Monitoring & Data Management in the Project "Cityringen Copenhagen"

ANGERMEIER INGENIEURE GmbH

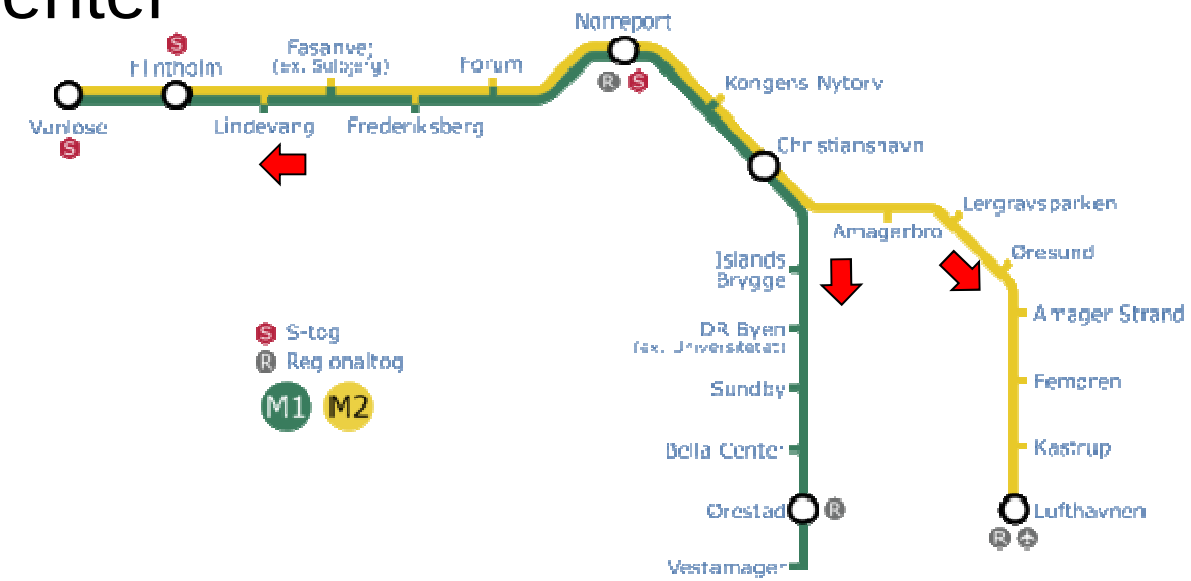
Dieter Heinz

- Metro Copenhagen,
  - History of the Metro
  - Cityringen – what does it mean?
  - Scope of project
  - Specials in realization

- Scope of our project activities
  - Geodetic and geotechnical measurement tasks
  - Data management
  - Visualization and data management in a project-specific GIS-Database

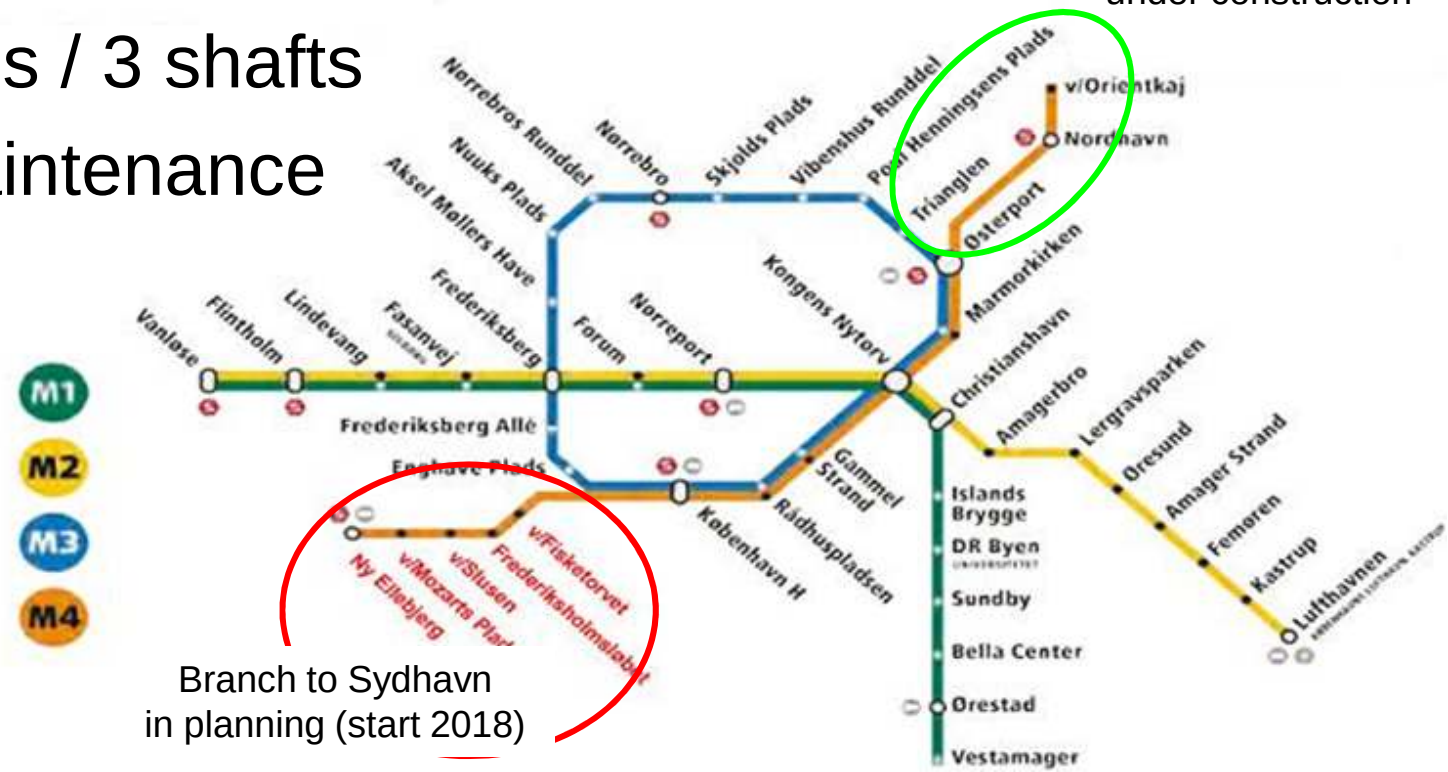
Metro Copenhagen

- Existing Metro lines M1 und M2
- Operating since 2002
- 22 stations thereof 9 underground
- Length 21 km
- 1 maintenance center



Graphic: Metroselskabet I/S

- New lines M3 & M4, complete below ground
- Under construction since 2011 - opening 2019
- Length ≈15,5km with 2 tubes
- 17 stations / 3 shafts
- 1 new maintenance center



Graphic: Metroselskabet I/S

All Metro lines in an aerial view

Metro Lines

M1

M2

M3

M4

Branch to

CMC

Connection to

DSB

S-Tog

Metro

Photo: Metroselskabet I/S

Specifications of the Metro

- One of the most modern Metro systems
- Driverless transportation
- Frequency 100 seconds
- 24h per day in operation
- Transportation of total 130.000.000 people/year (=365 000/day)

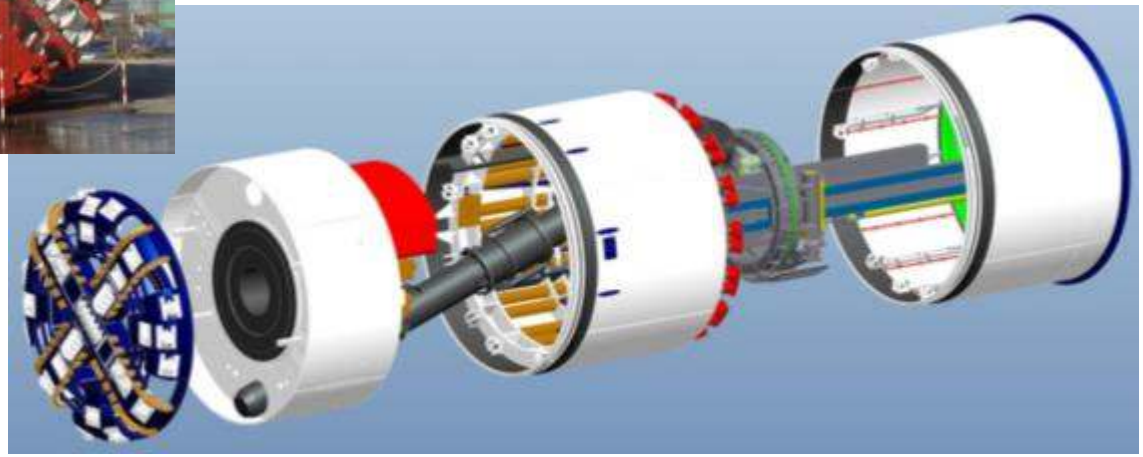
- New: Connection to central railway main station and 2x „S-Tog“ train stations (Nørrebro / Østerport)
- The both Metro’s there are a fast, safe and environmentally friendly transportation established

