The Croatian experience in the use of the interactive design method

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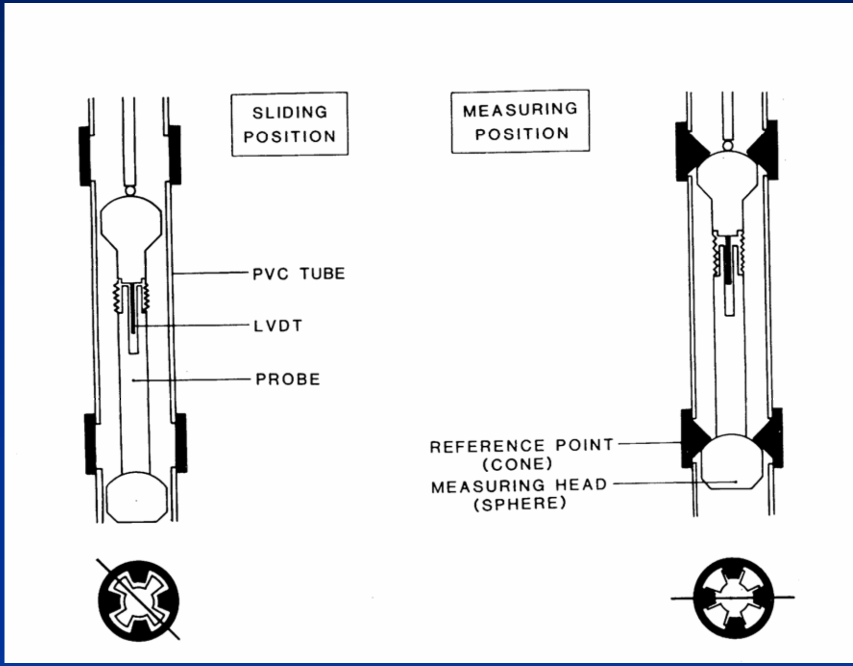
Incentives

