MONITORING / SHORT–TERM PREDICTION

TARGETS

- Verify design assumptions
- Together with updated geotechnical model allow short term prediction
- Provide input for final design and optimization of excavation and support on site
- Prediction of final displacements
- Control stability
- Data collection for future developments (expert systems)

Construction

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MONITORING / SHORT–TERM PREDICTION

METHODS

- Absolute displacements of tunnel wall with electronic total station
- Relative displacement measurements with precision measuring tape, extensometers, inclinometers
- strains

Construction

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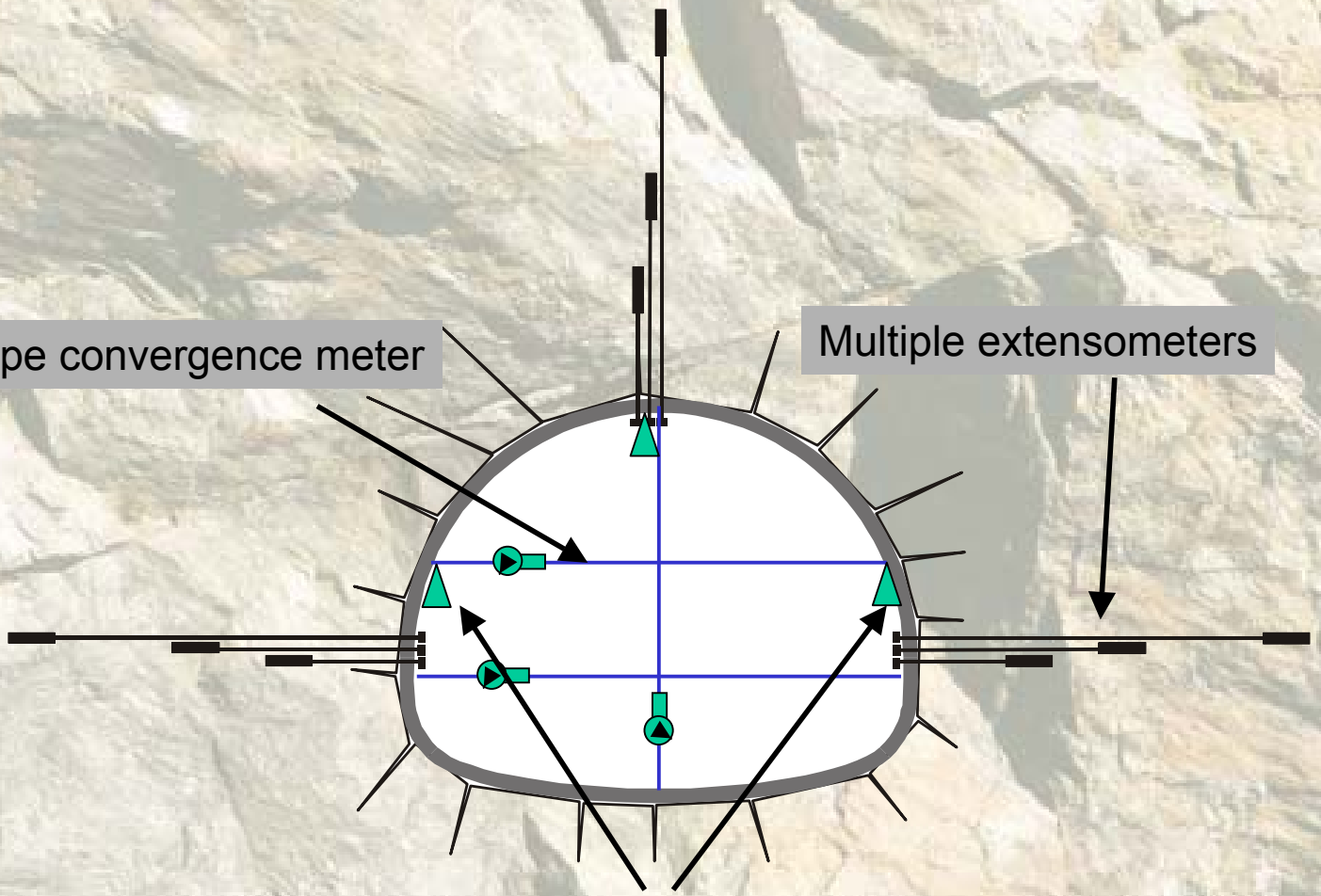
MONITORING / SHORT–TERM PREDICTION

METHODS



Construction

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MONITORING / SHORT–TERM PREDICTION

ABSOLUTE DISPLACEMENTS

Construction

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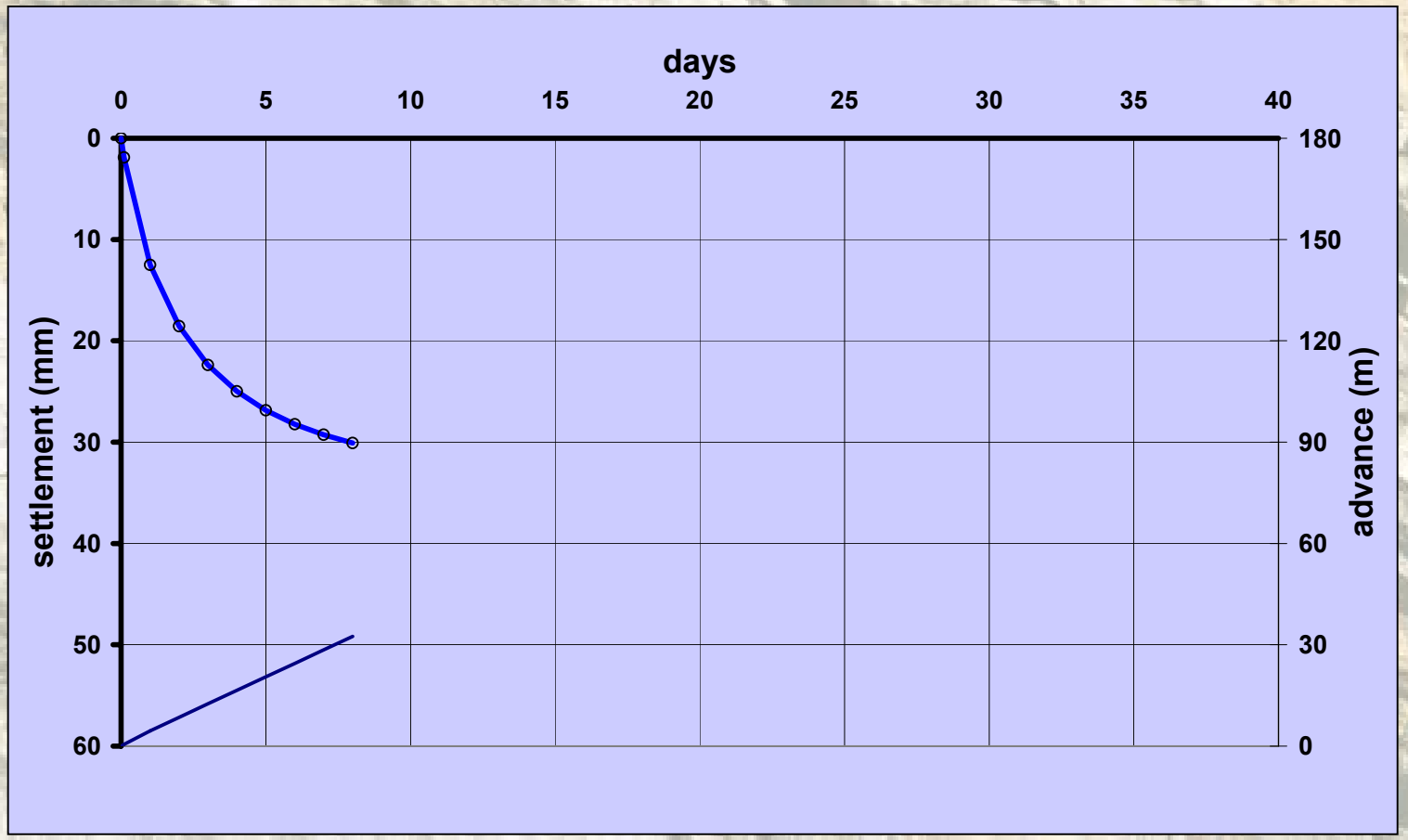
MONITORING / SHORT–TERM PREDICTION

