The Croatian experience in the use of the interactive design method

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Incentives

- Large infrastructure projects
- Ground conditions that defy standard design methods (soft, fissured, jointed and heterogeneous rocks/soils)
- Risk management
Monitoring instruments

- Surveying
- Borehole measurements:
  - Inclinometers
  - Sliding micrometers
  - Piezometers
- Anchor load cells
- Total pressure cells
- Clinometers, etc.

Sliding micrometer,
Solexperts, Switzerland
Case history I – St Mark’s tunnel
St Mark’s tunnel (2)

- **Tunnel:**
  - < 22 m overburden, length 264 m, two tubes
- **Geology:**
  - from 0 m – 20 m: layers of mixed clay, sand, silt and sandstone lumps
  - > 20 m: dolomites, irregularly disintegrated
- **Requirements:**
  - limit surface settlements (preservation of cemetery)
- **Design:**
  - Pipe roof, short excavation segments, immediate closure of the support ring, reinforced shotcrete, self-boring anchors
St Mark’s tunnel (3)

Inclinometer and sliding deformeter layout
St Mark’s tunnel (4)

• Observational method:
  – establishing acceptable limits of behaviour (acceptable surface settlements)
  – initial design
  – monitoring surface settlements and strains along boreholes; pressure cells; measuring anchors
  – applying contingency actions (adjusted excavation method; added additional rock bolts)
Case history II: Zagrad excavation

- **Excavation**
  - Vertical cut 14 m – 20 m deep
  - Adjacent 5 storey old brick apartment house

- **Geology**
  - Flysch deposits overlain by 5 m of irregular fill

- **Design**
  - Staged excavation, RC box girder, rock bolts
Zagrad excavation (2)

- Observational method:
  - Initial design → limits of behaviour (strain distribution, anchor loads)
  - Monitoring: inclinometer, sliding deformeter, load cells on anchors; benchmark survey
  - Contingency actions: anchor prestressing, additional anchors
Case history III: Kaufland excavation

- Excavation: 17 m deep, adjacent 8 storey apartment building
- Geology: jointed and layered limestone partially degraded
- Design: staged excavation, reinforced shotcrete, rock bolts
Kaufland excavation (2)

- Observational method:
  - Initial design
  - Monitoring: inclinometer, horizontal sliding deformeter
  - Contingency actions due to non stabilizing deformations above the excavation section:
    - shortening of excavation section
    - additional layer of shotcrete
Case history IV: Lenac excavation

- **Excavation**
  - 35 m to 55 m deep

- **Geology**
  - Weathered limestone, breccia, flysh

- **Design**
  - Staged excavation, multilayered reinforced shotcrete, rock bolts
Lenac excavation (2)

• Observational method:
  – Initial design → limits of behaviour (strain distribution, anchor loads)
  – Monitoring: inclinometer, sliding deformeter
  – Contingency actions: prestressed anchor, additional anchors, shortening of excavation sections
Case history V: WTC excavation

- **Excavation**
  - 15 m deep

- **Geology**
  - Weathered limestone, breccia, flysh

- **Design**
  - Staged excavation, reinforced shotcrete, rock bolts, prestressed anchors
WTC excavation (2)

- Observational method:
  - Initial design → limits of behaviour (strain distribution, displacements)
  - Monitoring: inclinometer, sliding deformeter
  - Contingency actions: additional shotcrete layer, additional anchors
New developments

- Initial research in acoustic emission as a means to detect rock bolt overstressing
Final remark on the initial design for the observational method

- Peck, R. B. (1969): Establish design based on a working hypothesis of behaviour anticipated under the *most probable conditions* \((p = 0.5)\);
- Powderham, A. J. (1994): A moderately conservative initial design based on *more probable conditions* \((p > 0.5)\);
- Muir Wood, A. (2000): A conservative initial design for tunnels based on a simplified *economical analysis* (usually \(p > 0.5\)).

![Chart showing optimal probability for initial design, Peck (1969), Muir Wood (2000)]
References


Thank you for your attention