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

The Croatian motorway project

Monitoring instruments

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

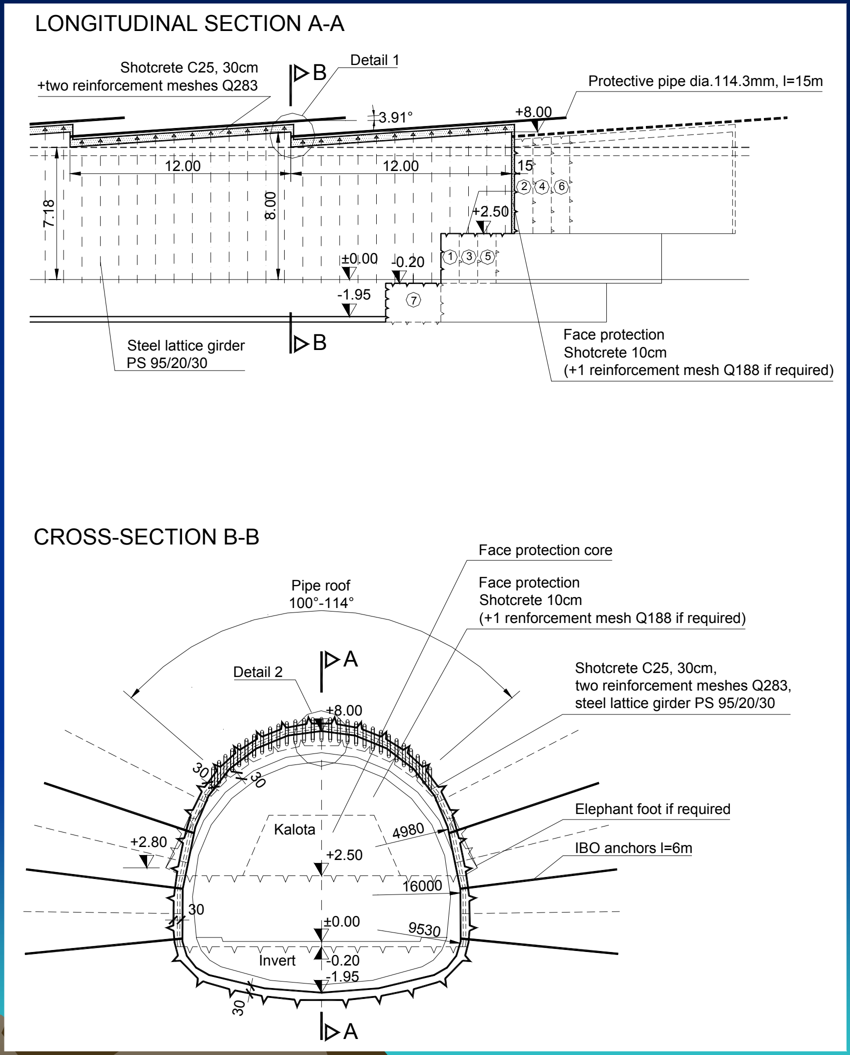


Sliding micrometer, Solexperts, Switzerland

Case history I – St Mark's tunnel

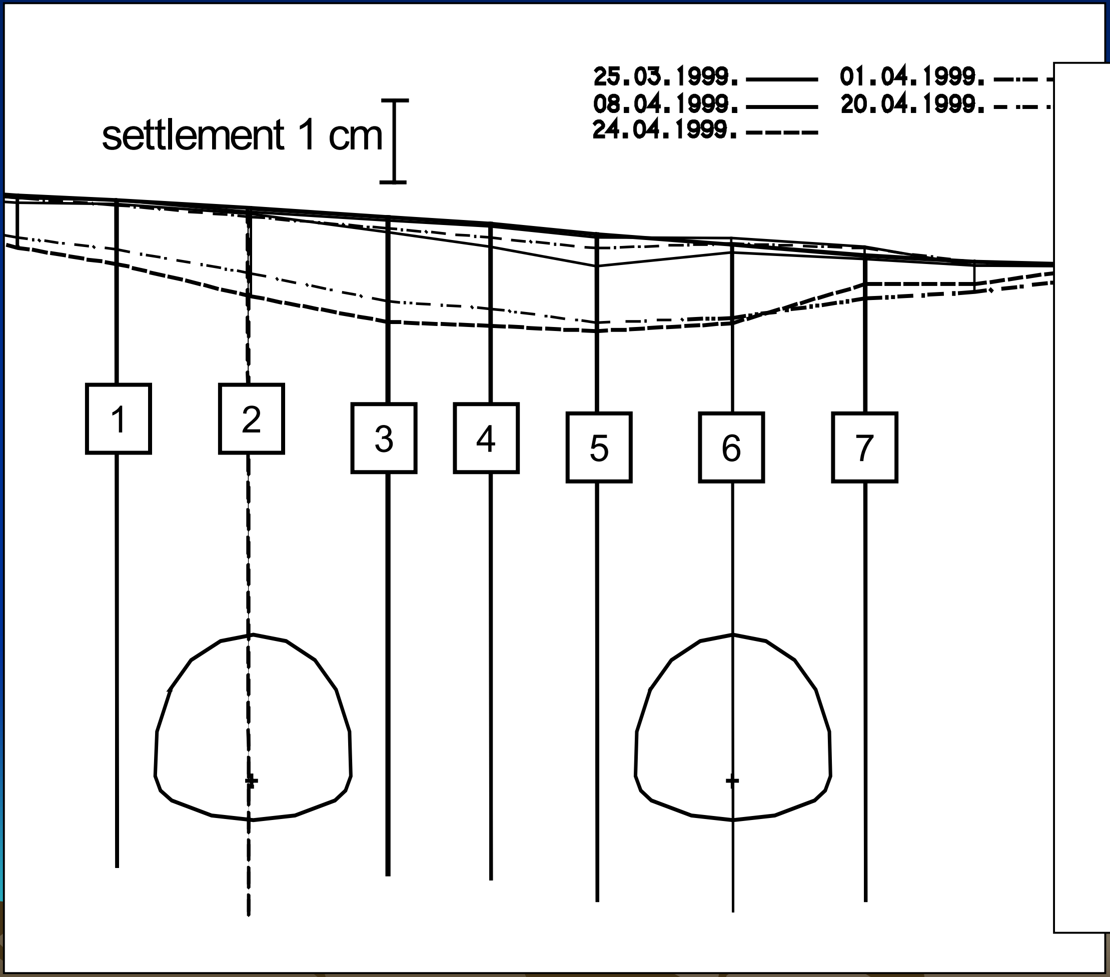
St Mark's tunnel (2)