INFLUENCING FACTORS

- **Displacements influenced by:**
  - Rock mass properties
  - Heterogeneity
  - Tunnel size
  - Primary stresses
  - Excavation sequence
  - Excavation rate
  - Support

MONITORING / SHORT–TERM PREDICTION

TIME – DISPLACEMENT
continuous advance



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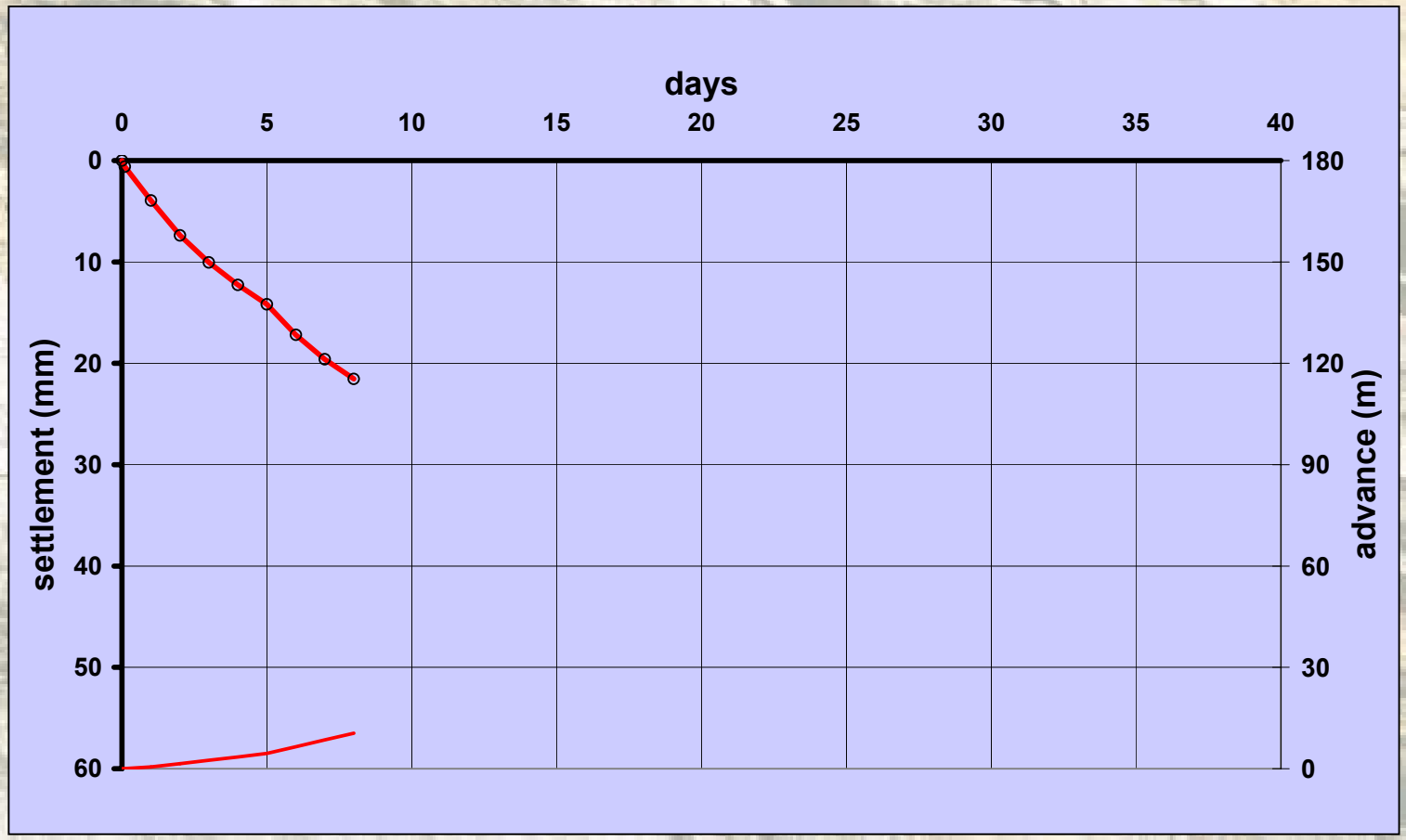
MONITORING / SHORT–TERM PREDICTION

TIME – DISPLACEMENT
discontinous advance



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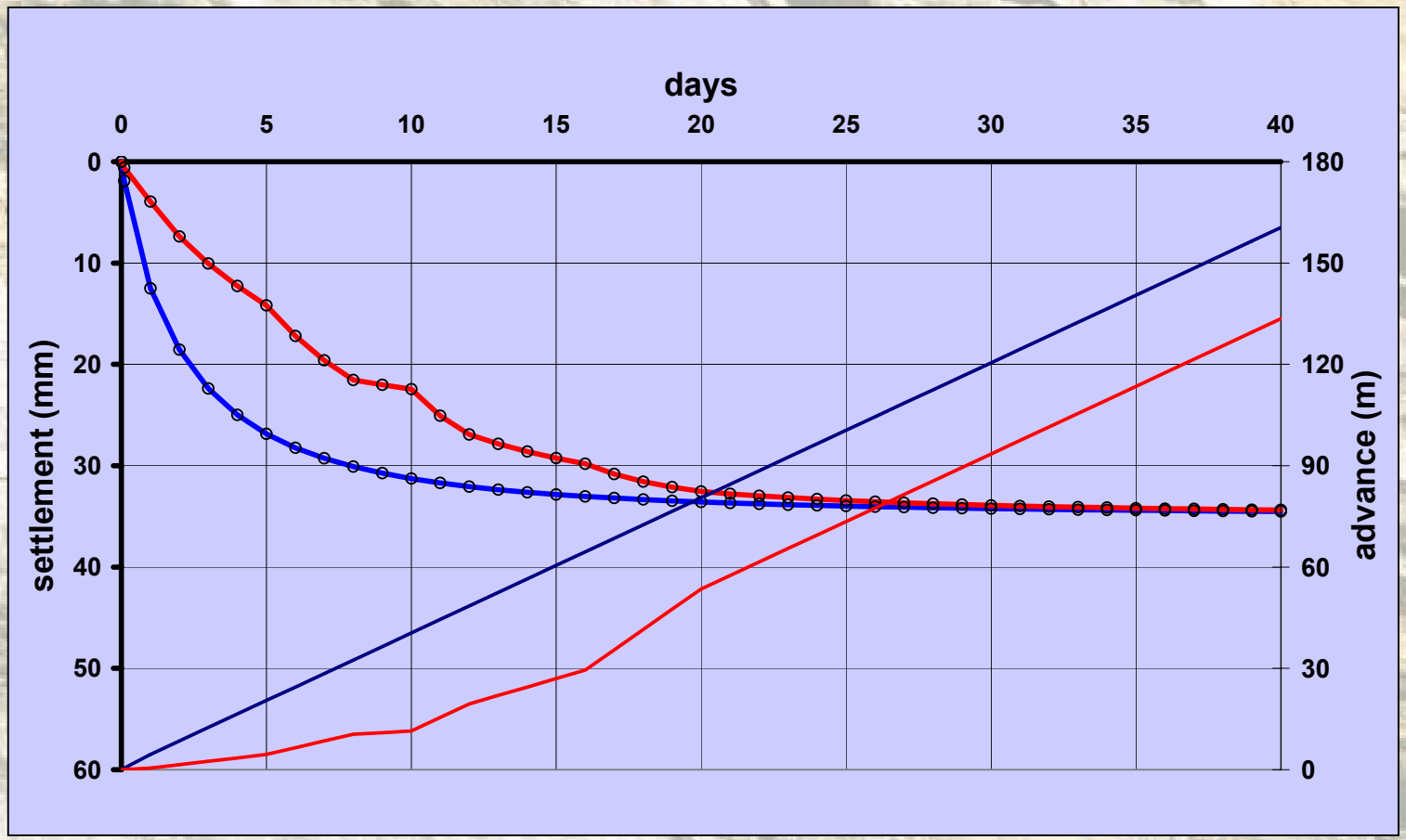
MONITORING / SHORT–TERM PREDICTION

