Monitoring & Data Management in the Project "Cityringen Copenhagen"

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Outline of Presentation

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

Branch to Nordhavn under construction

Branch to Sydhavn in planning (start 2018)
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
• 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
- 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)
Main structure works at stations in final stage (inner linings, concourse level, technical rooms)

69% of TBM Tunnel finished
Specials of the construction of the Metro

- 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.
• 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
- Tunnel tubes over each other
• Half of station below a small channel
• Joint Venture
  - GEODATA Ziviltechnikergesellschaft mbH (Austria)

  - ANGERMEIER INGENIEURE GmbH (Germany)

Arrow: SMT Denmark ApS
• tasks and responsibilities:
  - 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
• 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
• **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
- …
- 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.
• Alarm workflow shown as an example of a 3D point

Measurement exceeds 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/displacement - vertical/-longitudinal/-lateral)
• Detail visualization of results
  - Single diagram 3D (time/displacement - 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)
• 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)
• Reports / documents
  - Reports: definition of graphs for external documentation
  - Documents: calibration protocols, soil investigations, …
During the last excavation level inside a shaft a huge leakage between the piles was detected.

Together with groundwater a huge amount of sand was washed in the station pit.

One building close to the leakage area was evacuated during the night.
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.
• 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