Photo: SMT Denmark ApS

CMT COPENHAGEN METRO TEAM

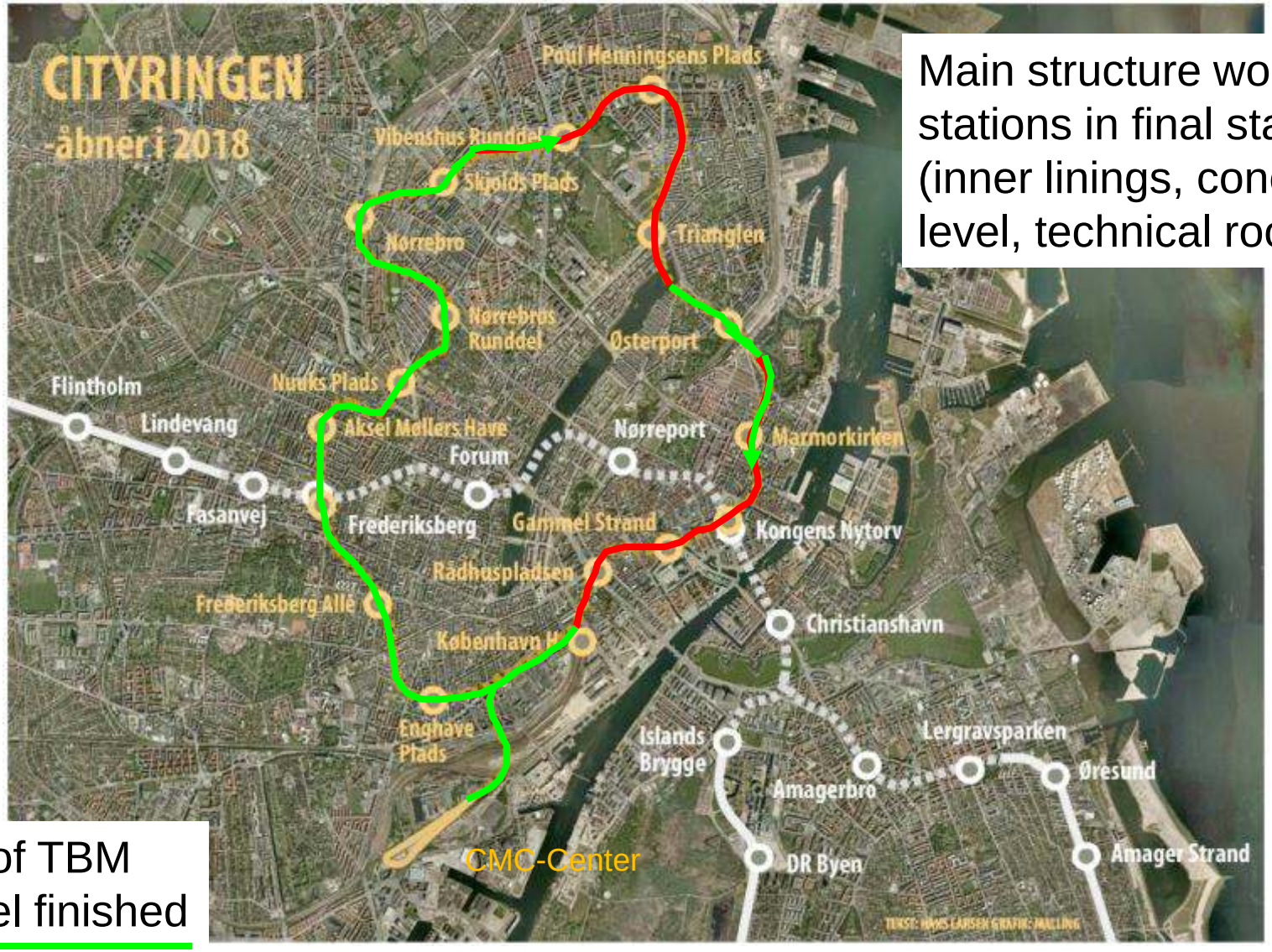
- Italian joint venture
  - Salini / Impregilo (leader)
  - Tecnimont
  - Seli
- Launching of research 2009/2010
- CMT starts construction in Nørrebroparken in 2011
- Start of the first measurements in October 2011
- Structural works until Spring 2017
- Professional Operation starts in Summer 2019
- Construction costs about ca. 21.3 Mrd DKK (= 2.8 Mrd EUR)

- Start of TBM works in 2013, end in 2017
- Operating simultaneously up to 4 TBM’s
- Type EPB-shields (Earth Pressure Balance)



Photos: Seli

Overview construction progress TBM‘s

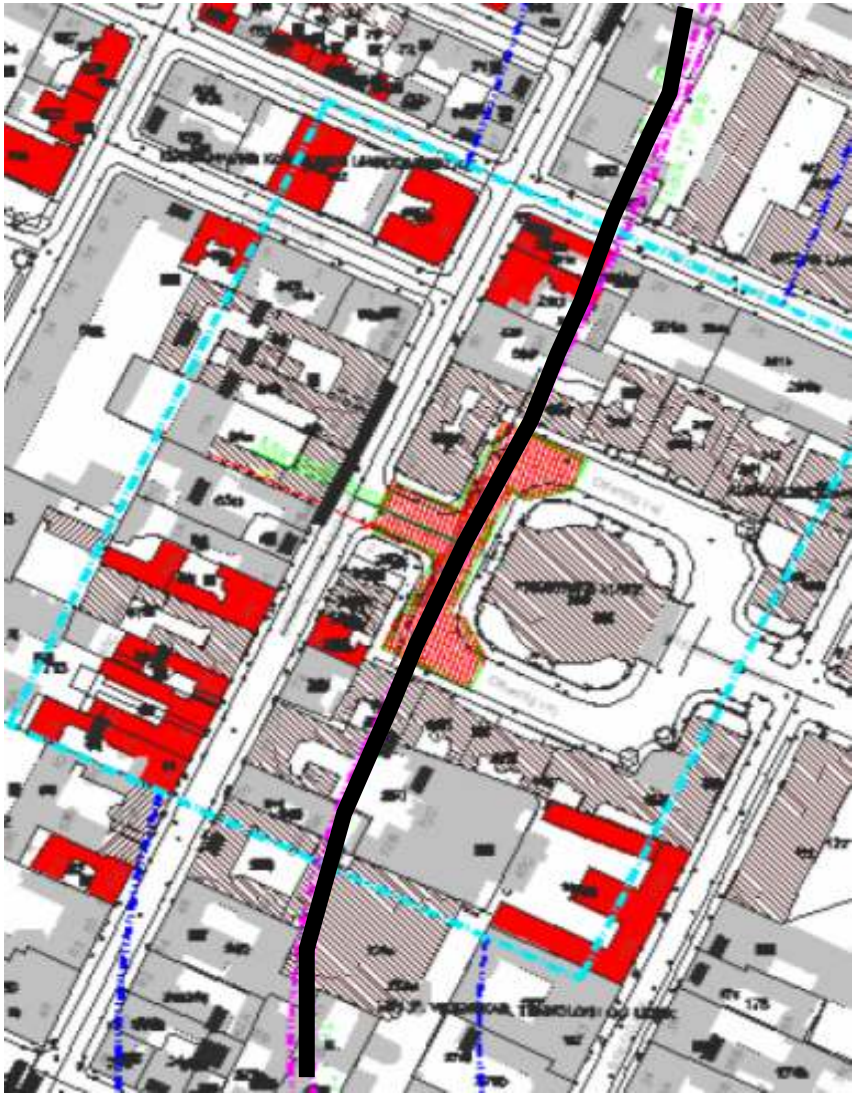


Main structure works at stations in final stage (inner linings, concourse level, technical rooms)

69% of TBM Tunnel finished

Photo: Metroselskabet I/S

- Construction in surrounding properties hides always great risks, especially in such dimensions
- Very old buildings, many „listed buildings“
- Foundation of old buildings on oak piles,
- High groundwater level

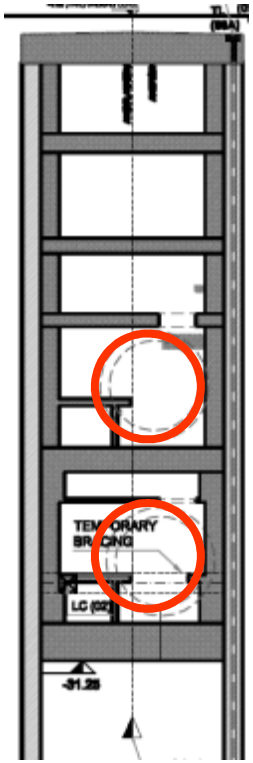


Frederiks church (Marmorkirke) I

- Station is located very close to a church
- Foundation of the church and the adjacent old buildings on countless oak posts
- Height 45m
- Diameter of Dome 31m
- Construction time
  1740 – 1894
  for many decades a ruin

