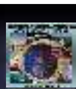

DEFORMATION MONITORING OF UNDERGROUND TECHNICAL WORKS

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Professor Emeritus

Course Title: Impact of Metro construction on the long term sustainability of a Metropolitan city: The case of Thessaloniki

Technical works and Engineering Surveying

Phases of construction		Surveying delivers:
• Idea/ Feasibility	<=	Maps, GIS
• General Planning	<=	Detailed GIS
• Design	<=	Coordinate references
• Real Construction	<=	Setting out, quality control
• Utilisation Phase Reconstructions	<=	As-built documentation + Monitoring
• Demolition		

Design – Setting out – Construction - Utilization

- High responsibility of the engineer, the constructor and the state to ensure the safe operation of the project, and thus eliminate the socio-economic damage: SAFETY
- The measurements contribute to monitoring and confirmation of theoretical static and geotechnical assumptions: Advancement of SCIENCE

Ensure safety at the largest economy

Tunnel failures

Year	Project	Cause	Costs (m US$)
2000	Metro Teagu, Korea	Collapse	24
2000	TAV Bologna-Florence , Italy	Collapse	12
2002	Taiwan High Speed Railway	Collapse	30
2002	SOCATAP Paris, France	Collapse	8
2003	Shanghai Metro, China	Collapse	60
2004	Singapore Metro	Collapse	tba
	Total		> 134

Factors contributing to the creation of deformation in technical works

- Landslides
- Settlement of the ground
- Dynamic movements - Vibrations
  - Earthquakes
  - Explosions
  - Operation of big machines
  - Heavy vehicle traffic
  - Train or Metro traffic
  - Strong wind
- Atmospheric pollution
- Geological properties

Computation of deformation

In order to monitor deformation with geodetic methods we have to measure and compare the change with time of the position of monitoring points located on the construction and/or the surrounding area

Computation of deformation

- First time measurement of position of monitoring points:

Time t_0 (zero measurement) $F_0\ (x_0, y_0, z_0)$

- Measurements at later time periods:

Time $t_1 \rightarrow F_1\ (x_1, y_1, z_1)$

Time $t_2 \rightarrow F_2\ (x_2, y_2, z_2)$

……………………… ↓

Time $t_n \rightarrow F_n\ (x_n, y_n, z_n)$

Computation of deformation

The deformation is computed as difference of horizontal coordinates (for lateral deformation) or height differences (for vertical deformation)

From the zero measurement at t_0 to a next measurement t_n:

$t_n, t_{n-1}, \ldots, t_2, t_1 - t_0$ $F_n\ (x_n, y_n, z_n) - F_0\ (x_0, y_0, z_0)$ (total deformation)

Between two measurement periods i και j:

$t_j - t_i,\ t_n - t_{n-1}, \ldots$ $F_j\ (x_j, y_j, z_j) - F_i\ (x_i, y_i, z_i)$

Accuracy requirements in technical works and deformation

Deformation monitoring
0.1 mm – 1 mm
Sometimes 1 – 2 cm

High accuracy setting out:
Underground works
1 mm – 1 cm
Industrial works
0.01mm – 1 mm

Ordinary surveying projects
1 – 5 cm

Computation of deformation: Methodology

- Establishment of control networks
- Special surveying markers
- Geodetic instruments of high accuracy
- Special computational methods and statistical elaboration of measurements
- Evaluation and estimation of deformation

High accuracy!

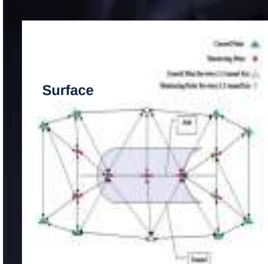
Deformation or no deformation? This is the question…

Setting out of underground constructions

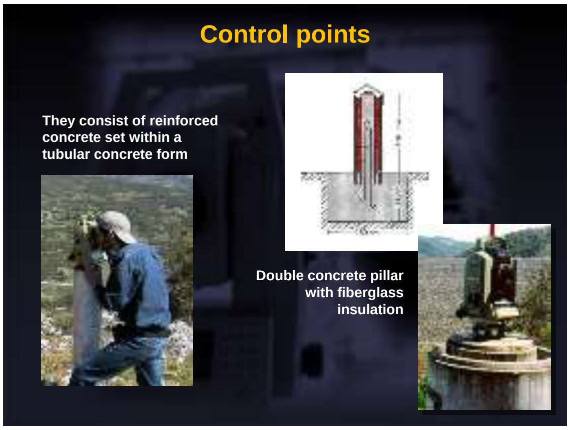
- Surface Control Network
- Underground Control Network