TIME – DISPLACEMENT
comparison



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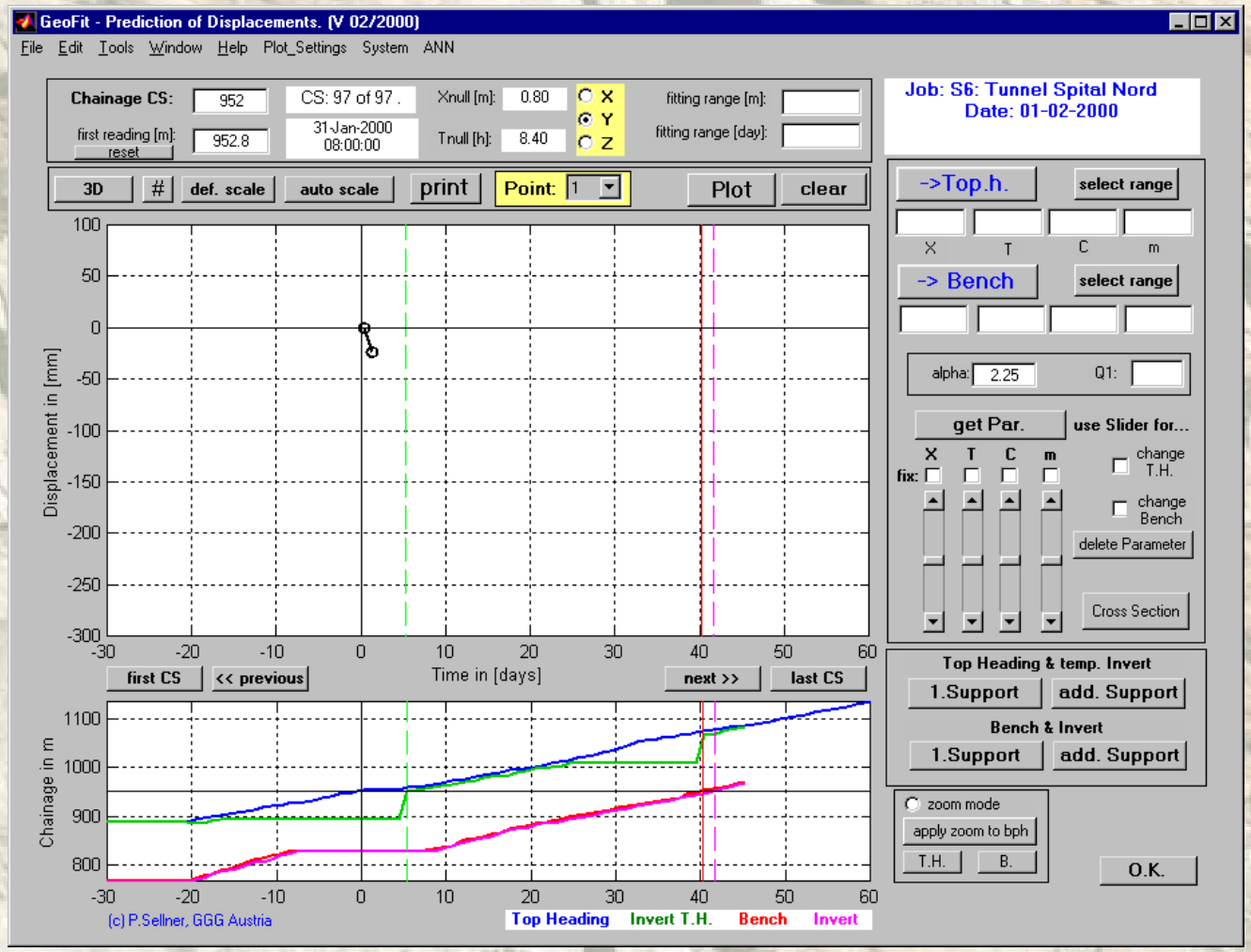
MONITORING / SHORT–TERM PREDICTION

PREDICTION OF DISPLACEMENTS



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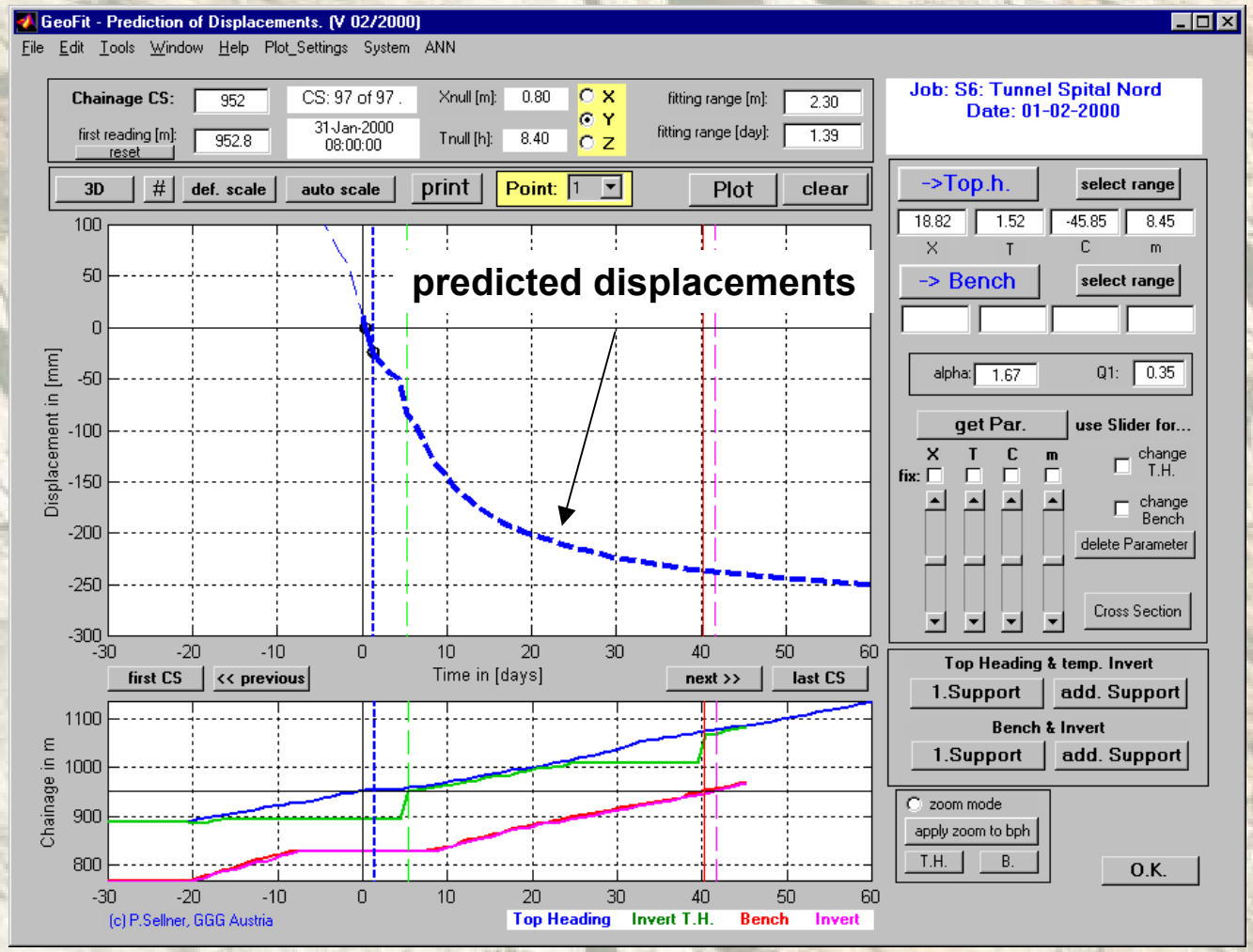
MONITORING / SHORT–TERM PREDICTION

