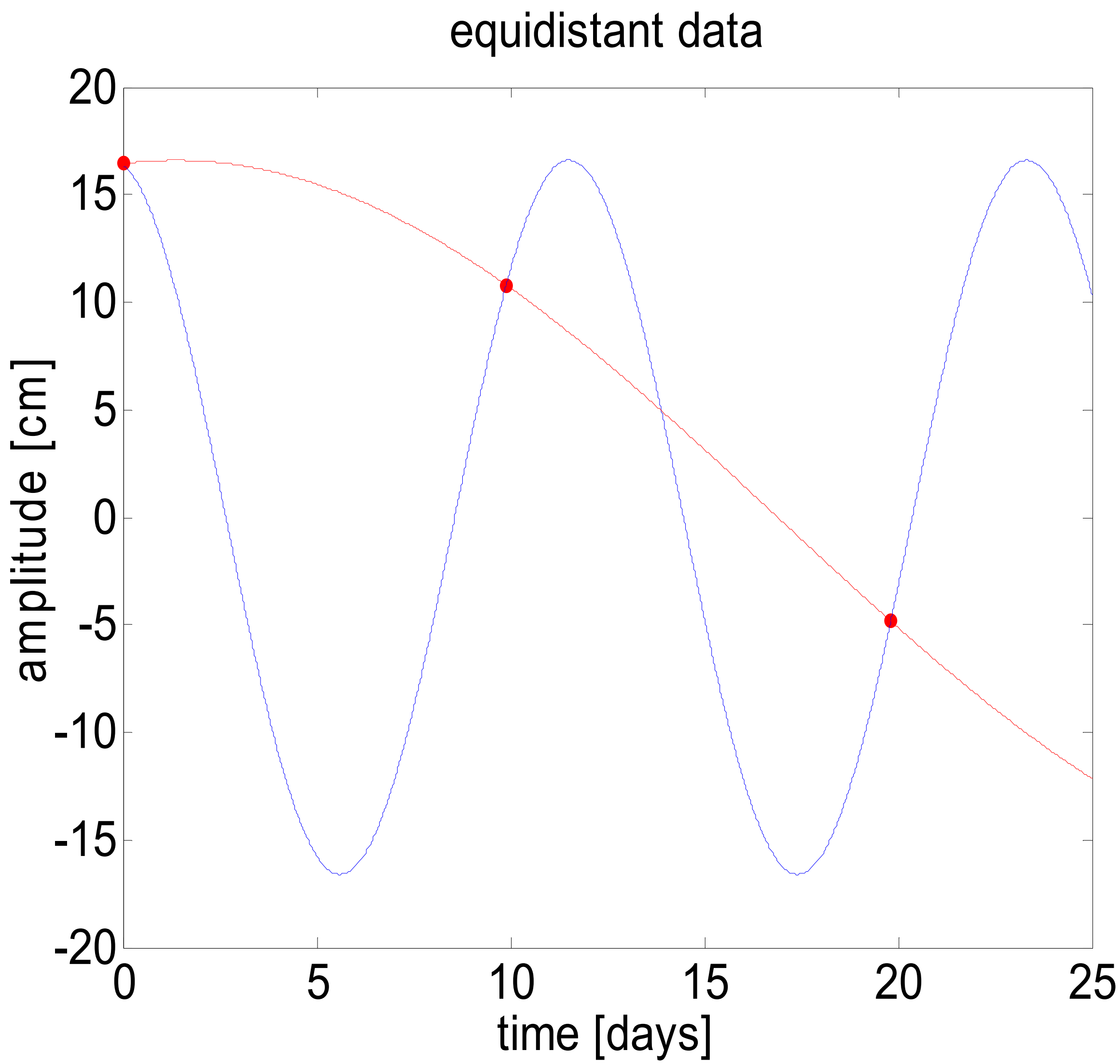


from: Möser, Ingenieurgeodäsie

Aliasing Effect

The red plot has a
62 day period,

the blue plot has a
frequency of 0.0847
cycles per day
(= **12 day period**)