- Need for very high accuracy
- Difficult conditions for measurements
- Transfer of tunnel direction from the surface through wells
- Special markers (usually on the tunnel roof)
- Measurement of tunnel cross-sections

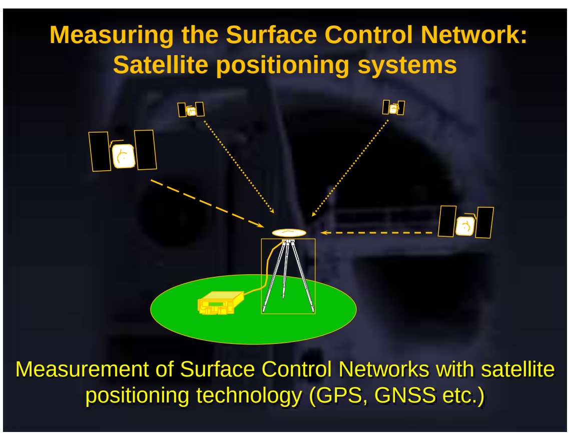
Setting out of underground constructions Surface Control Network



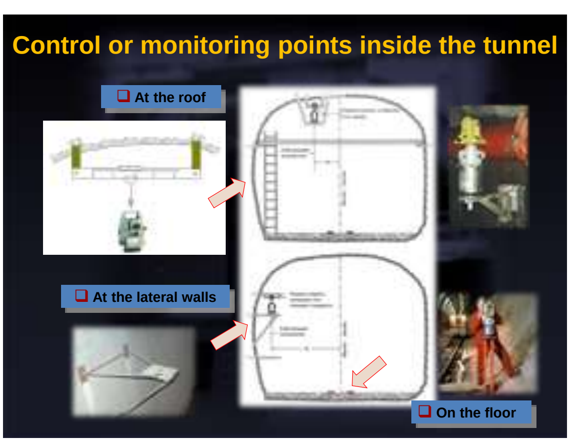
- A surface control network extending along and across the tunnel axis.
- It consists of control points located at geologically stable areas and monitoring points that are located along the surface projection of the tunnel axis and in front of the tunnel entrances
- The surface control network can be used for setting out the tunnel during construction as well as for monitoring surface ground deformation.

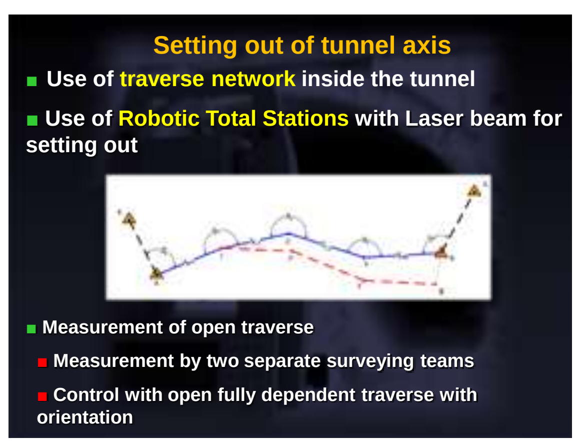

Control points
They consist of reinforced concrete set within a tubular concrete form
Double concrete pillar with fiberglass insulation


Control or monitoring points
They consist of steel tubes with instrument mount
GPS antenna

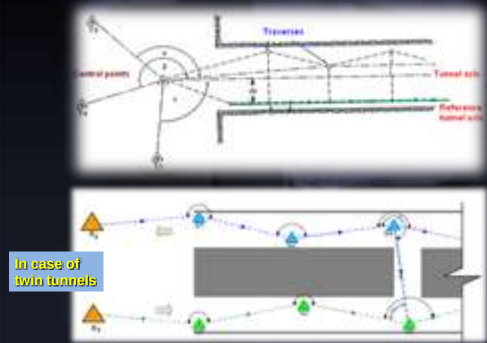

Measuring the Surface Control Network: Satellite positioning systems
Measurement of Surface Control Networks with satellite positioning technology (GPS, GNSS etc.)


Measuring the Surface Control Network: Special centering devices


Control or monitoring points inside the tunnel
At the roof
At the lateral walls
On the floor


Setting out of tunnel axis
Use of traverse network inside the tunnel
Use of Robotic Total Stations with Laser beam for setting out
Measurement of open traverse
Measurement by two separate surveying teams
Control with open fully dependent traverse with orientation

Use of traverse network inside the tunnel



Use of Robotic Total Stations with Laser beam for setting out the tunnel

Tunnel axis

Use of Robotic Total Stations with Laser beam for setting out the tunnel

Contour display

Use of Robotic Total Stations with Laser beam for steering TBMs

Tunnel Boring Machines, TBM

Monitoring of deformation

What?