PREDICTION OF DISPLACEMENTS



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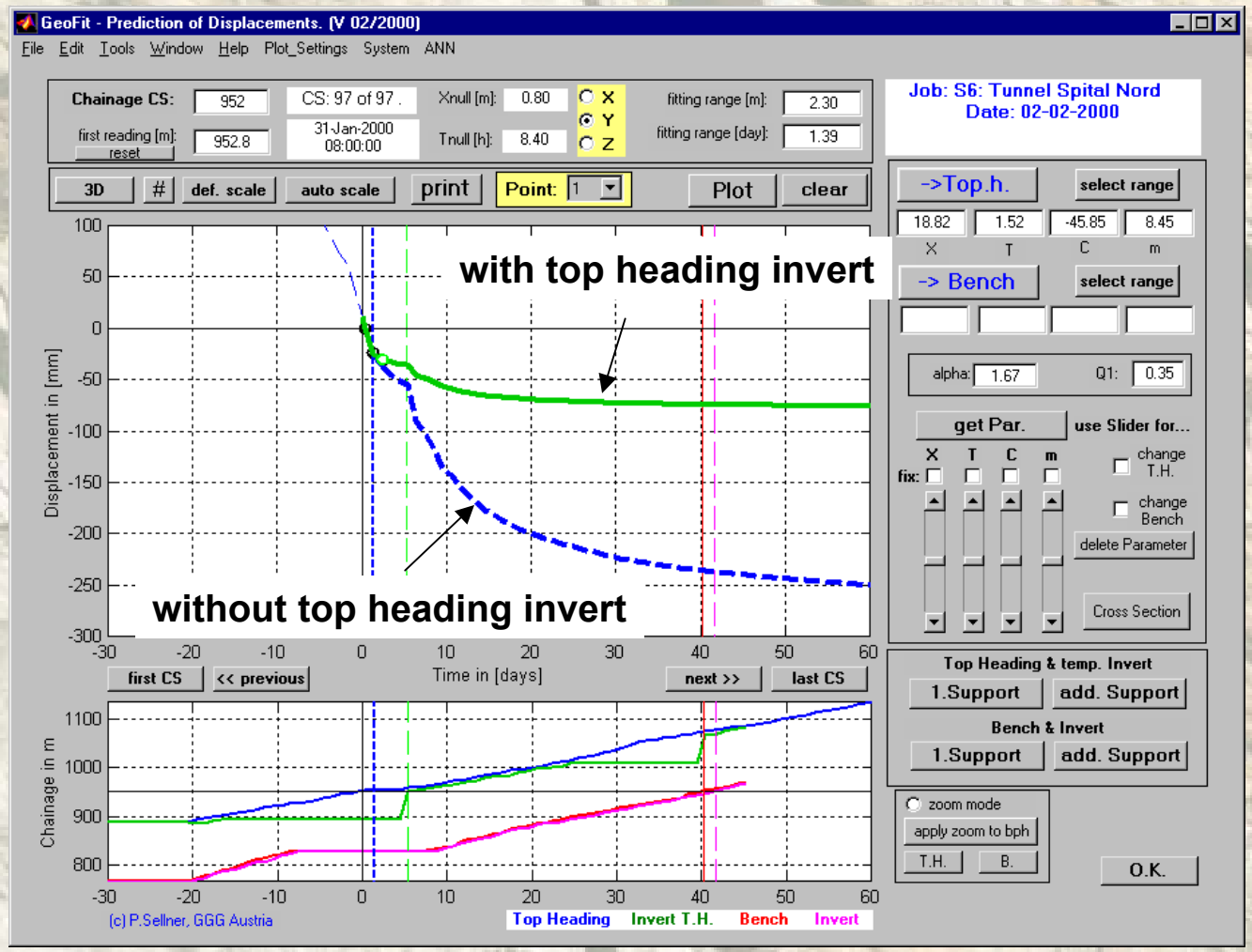
MONITORING / SHORT–TERM PREDICTION

DIFFERENT SUPPORT



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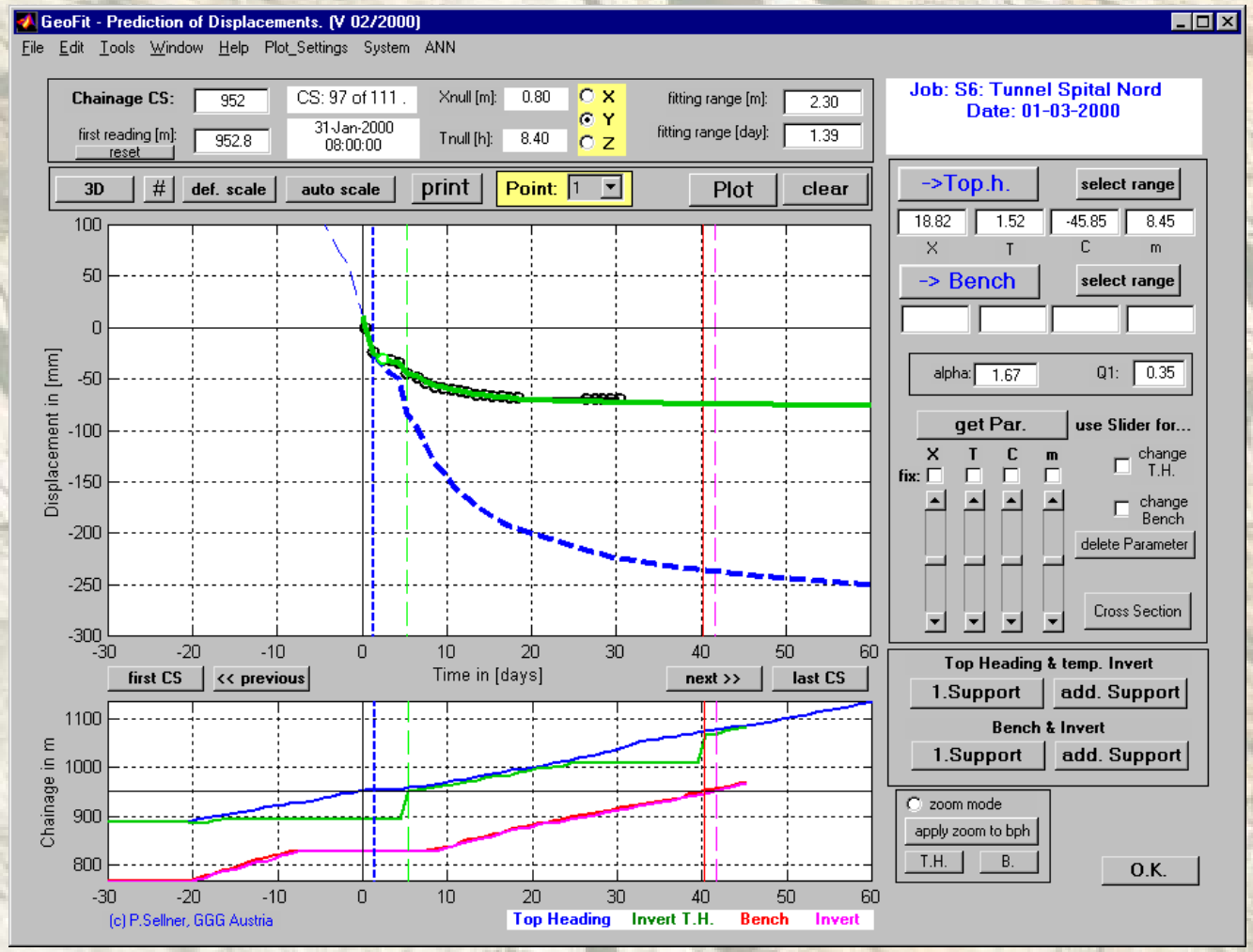
MONITORING / SHORT–TERM PREDICTION