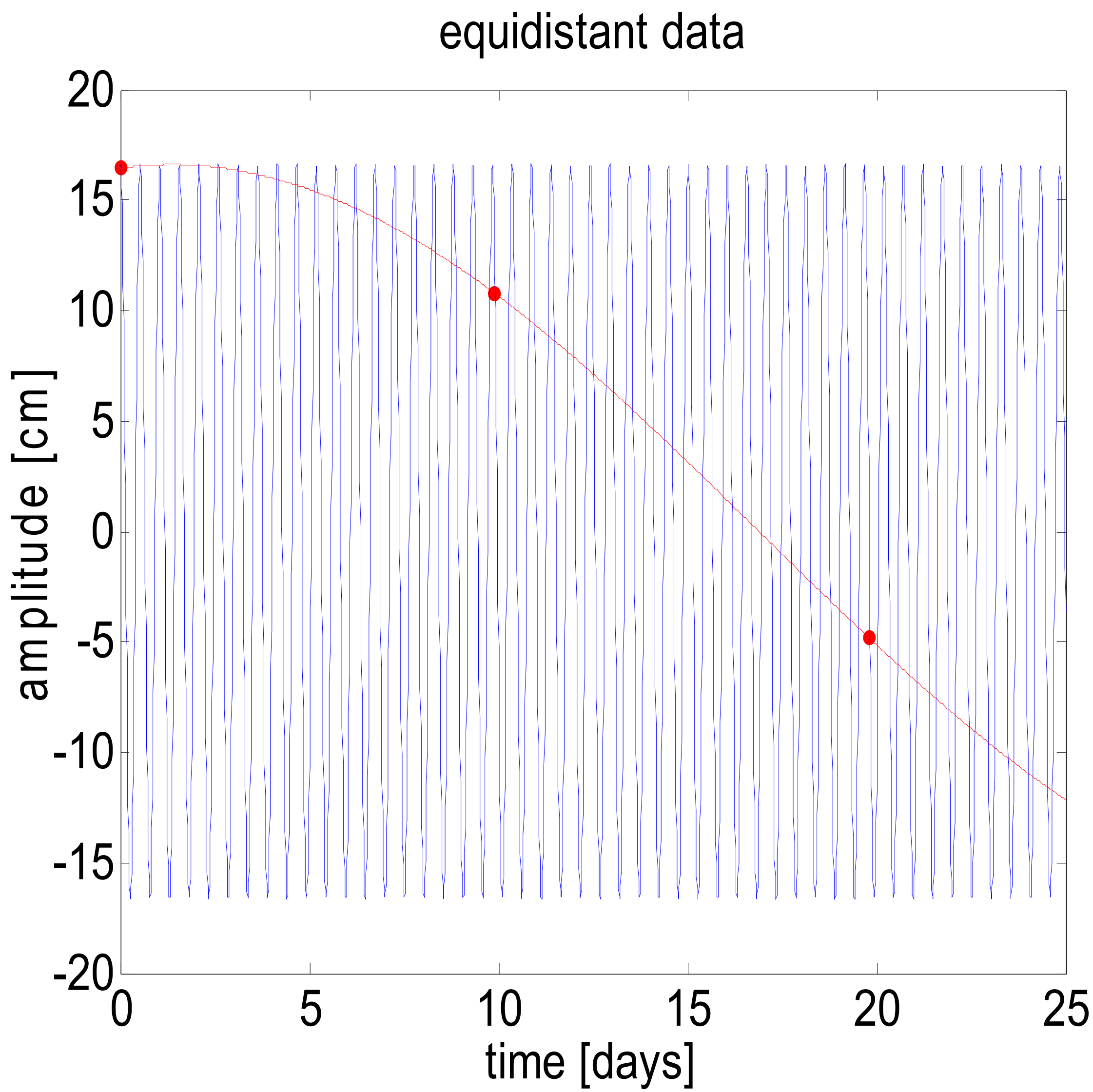


Aliasing Effect

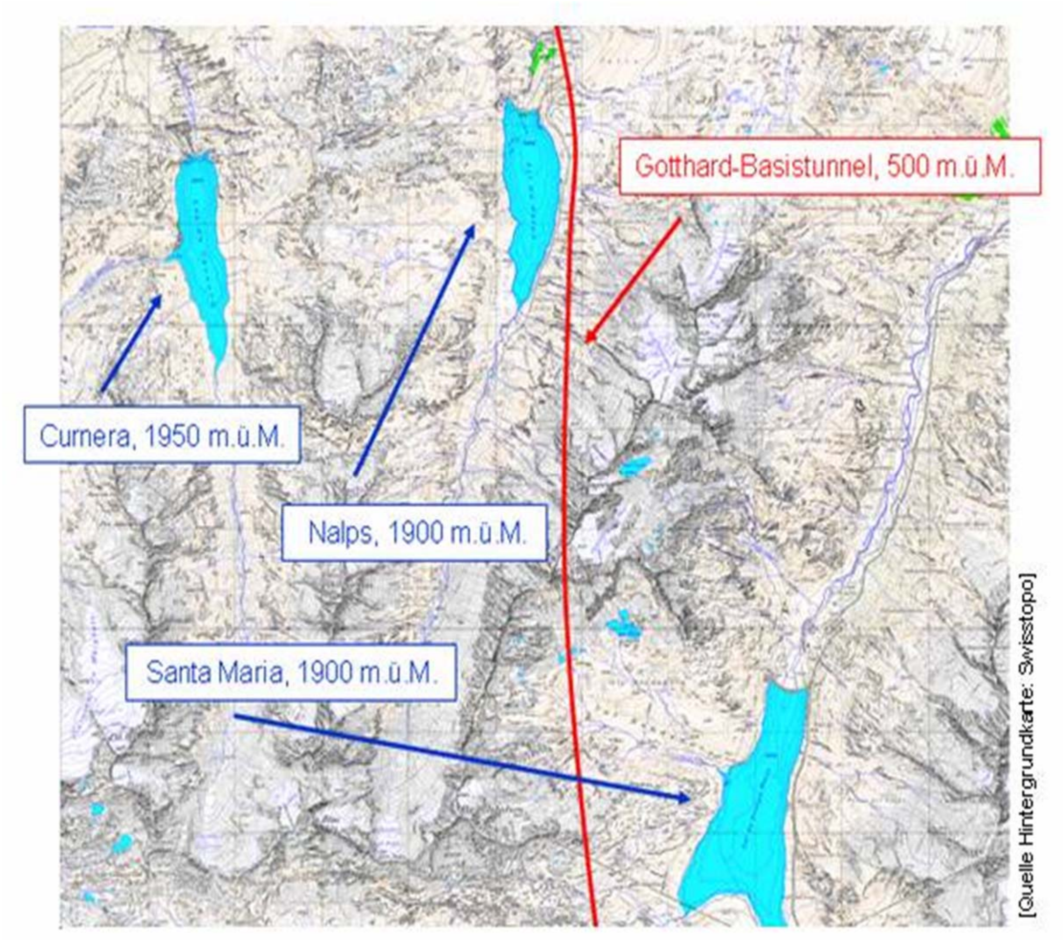
The red plot has a 62 day period,