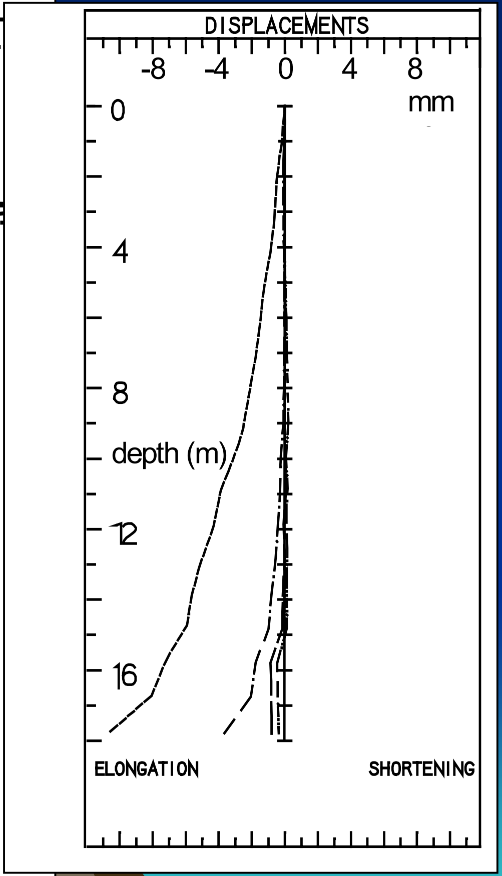
- Tunnel:
  - < 22 m overburden, length 264 m, two tubes
- Geology:
  - from 0 m – 20 m: layers of mixed clay, sand, silt and sandstone lumps
  - > 20 m: dolomites, irregularly disintegrated
- Requirements:
  - limit surface settlements (preservation of cemetery)
- Design:
  - Pipe roof, short excavation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



St Mark's tunnel (3)

Inclinometer and sliding deformeter layout



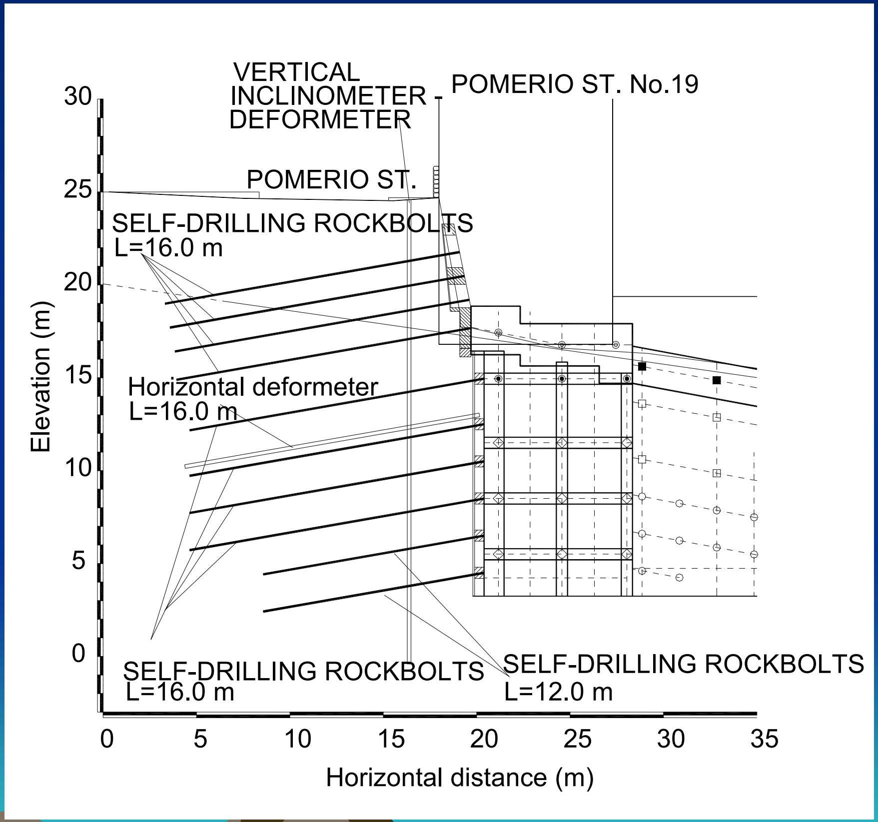


St Mark’s tunnel (4)