- Settlements of ground surface
- Settlements of buildings above the tunnel construction zone
- Horizontal deformation beneath the building foundation level
- Crack opening change in buildings and constructions
- Convergences and movements of temporary and permanent structures
- Deformation of structural elements of the tunnel
- Meteorological data, etc.

Monitoring of deformation

Points

Instruments & Control points placed:

- In buildings and structures (either internally or externally) including buildings of special interest (churches, monuments, archaeological sites, public buildings, etc.) located within the zone of influence of the project
- In open areas above the zone of influence of the tunnel (streets, sidewalks, squares, plots, land, parks, gardens, courtyards, etc.)
- In the surrounding territorial zone of underground works (stations, tunnels, shafts)
- In temporary or permanent structures of the project during construction

Ground Settlements

They happen because of the:

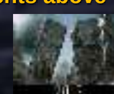
- Removal of ground material (earth, gas, water etc.)
- Reaction of ground to the construction load
- Underground water
- Geological structure
  - Clay (moisture)
  - Rock

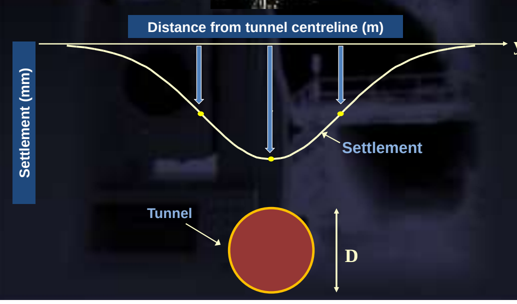
Differential settlements

Ground Settlements above tunnel construction

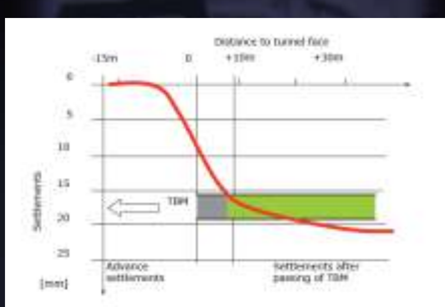
Underground technical works – Deformation of the ground surface above them

Ground Settlements above tunnel construction





Ground Settlements above tunnel construction



Monitoring deformation at the surface

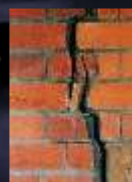
Monitoring existing structures

Underground works may cause:

- Subsidence of the foundation system of buildings at the surface above them
- Differential settlements
- Damage and cracks to walls
- Damage to beams and columns
- Inclinations - Tilt in buildings
- Collapse

Settlements of the ground and buildings

- The simplest kind of monitoring involves the detection and tracking of joint separations and crack propagation in structural concrete or architectural finishes
- The ideal is to detect and mitigate some or all of these movements before they have become severe enough to cause serious damage or perhaps constitute a hazard



Ground Settlements above tunnel construction

Major problem in urban environment and metro construction

Contour lines
of equal settlement

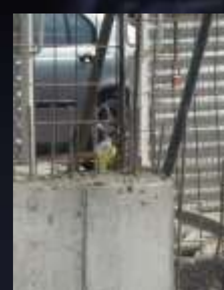
Measurement of surface deformation

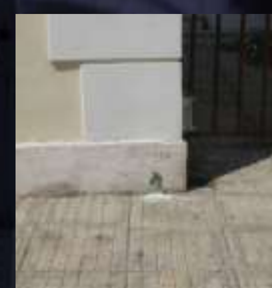
Geodetic leveling with digital levels

Monitoring of cracks

Elevation markers on building

Measurement of surface deformation

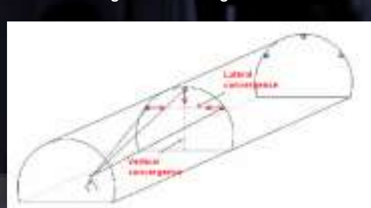




Monitoring tunnel deformation

Vertical & Lateral Deformation in the tunnel

The primary purpose for monitoring ground movements is to detect them while they are still small and to modify construction procedures before the movements grow large enough to constitute a real problem by affecting the advancing excavation



Underground measurements in difficult environment

- Limited space
- Deep in the ground
- Air streams
- Increase of air temperature with depth
- Increase of atmospheric pressure with depth
- Dust, gases, water vapor, mud, water, noise, inadequate light
- Danger of landslide, ground movements, explosions
- Traffic of equipment and machinery
- Time is never enough

High accuracy!