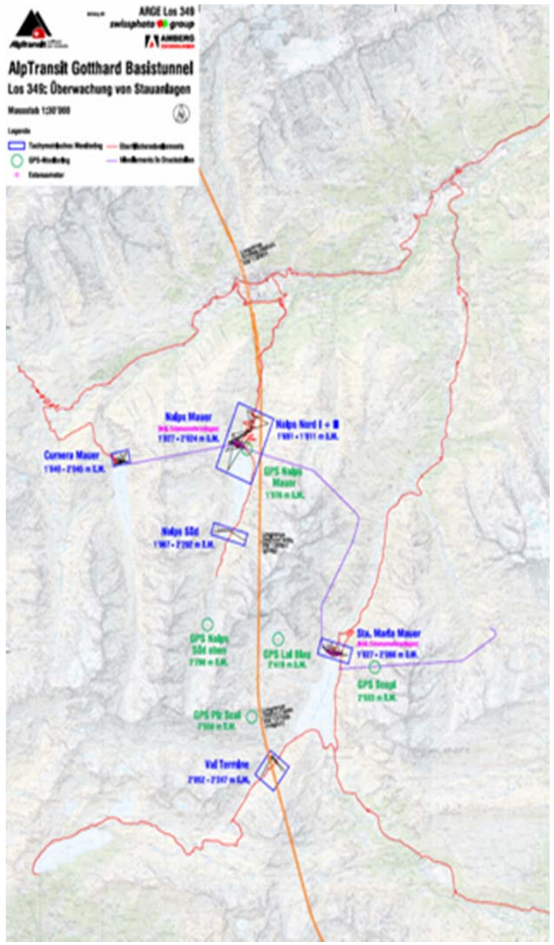
the blue plot has a frequency of 1.93 cycles per day or a **0.52 day period.**

That's the true frequency.