- 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)

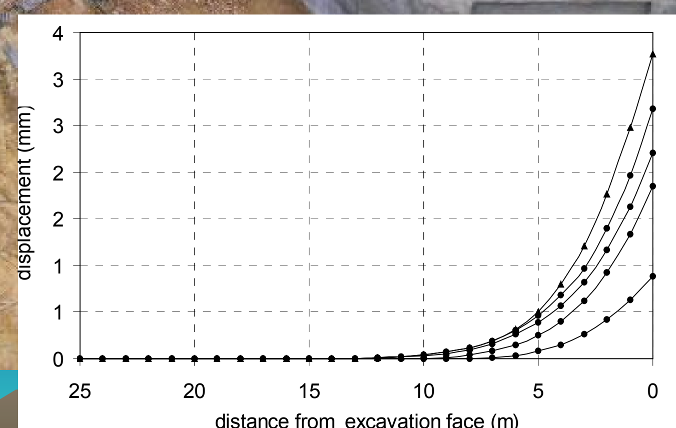
Case history II: Zagrad excavation

- Excavation
  - Vertical cut 14 m – 20 m deep
  - Adjacent 5 storey old brick apartment house
- Geology
  - Flysh deposits overlain by 5 m of irregular fill
- Design
  - Staged excavation, RC box girder, rock bolts



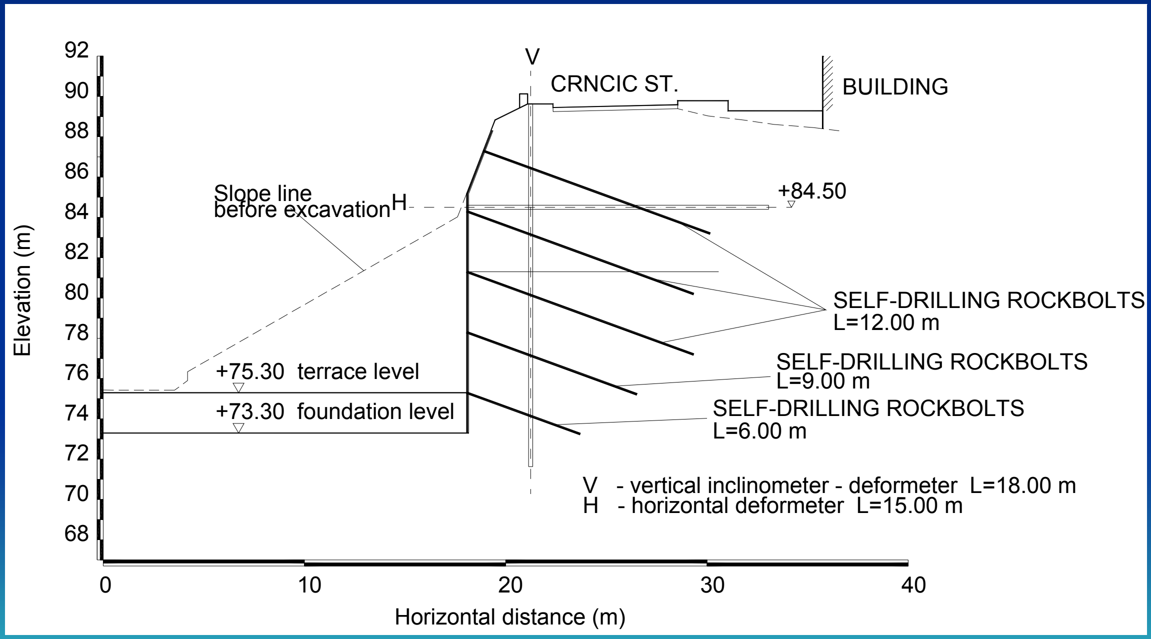
Zagrad excavation (2)