Photo: SMT Denmark ApS

- Tunnel tubes over each other



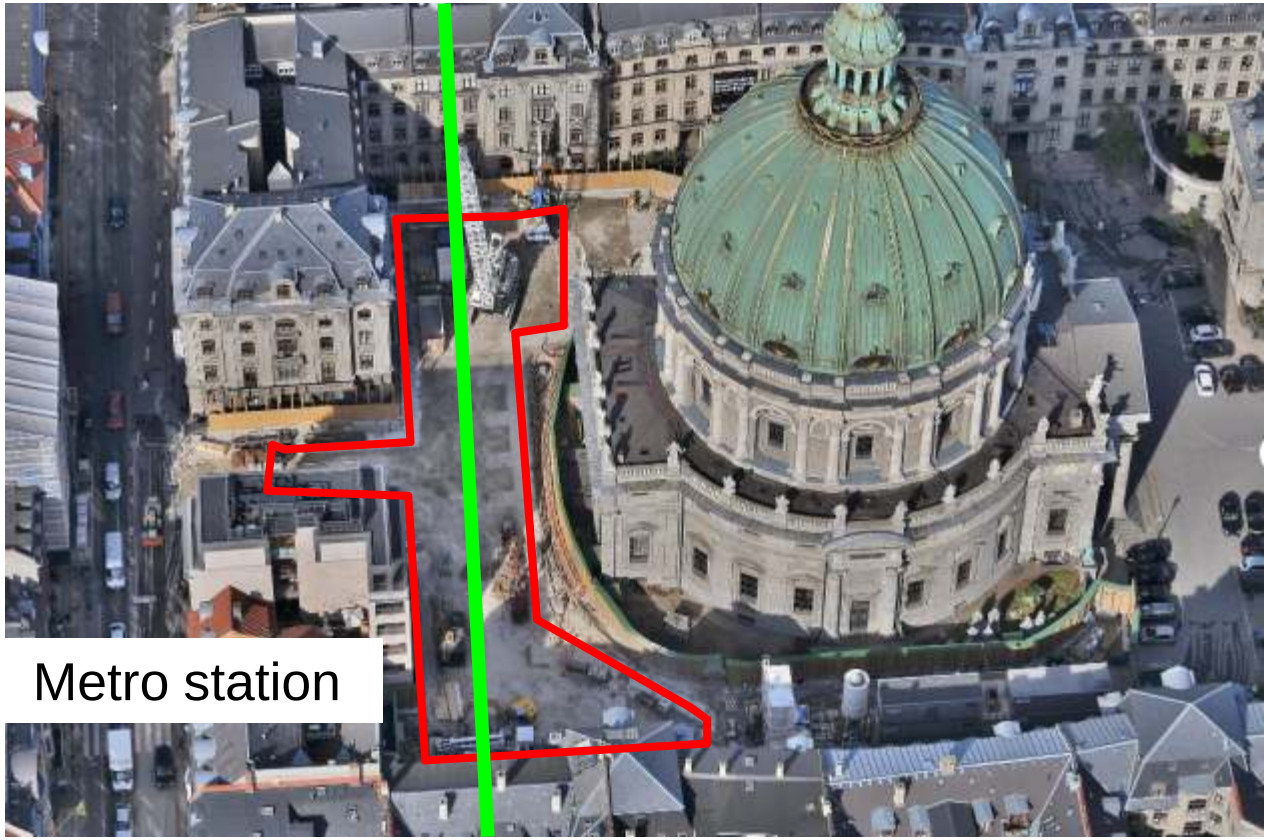


Photo: Dragør Luftphoto
Drawing: Copenhagen Metro Team I/S

- Half of station below a small channel

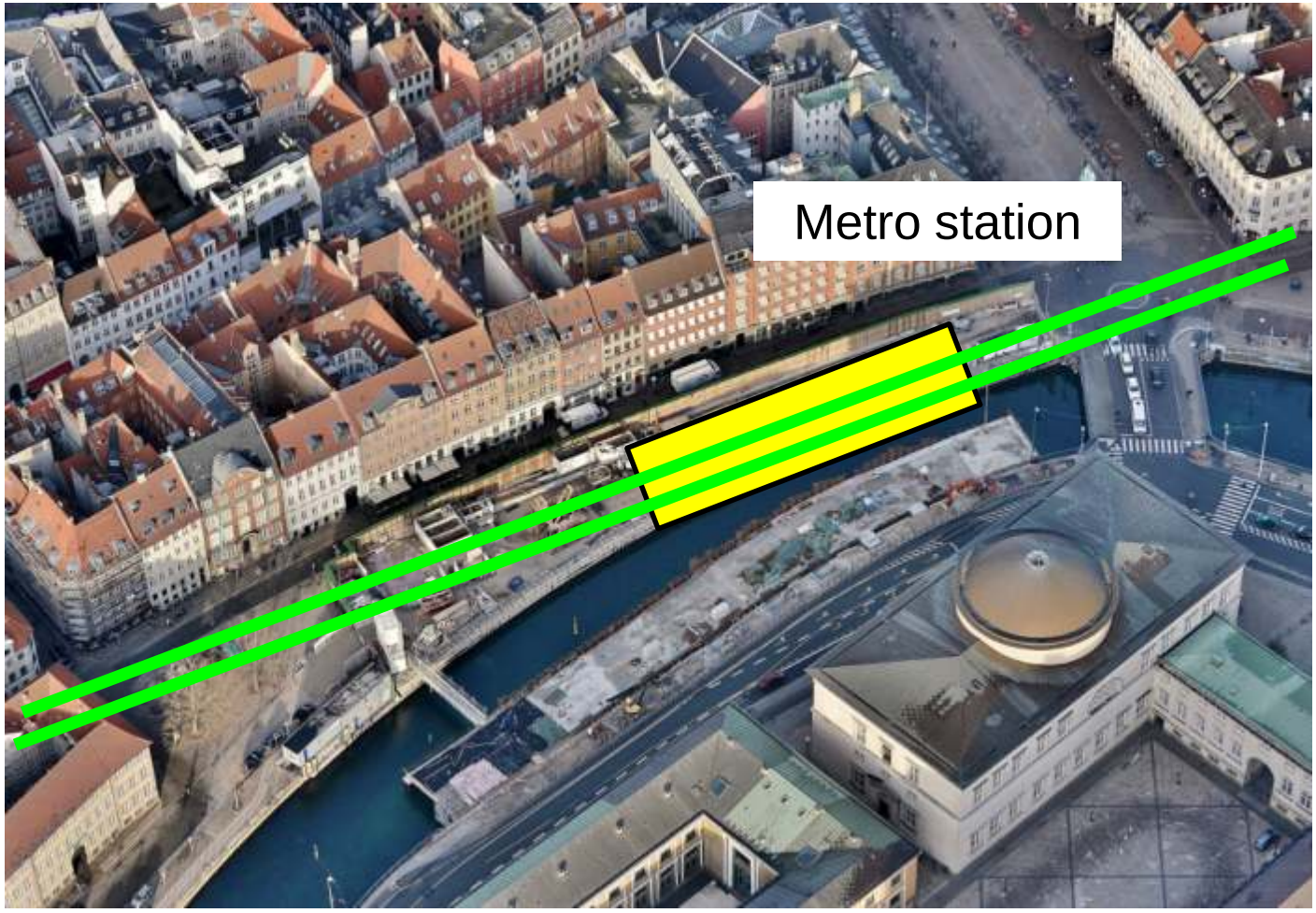


Photo: Metroselskabet I/S

- Joint Venture
  - GEODATA Ziviltechnikergesellschaft mbH (Austria)

  - ANGERMEIER INGENIEURE GmbH (Germany)