COMPARISON PREDICTION - REALITY



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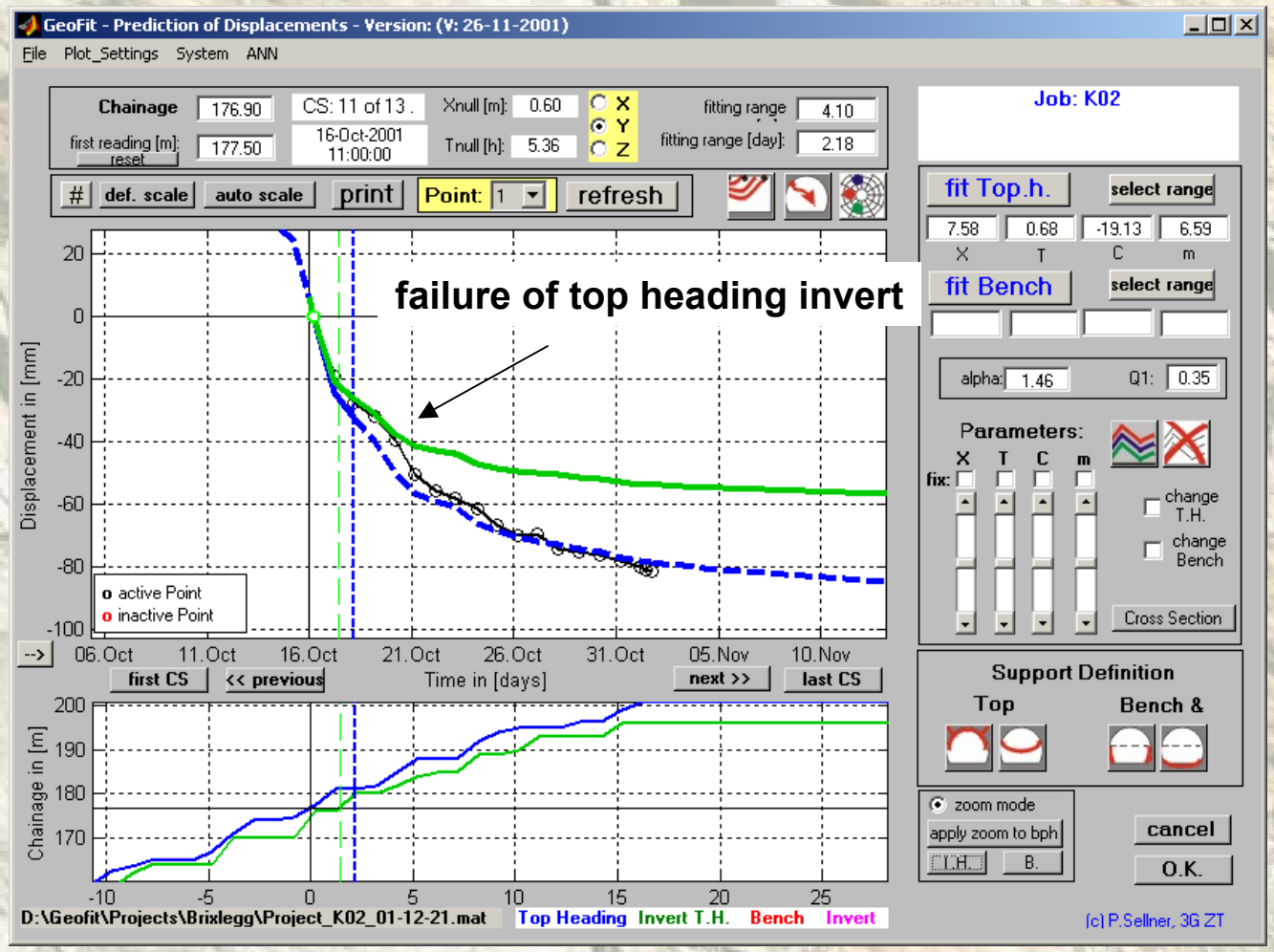
MONITORING / SHORT–TERM PREDICTION

DEVIATIONS FROM PREDICTION



Construction

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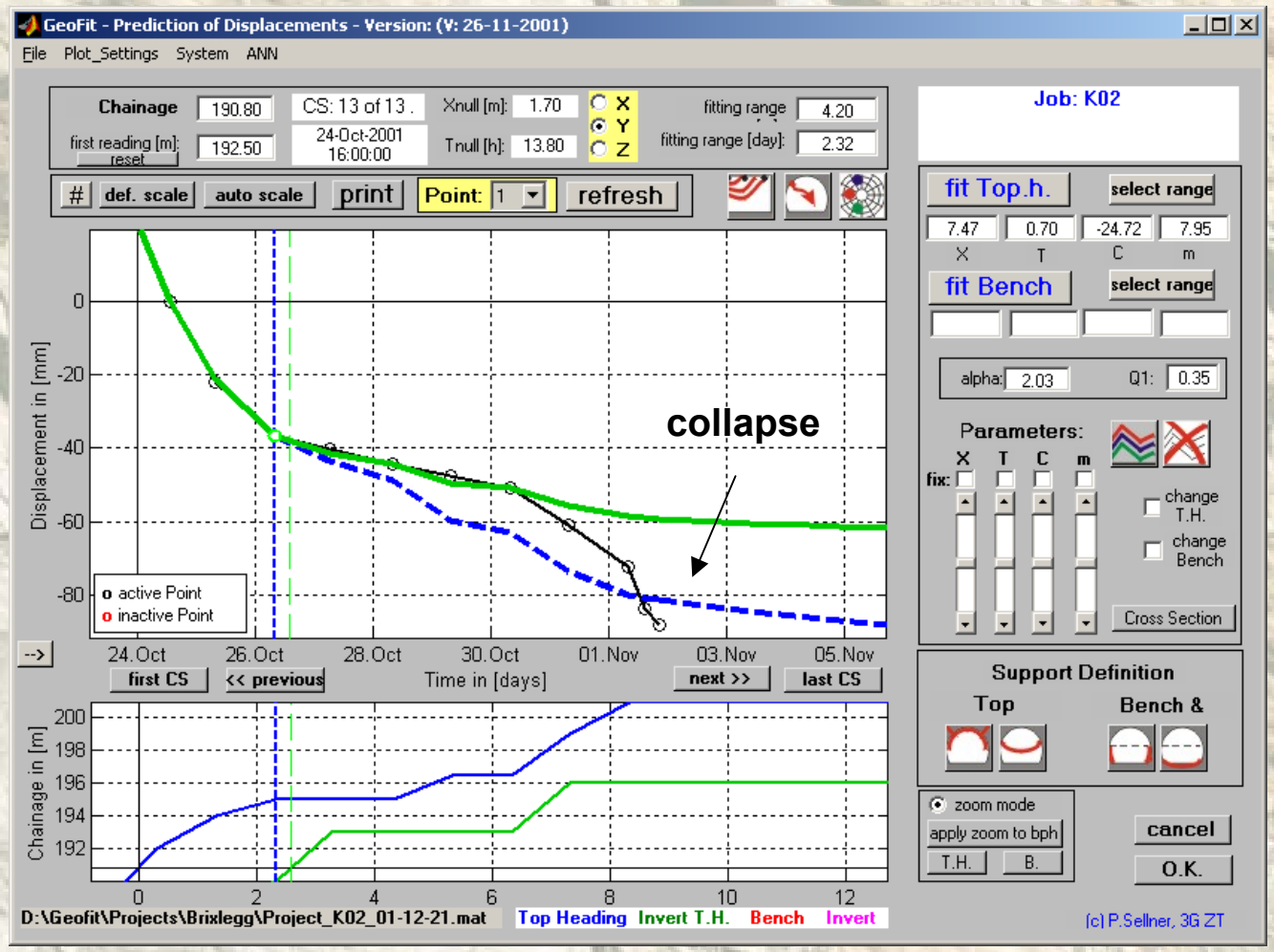
MONITORING / SHORT–TERM PREDICTION