- 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

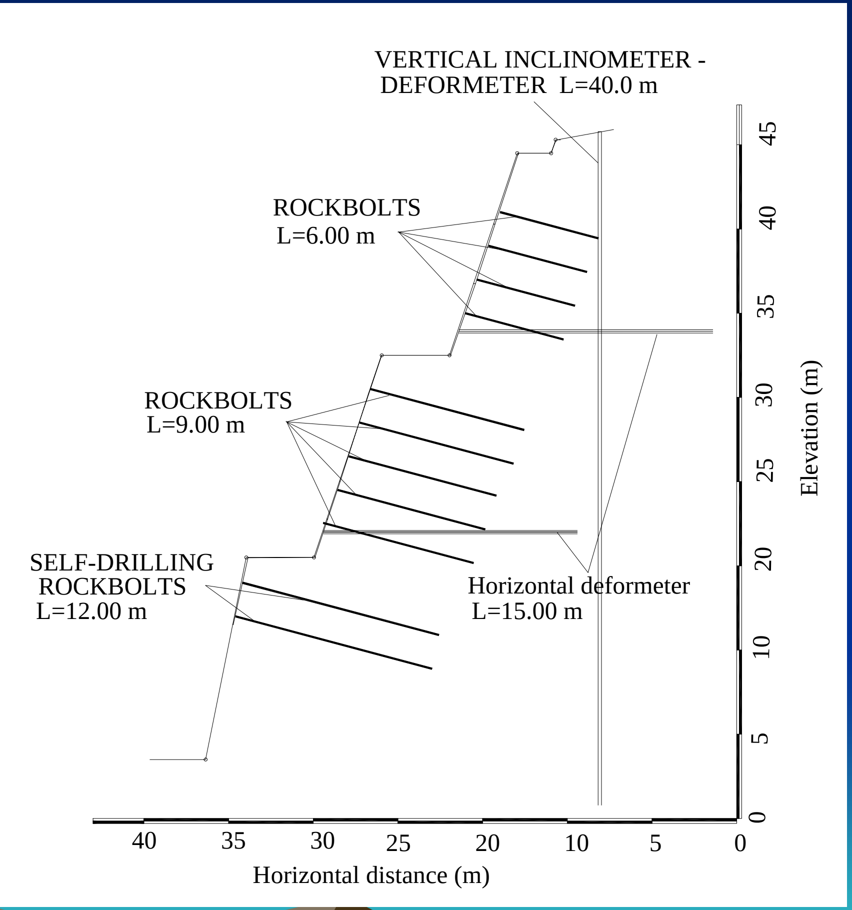


Kaufland excavation (2)

- 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

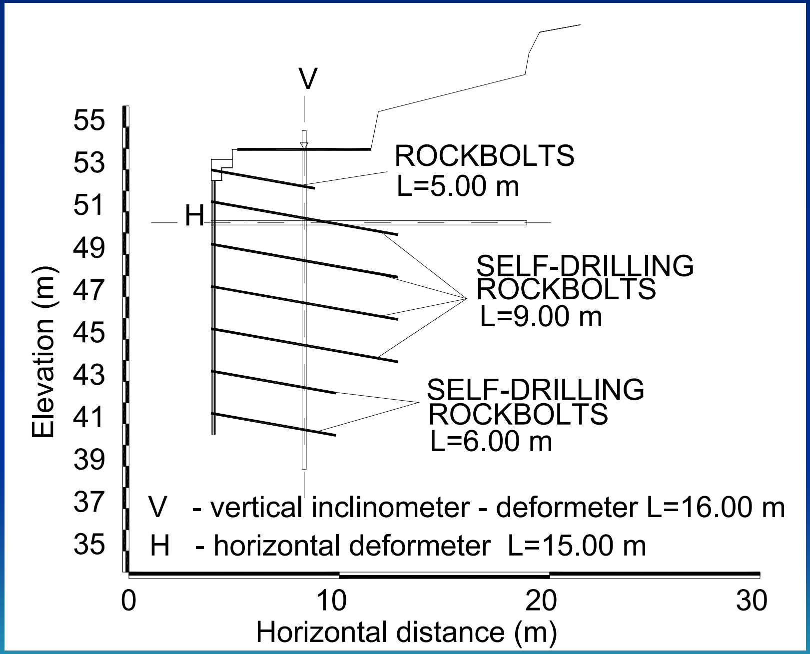


Lenac excavation (2)