  ➔ SMT Denmark ApS

SMT Denmark ApS
Survey & Monitoring Team

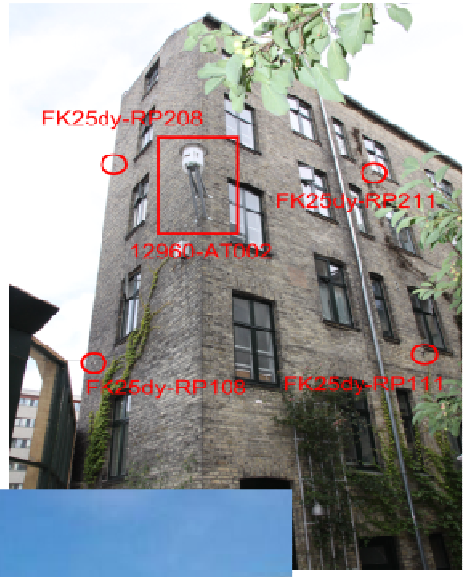
- tasks and responsiblitities:
  - geodetic monitoring
    - High precision levelling measurements
    - Automatic 3D-Monitoring (installation, maintenance)
    - Manual 3D measurements
  - geotechnical monitoring
    - Manual inclinometer measurements
    - Automatic inclinometer (installation, maintenance)
    - Strain Gauges (installation, maintenance)
    - Automatic extensometer (installation, maintenance)
    - Manual extensometer measurements
    - Liquid levelling systems (installation, maintenance)
  - Maintenance of database (KRONOS)

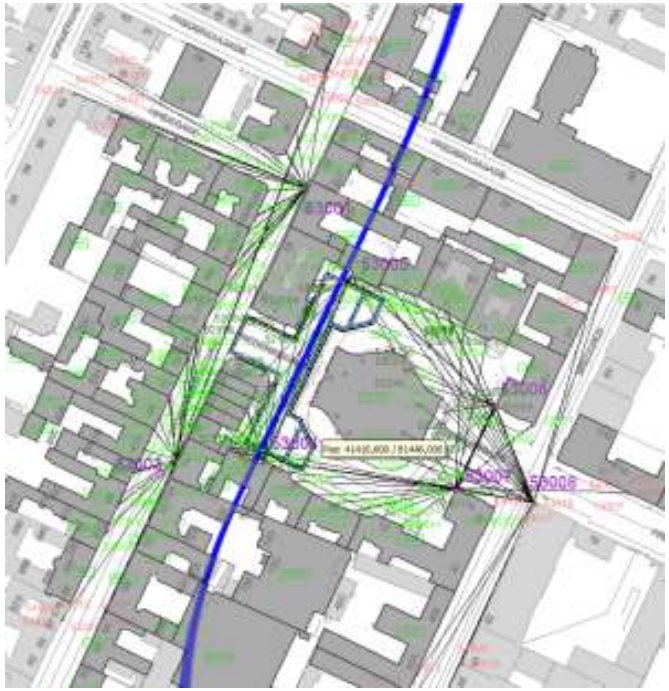
- High precision Levelling

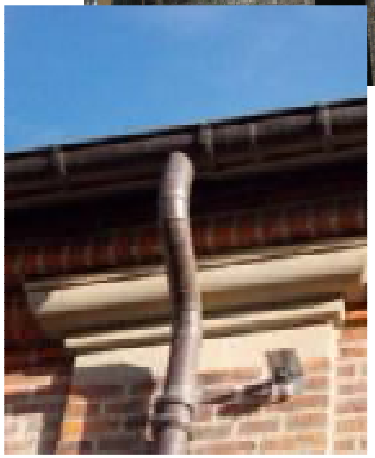
- 4.000 leveling bolts
- 835.000 measurements
- 5-8 crews in parallel

Photos: SMT Denmark ApS

- Automated 3D-Monitoring Systems
  - 100x Leica TM30 0,5“
  - 79.600.000 measurements







- 3D Net of 4 connected ATS and 3 additional independent working ATS in backyards at SKP

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Result:
3D –
Displacement
Scale 1:1

- Inclinometer
  - 158 inplace inclinometer chains
  - 3 probes for manual readings



- Extensometer measurements
  - 30 boreholes equipped with up to 5-fold sensors

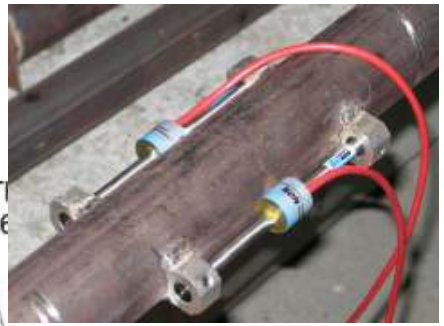
- Groundwater measurements
  - 225 boreholes with open standpipe water level transmitter

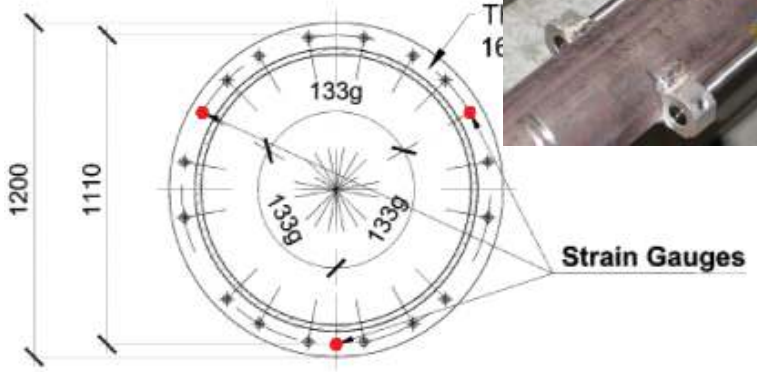
Photos: Geodata Messtechnik GmbH

- strain gauges

  1850 sensors installed to monitor temporary struts in stations

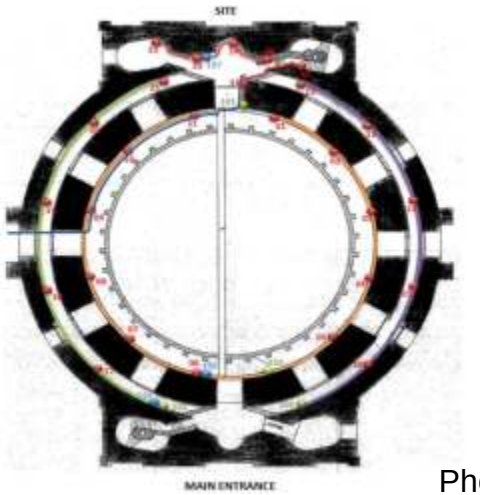
- readings every 4 hours





- liquid leveling systems

  28 sensors installed to monitor Marmorkirke



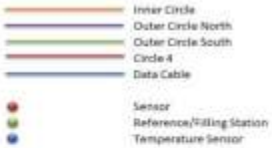


Photo: Geodata Messtechnik GmbH
Photo: SMT Denmark ApS
Drawing: Cophagen Metro Team I/S

- Requirements of the Client (abstract)

  - Results of all monitoring measurements
  - Thresholds with automatic alarming
  - Geotechnical and hydrogeological data
  - Groundwater control systems
  - Tunnel alignment, station data
  - Construction progress (piling, d-walls)
  - TBM-parameter
  - Building information
  - …

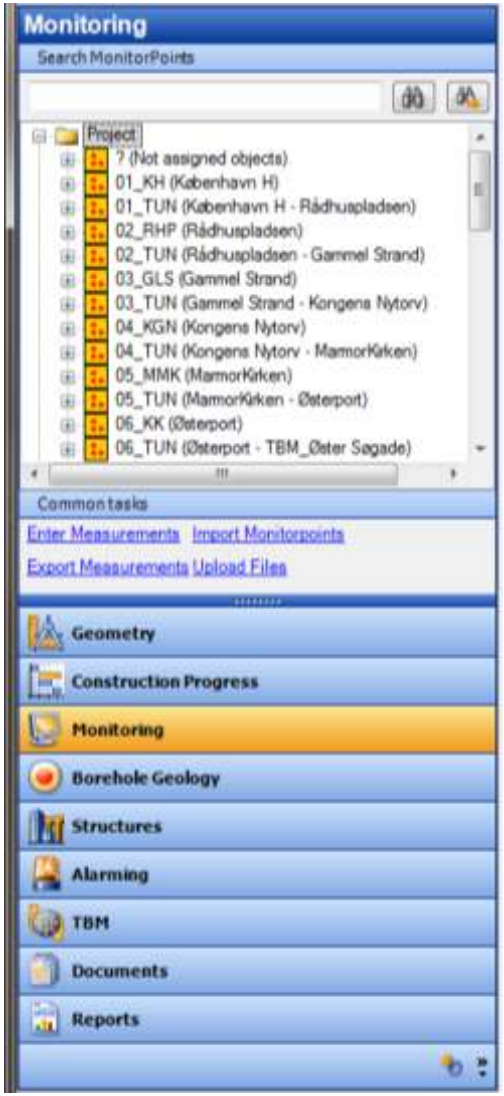
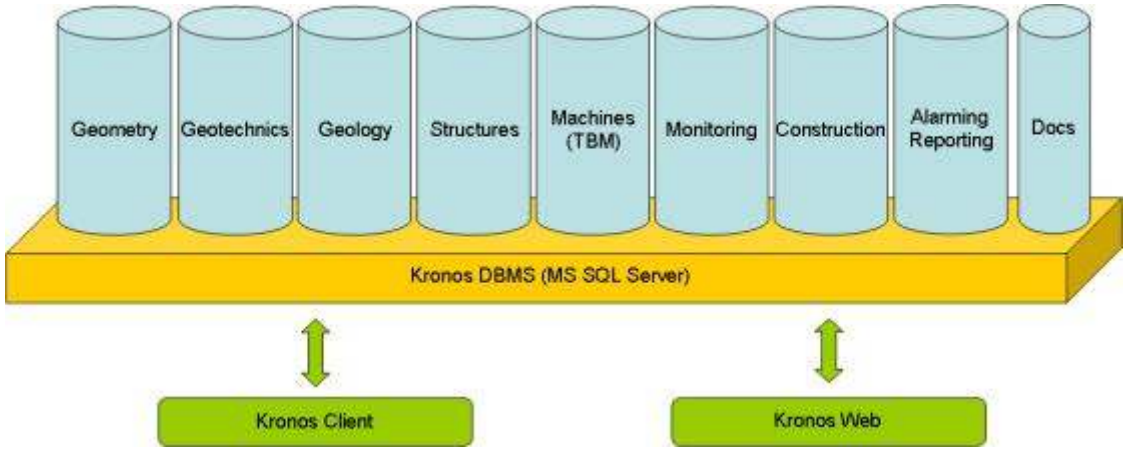