DEVIATIONS FROM PREDICTION



Construction

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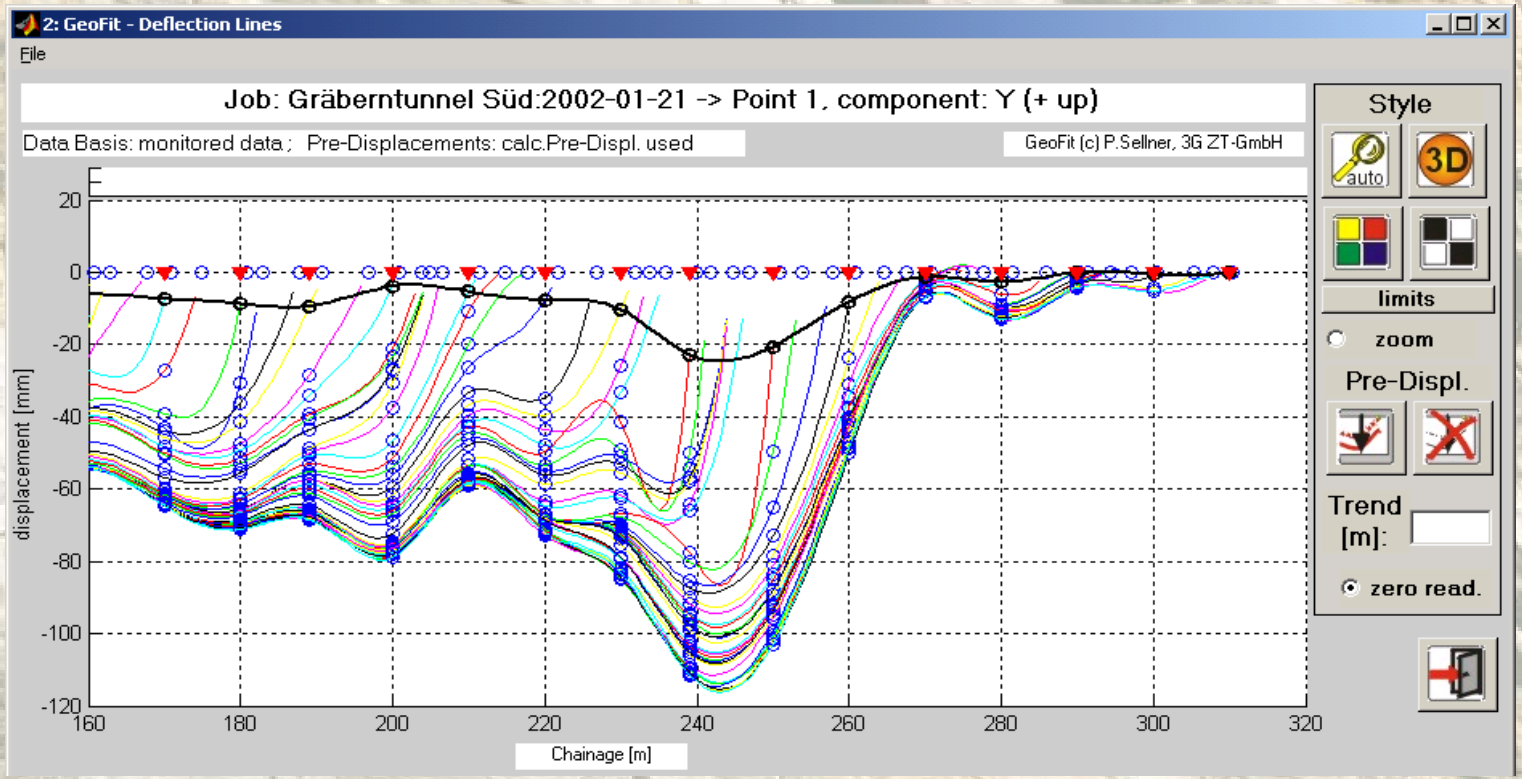
MONITORING / SHORT–TERM PREDICTION

ROOF SETTLEMENTS, DEFLECTION CURVES



Gräbern Tunnel, Austria

Construction

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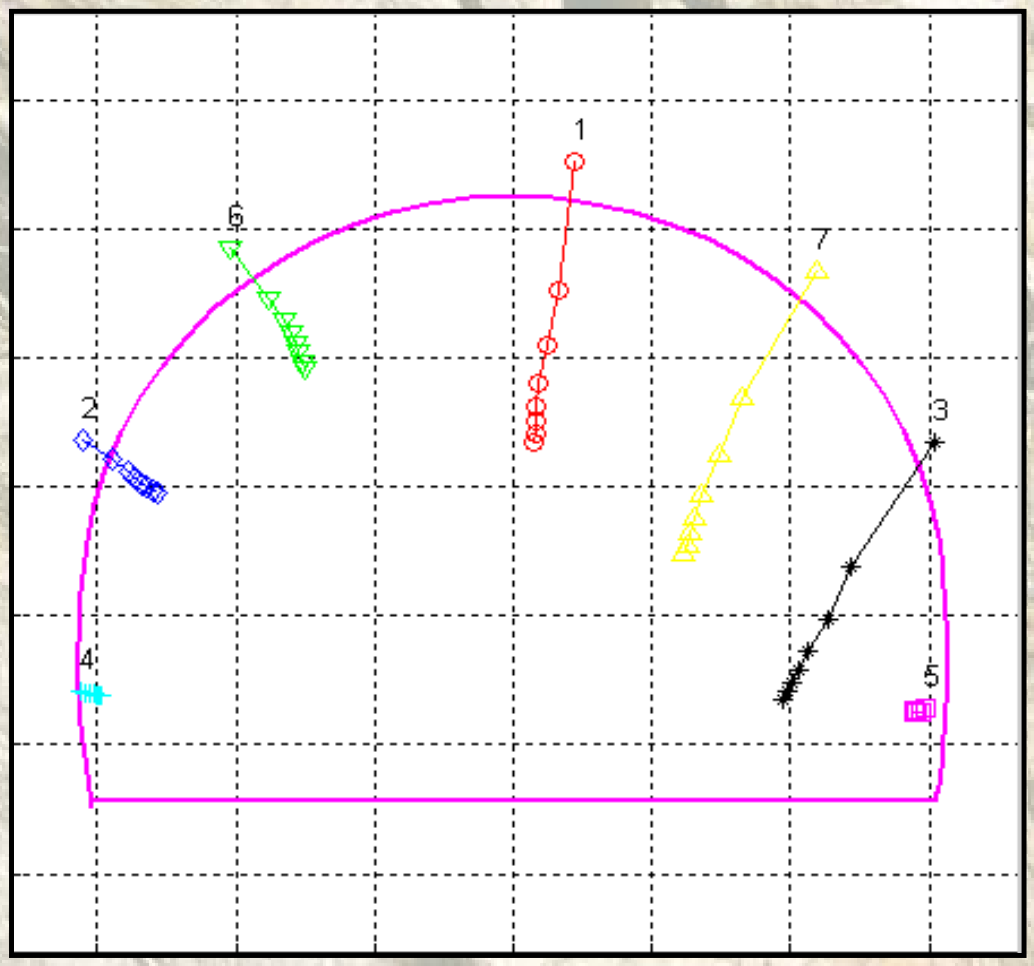
MONITORING / SHORT–TERM PREDICTION