- 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

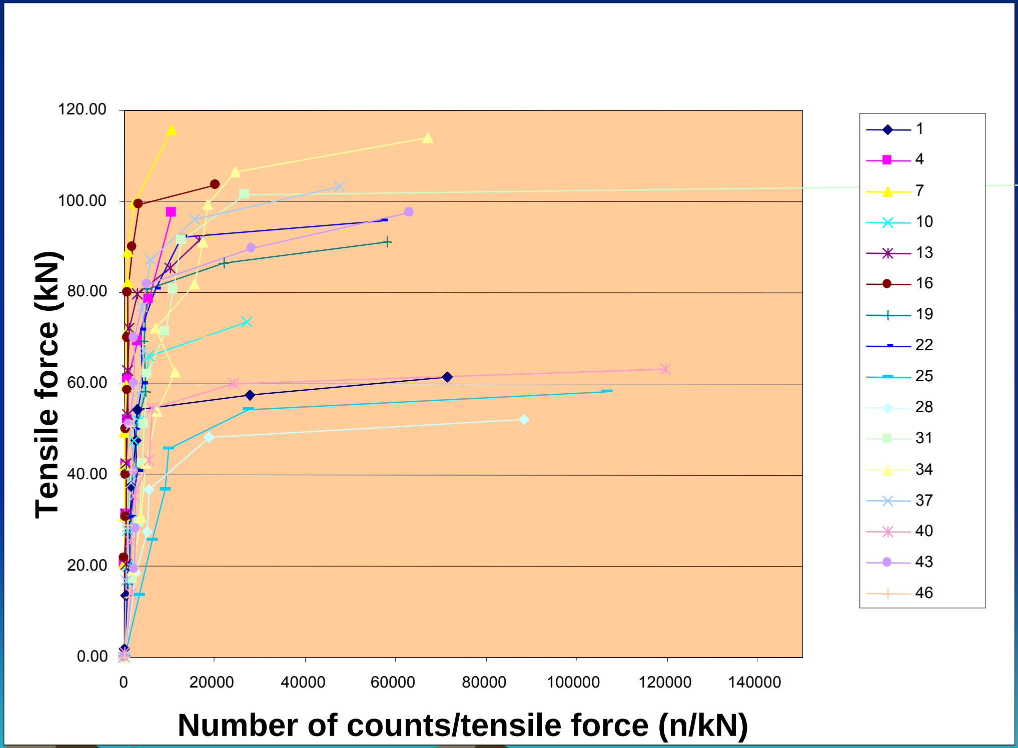


WTC excavation (2)

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

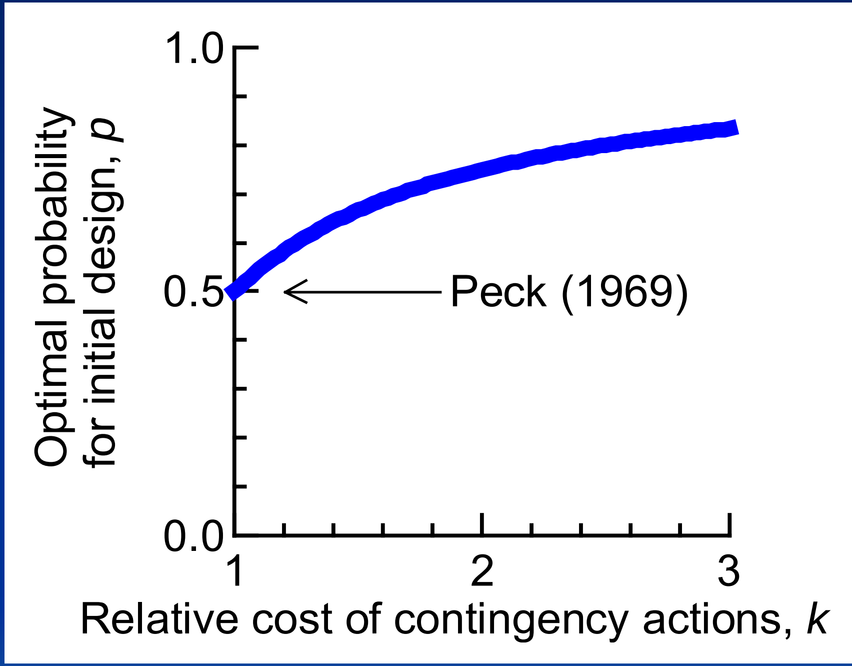
New developments

- 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) .



Muir Wood (2000)

References

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Peck, R. B. (1969). Advantages and limitations of the Observational Method in applied soil mechanics. *Géotechnique*, 44 (4), 619-636.

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Thank you for your attention