Photo: SMT Denmark ApS

- KRONOS Database



- Access to Database by various disciplines of the project
  - Automatic input data from sensors / TBM
  - Input (monitoring, groundwater, environmental departments)
  - Read / evaluate / checking (client, consultant, designer)

- For the monitoring data from critical areas and for the TBM data the KRONOS alarming functions and services are used.
- They allow for the configuration of a comprehensive alarm plan comprising alarm rules, alarm levels and alarm notification targets.

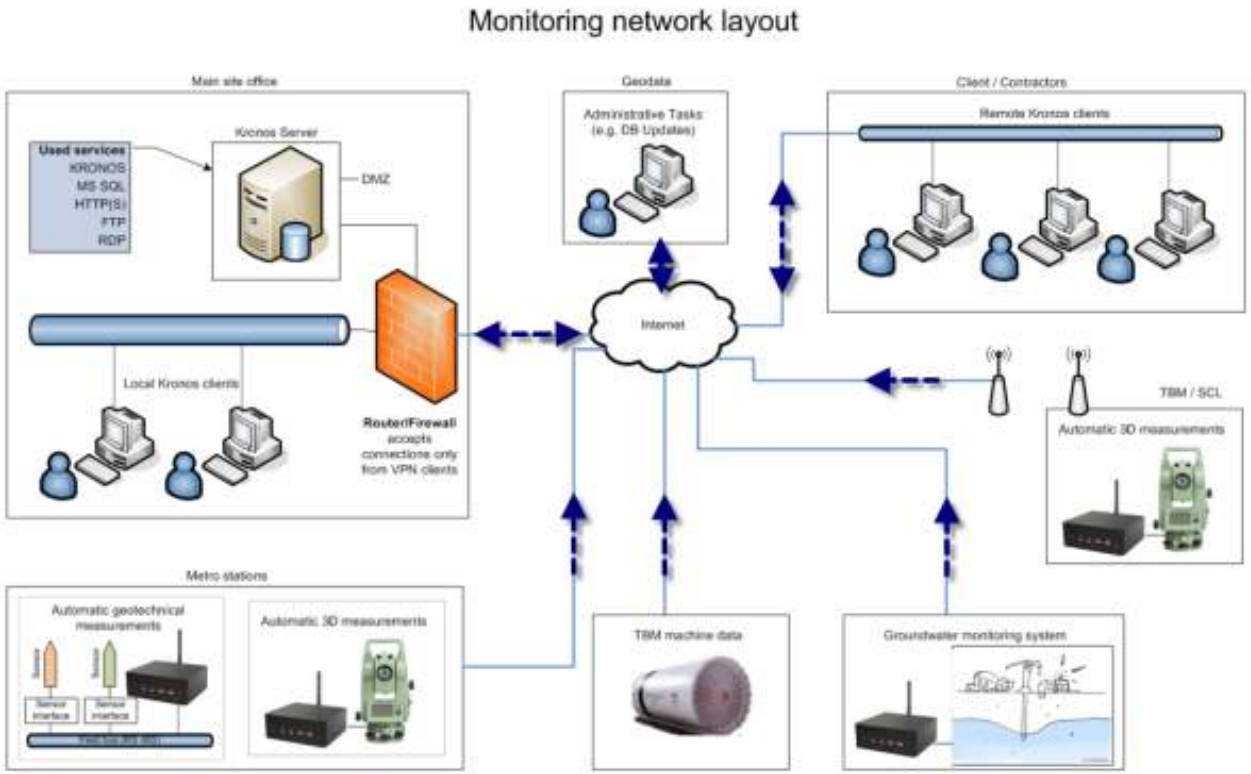
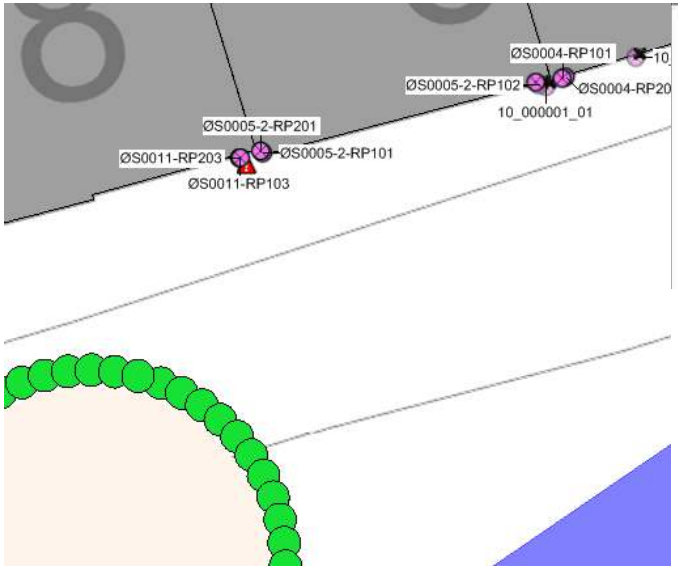
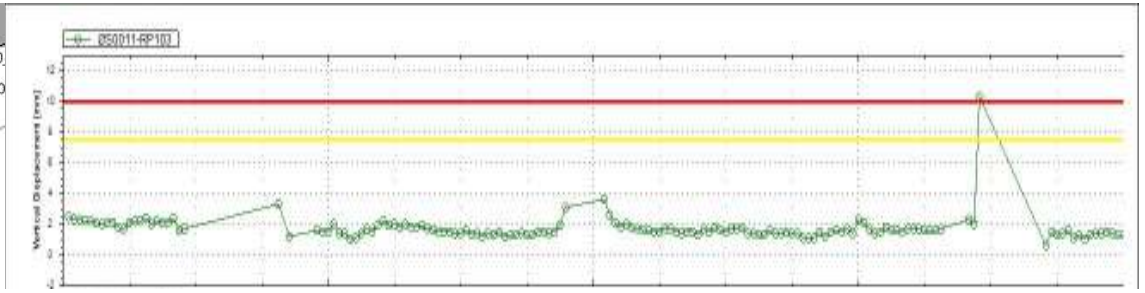