DISPLACEMENT VECTORS



Gräbern Tunnel, Austria

Construction

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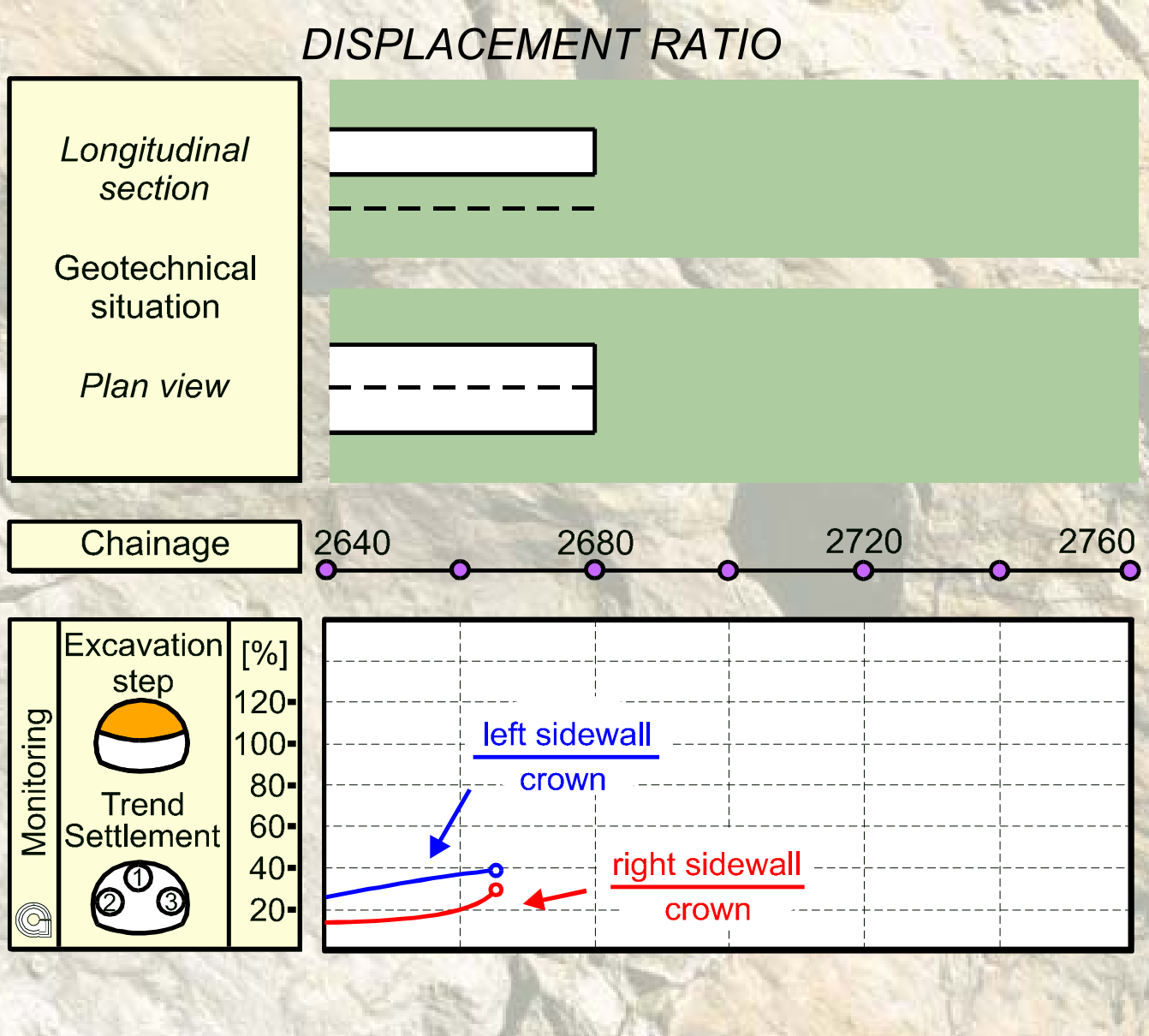

Construction

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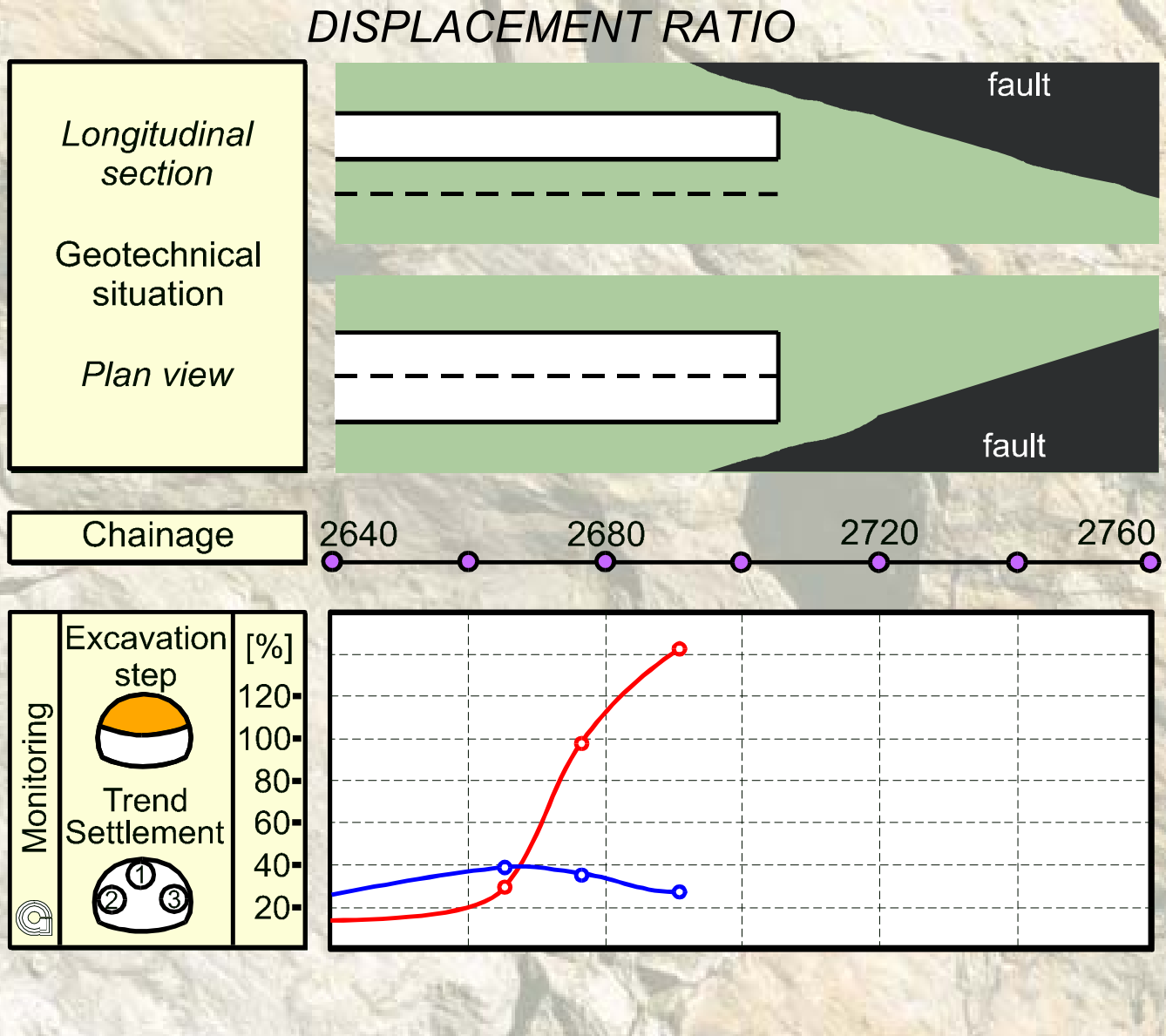
MONITORING / SHORT–TERM PREDICTION