Monitoring deformation inside the tunnel
Measurement of cross-sections

- Modeling of absolute 3D convergences inside the tunnel
- Vertical and lateral convergence of the cross-section in the tunnel

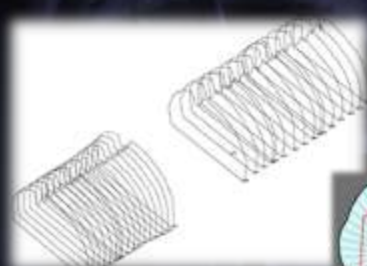
- Control points at certain tunnel profile cross sections (e.g. every 20 m, at least 5)

Measurement of tunnel cross-sections
Methods of measurement

Methods for tunnel cross-section measurements:

- The conventional traverse measurement
- The "free stationing" method
- Laser profiling
- Photogrammetric

Monitoring tunnel deformation
The conventional traverse measurement



Monitoring tunnel deformation
The "free stationing" method

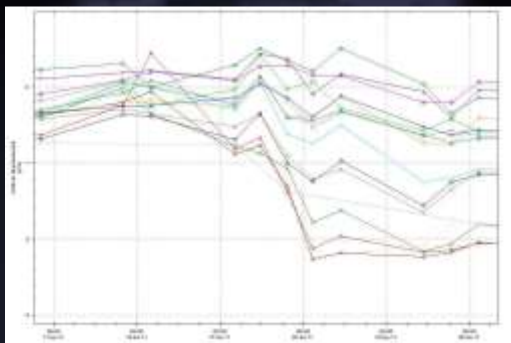
- Use of old targets as control points
- Put the Total Station where convenient
- 3D resections with angular and distance measurement to new targets
- Least squares adjustment of measurements
- Control with measurements from the entrance of the tunnel

Targets - Monitoring prisms

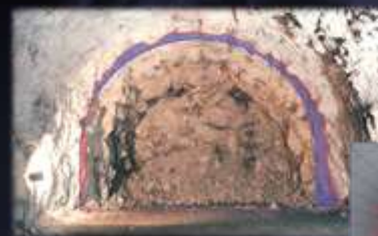
Monitoring tunnel deformation
The "free stationing" method

Monitoring targets & prisms

Monitoring tunnel deformation



Monitoring tunnel deformation

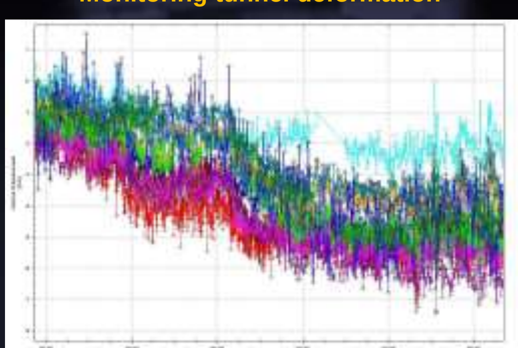


Excavation (red color) compared to theoretical excavation line

Robotic Total Stations

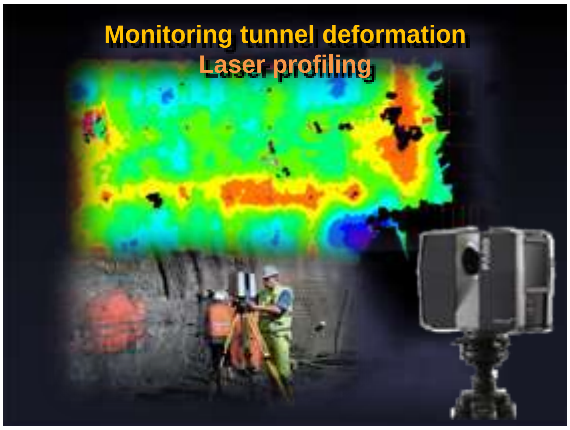
Robotic Total Stations

Monitoring tunnel deformation



Monitoring tunnel deformation
Necessary preconditions

- Accurate and high quality targets
- Specialised analysis and visualisation software
- Total stations with correspondingly high accuracy class
- Experienced staff
- Optional links to an information system and automatic online measurements


Monitoring tunnel deformation
Laser profiling


Monitoring tunnel deformation
Laser profiling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