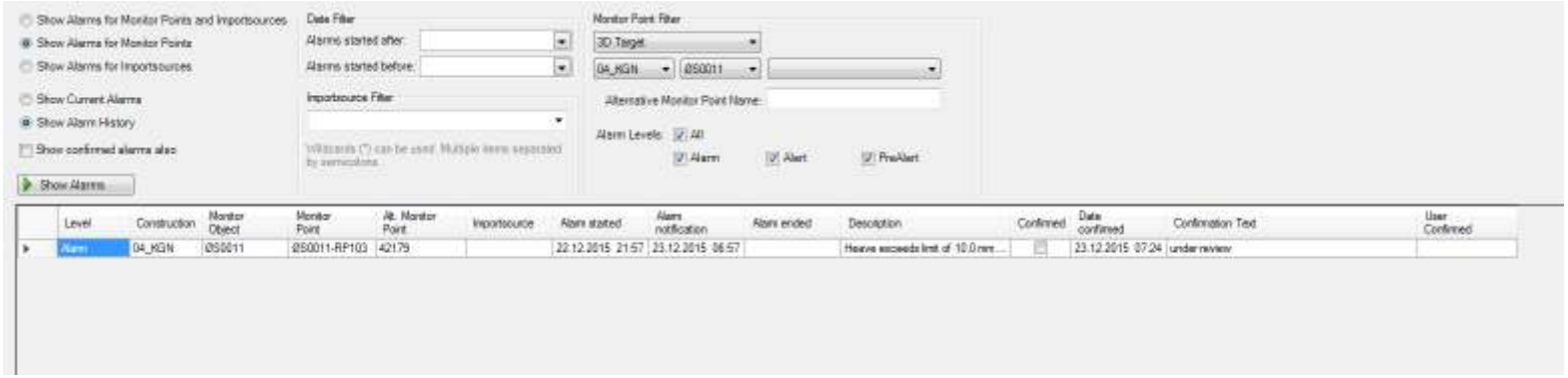
Photo: Geodata Ziviltechniker GmbH

- Alarm workflow shown as an example of a 3D point



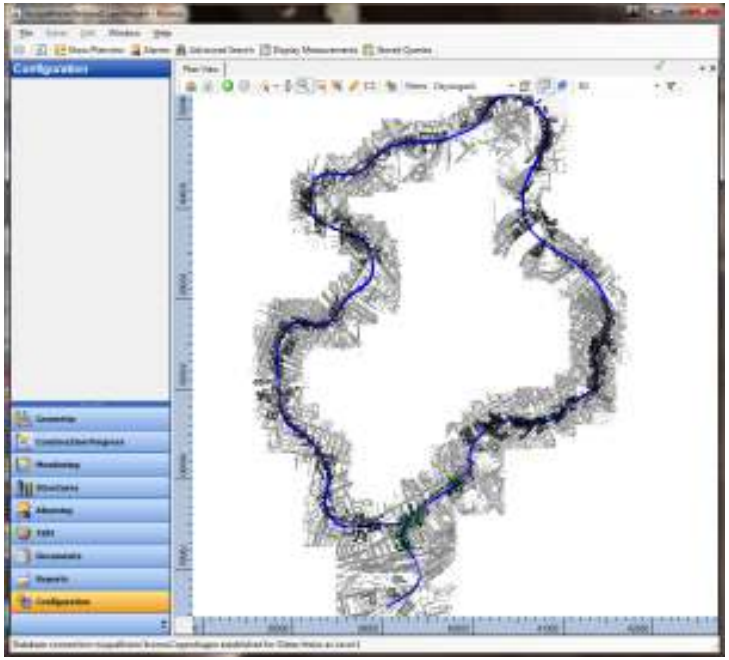


Measurement exeeds limit value → Alarm → message to relevant user → red or yellow triangle in planview. For deactivation: alarm has to be confirmed in Kronos alarm report

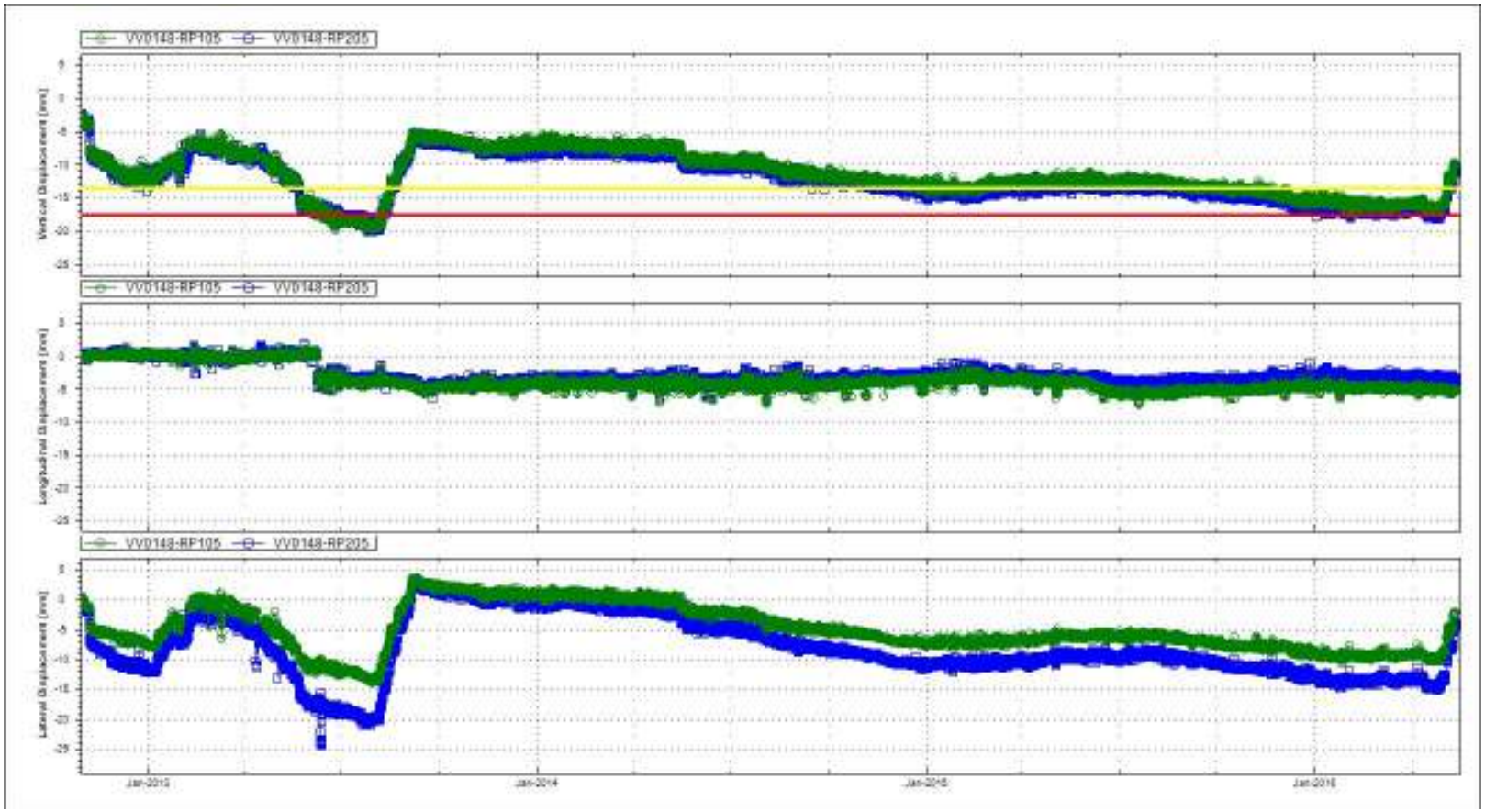


- Select a Station / Tunnel stretch define add. Information

- Overview in planview



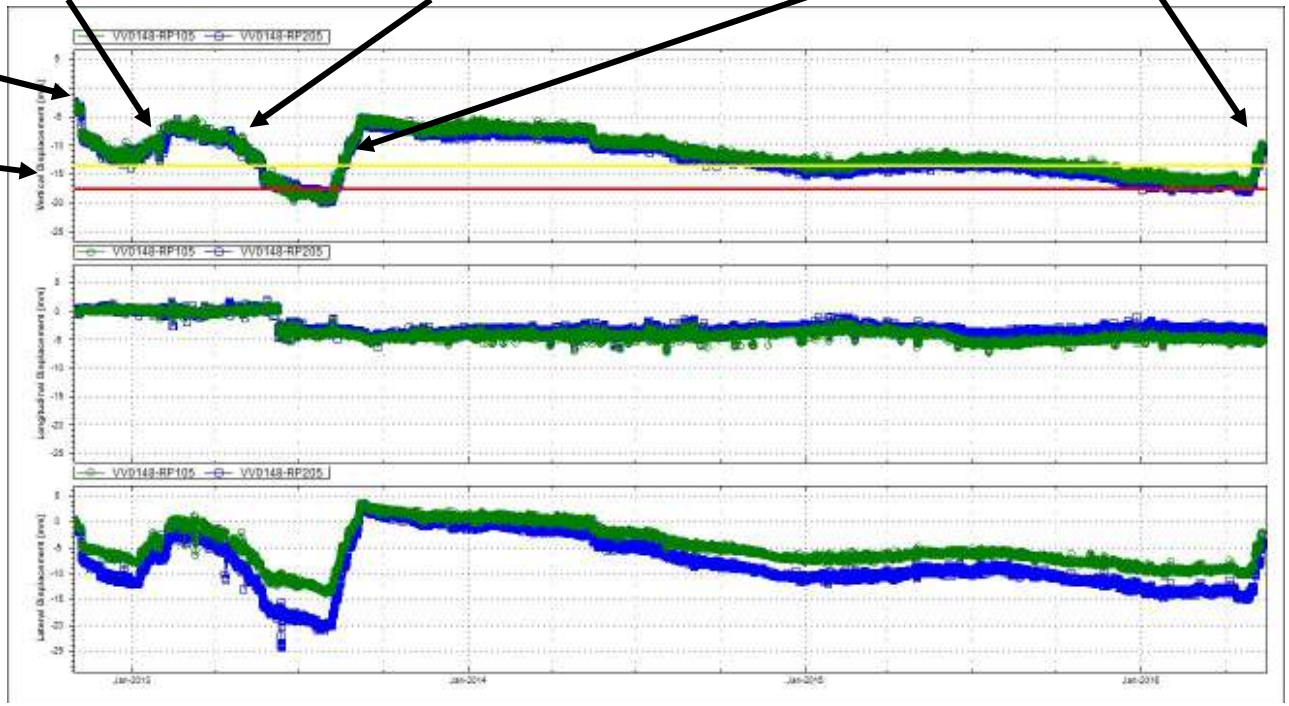
- Detail visualization of results
  - Single diagram 3D (time/displacem. -vertical/-longitudinal/-lateral)