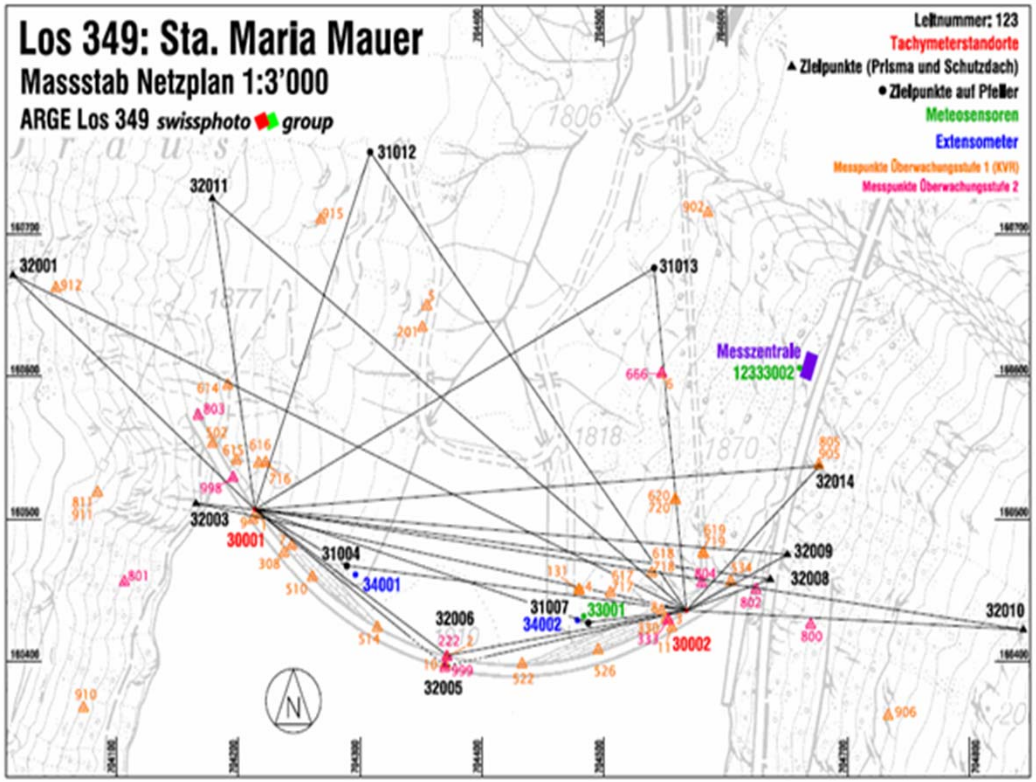


Drilling of NEAT Tunnels: possible seduction due to falling ground water level



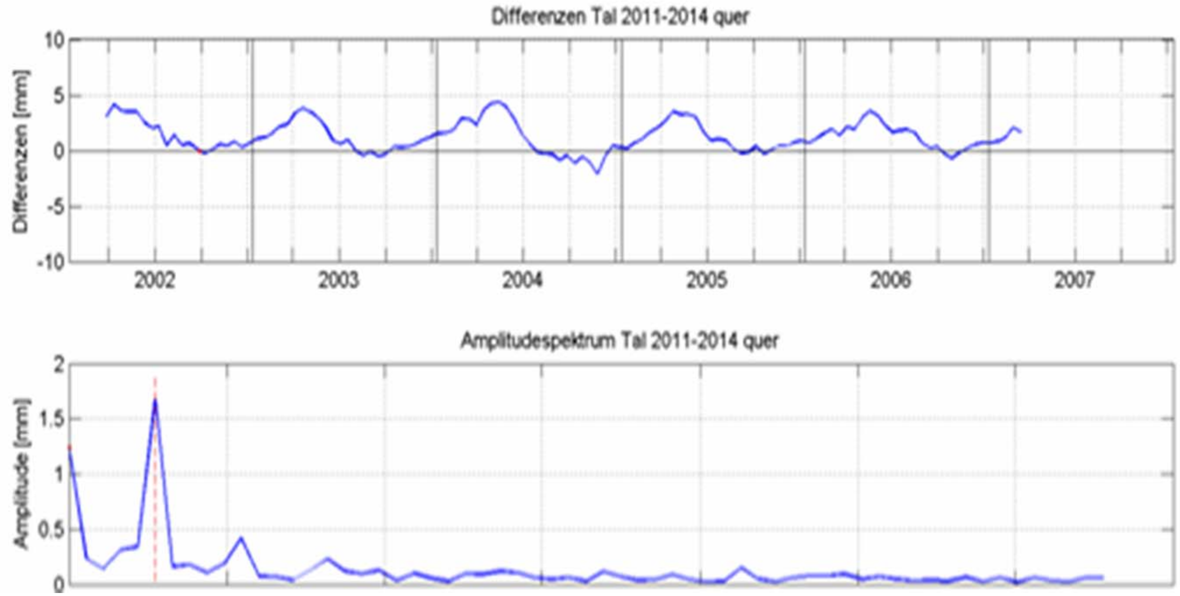


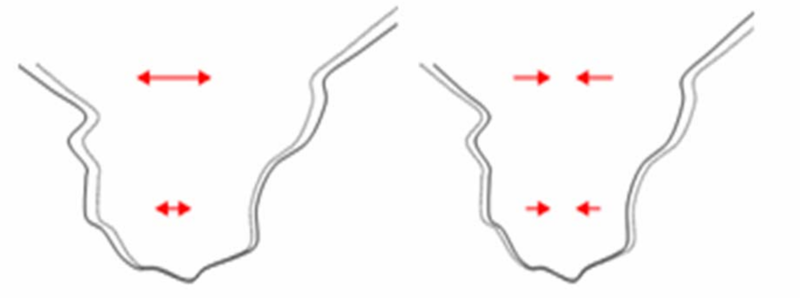
[Diploma Thesis Silvia Rossinelli 2007]



[Quelle: Swissphoto AG]

Automatic Deformation Monitoring





- PANDA: **P**rogram for the **A**djustment of geodetic **N**etworks and **D**eformation **A**nalysis. Hannover, for adjustments, deformation analyses of 1D, 2D und 3D nets within ordnance and engineering geodesy
- CAPLAN + NETZ2X: (**C**remer **A**uswertung und **Plan**erstellung) also for adjustment of geodetic networks. NETZ2X in particular for deformation analysis. München, Cremer Programmentwicklung GmbH
- NEPTAN und DEFAN (Technet GmbH) Berlin, also Adjustments and **Def**ormation **An**alyis
- LTOP – swisstopo, official Swiss governmental adjustment software