- Detail visualization of results
  - Single diagram 3D (time/displacem. - vertical/-longitudinal/-lateral)

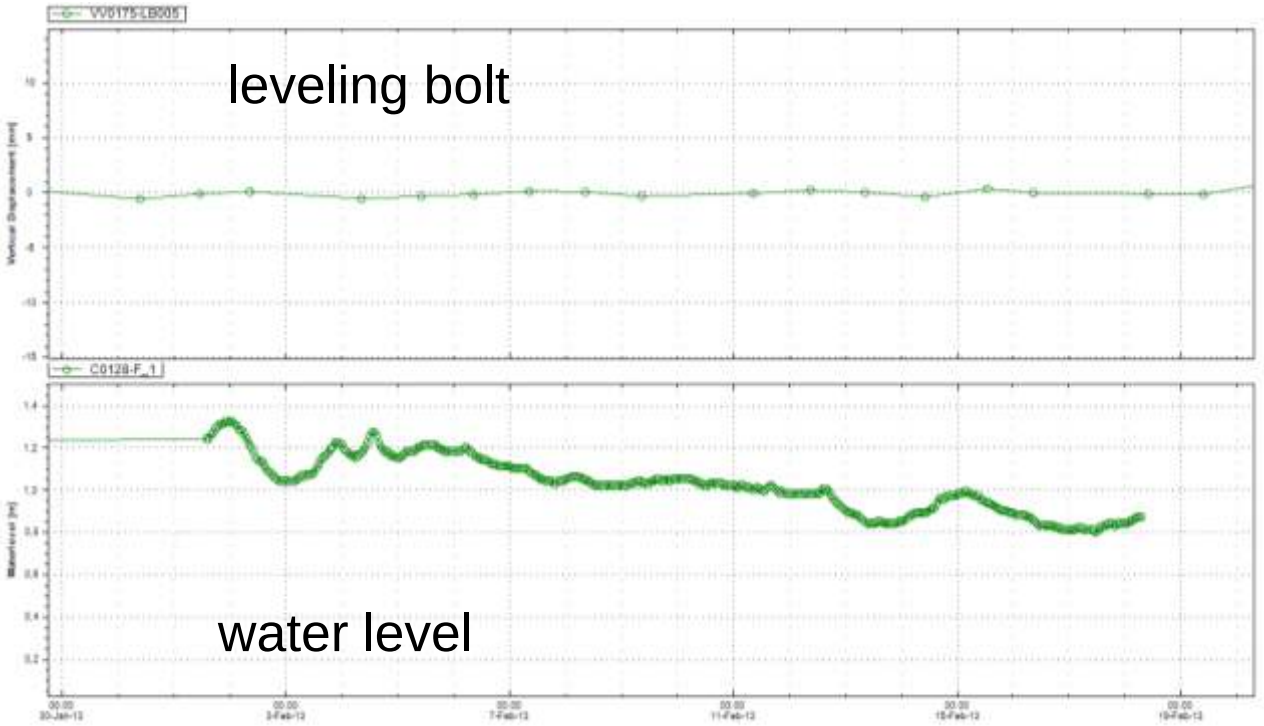
Piling works / 1. grouting / excavation of shaft / 2. grouting / 3. grouting

Warning (y) /
Alarm Limit (r)



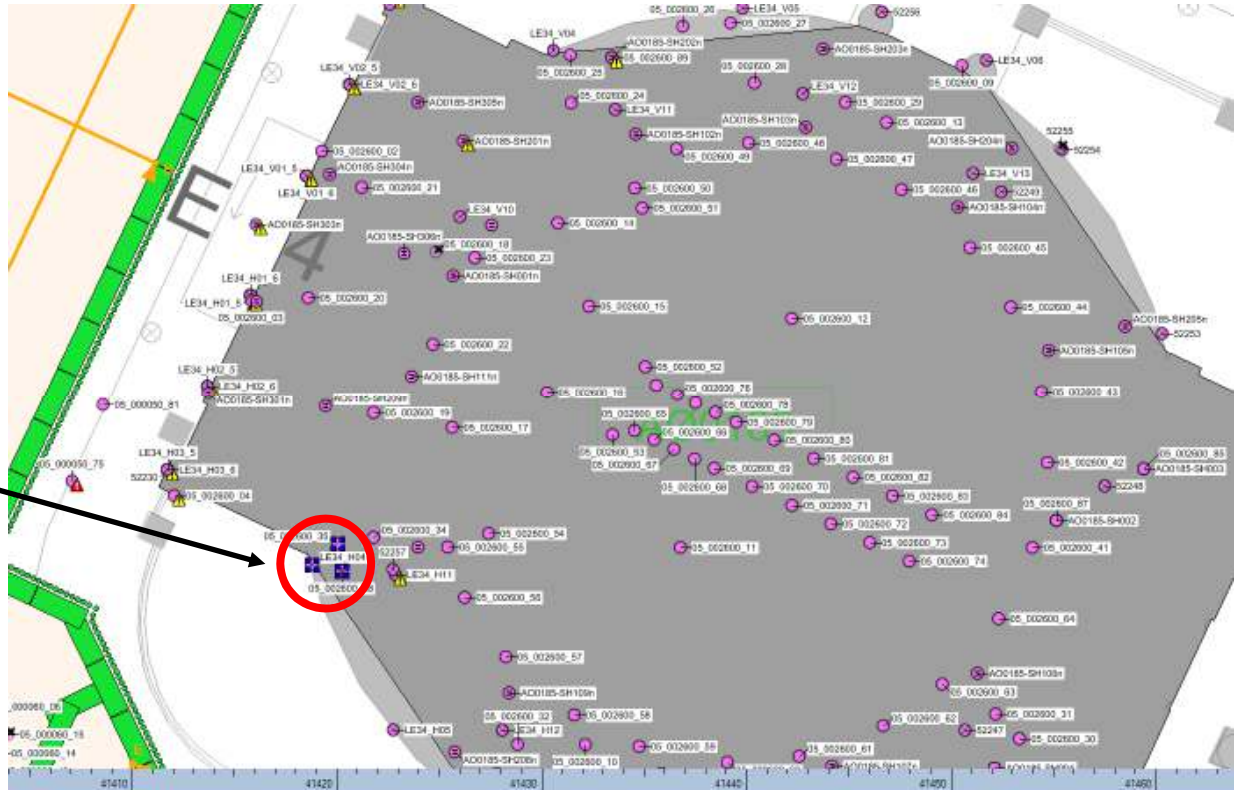
- Detail visualization of results
  - Combination of diagrams (leveling bolt & water level)

Water level sensor
Leveling bolt



- Detail visualization of results
  - Combination of diagrams (3D & leveling bolt & liquid level)

Frederikskirke or
Marmorkirke MMK:
Liquid level sensor /
Leveling bolt /
3D prism

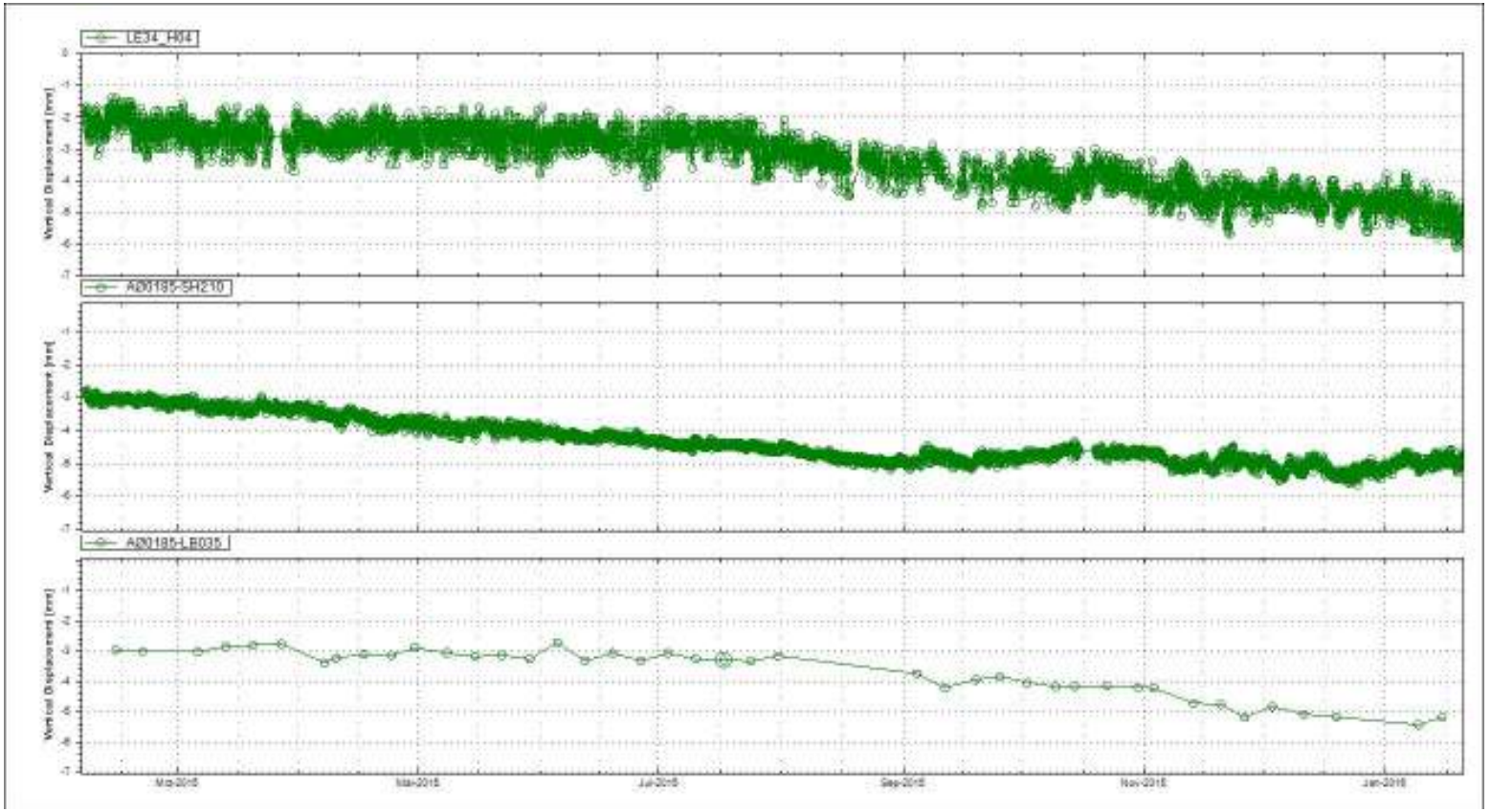


- Detail visualization of results
  - Combination of diagrams (3D & liquid level & leveling bolt)

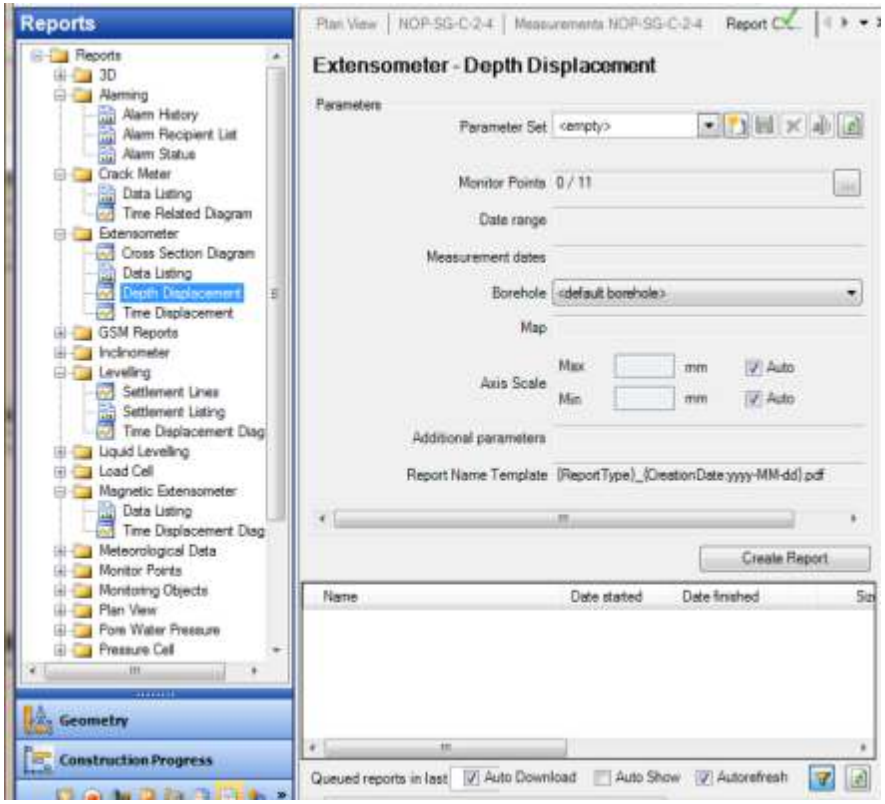
3D prism

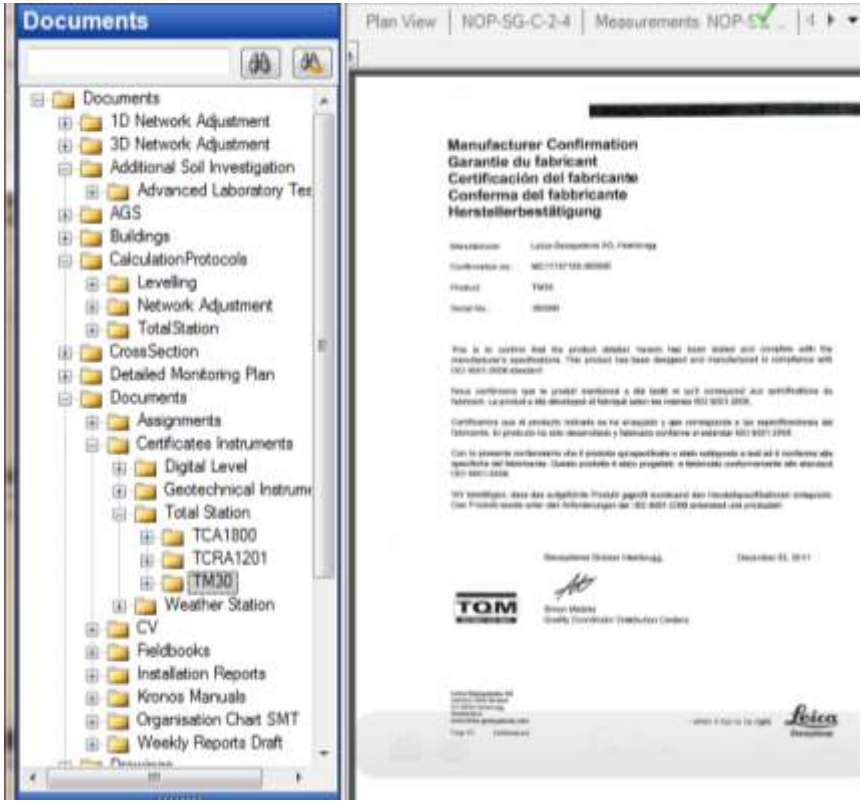
Liquid level

leveling bolt



- Reports / documents
  - Reports: definition of graphs for external documentation
  - Documents: calibration protocols, soil investigations, …





Leakage at one station shaft (1)

- During the last excavation level inside a shaft a hugh leakage between the piles was detected
- Together with groundwater a hugh amount of sand was washed in the station pit
- One building close to the leakage area was evacuated during the night

Photo: SMT Denmark ApS

Leakage at one station shaft (2)

- Together with mitigation measurements and permanent monitoring with additional leveling measurements and a high frequency running 3D system,
- settlements of the adjacent buildings of only 3-5 mm occur, so the residents of that building could go back after 2 days.
- The building was lifted up after leakage closing with grouting beyond the building

Photo: SMT Denmark ApS

- With a well-organized team and strictly procedures
  - the daily measurements will be performed in the required precision
  - all systems will be installed quickly
  - all systems has to be permanently maintained

- The key element KRONOS guarantees:
  - All measurements will be stored in the right structure, also with increasing measurement effort
  - All project participants are able to display results and export important information
  - Early warning and alert when thresholds are exceeded

➔ For the success of the whole project

Thank you very much for your attention!

And thanks to the
Client

Metroselskabet

And the Contractor

CMT COPENHAGEN METRO TEAM