Construction

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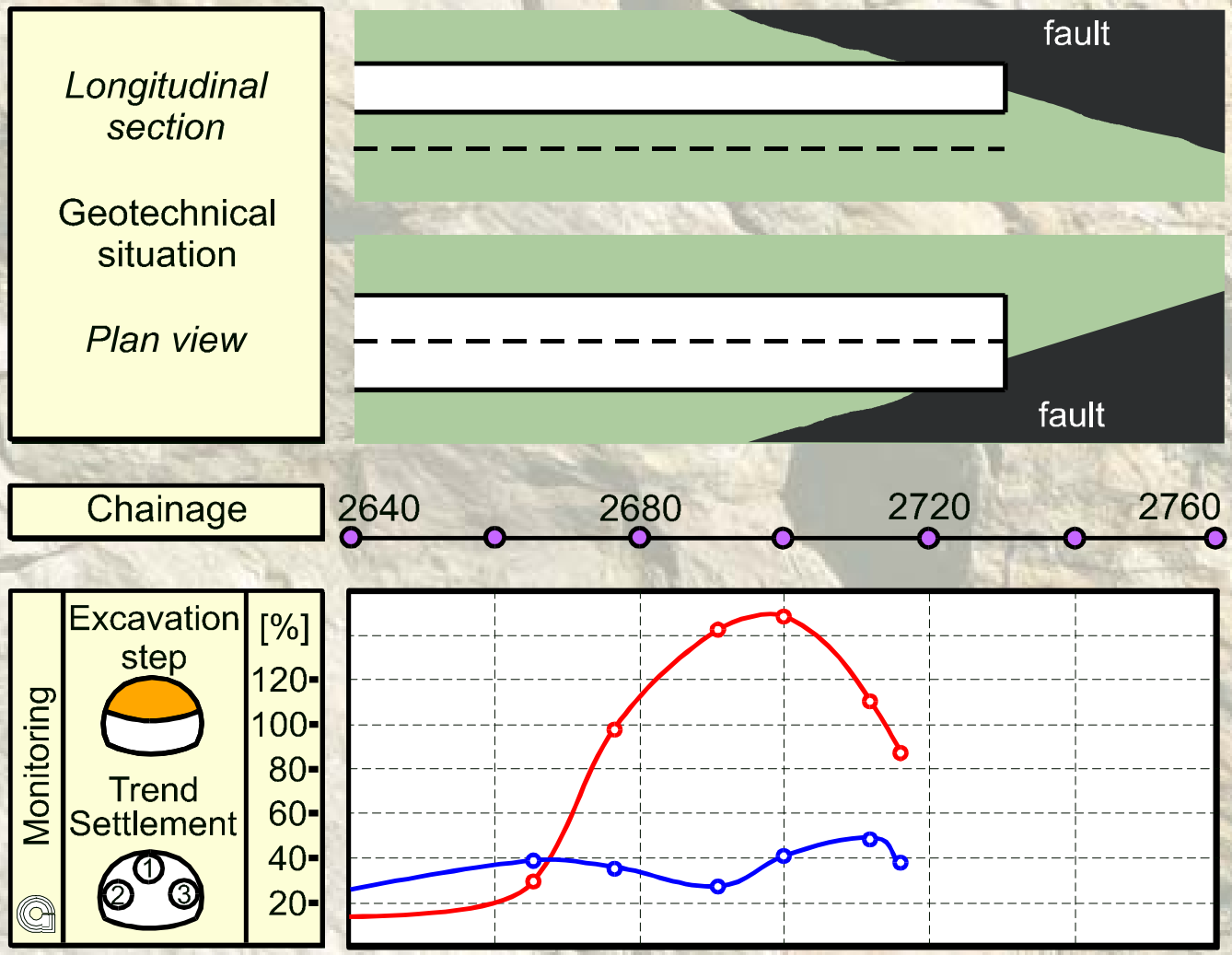
MONITORING / SHORT–TERM PREDICTION

DISPLACEMENT RATIO



Construction

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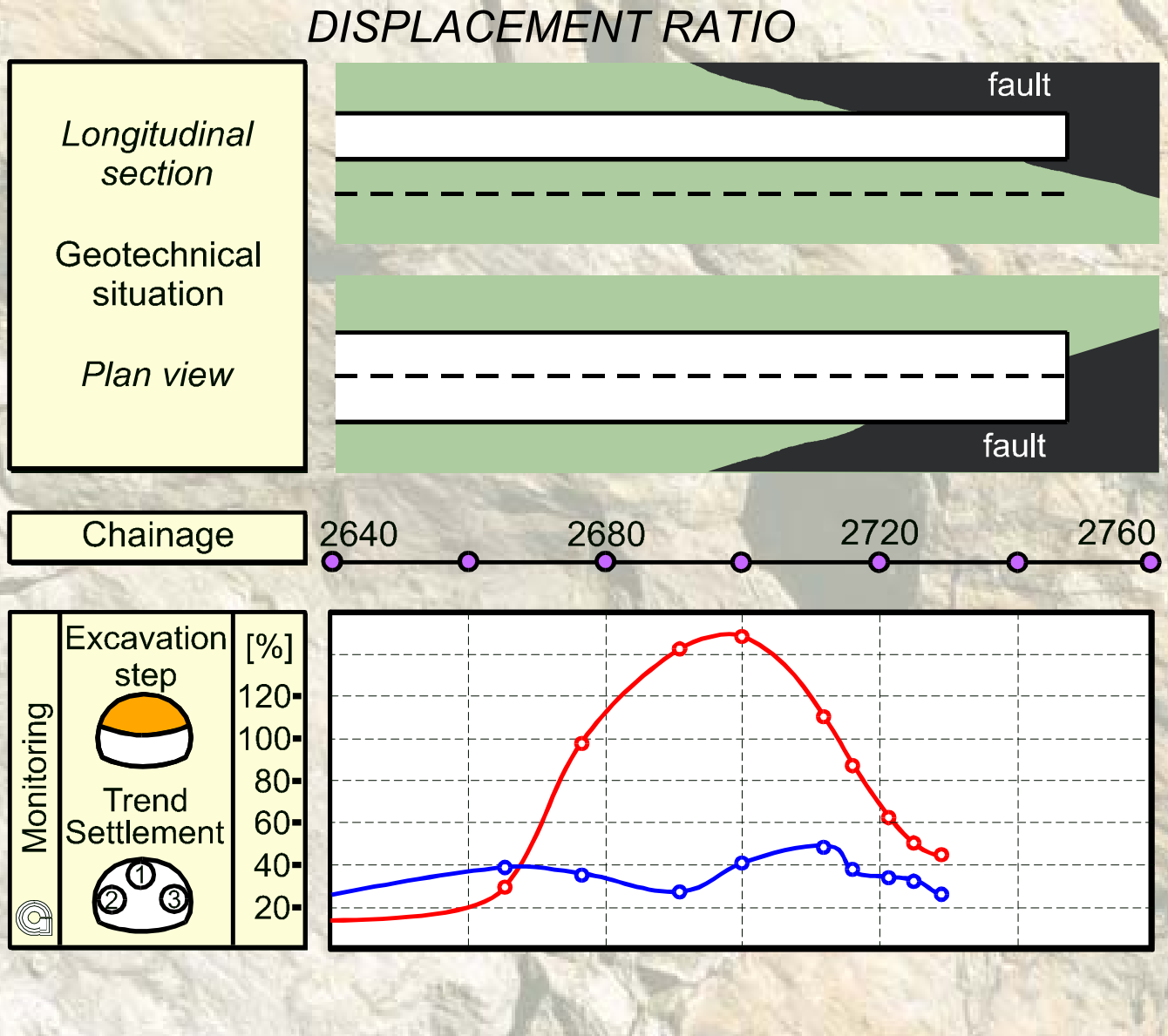
MONITORING / SHORT–TERM PREDICTION



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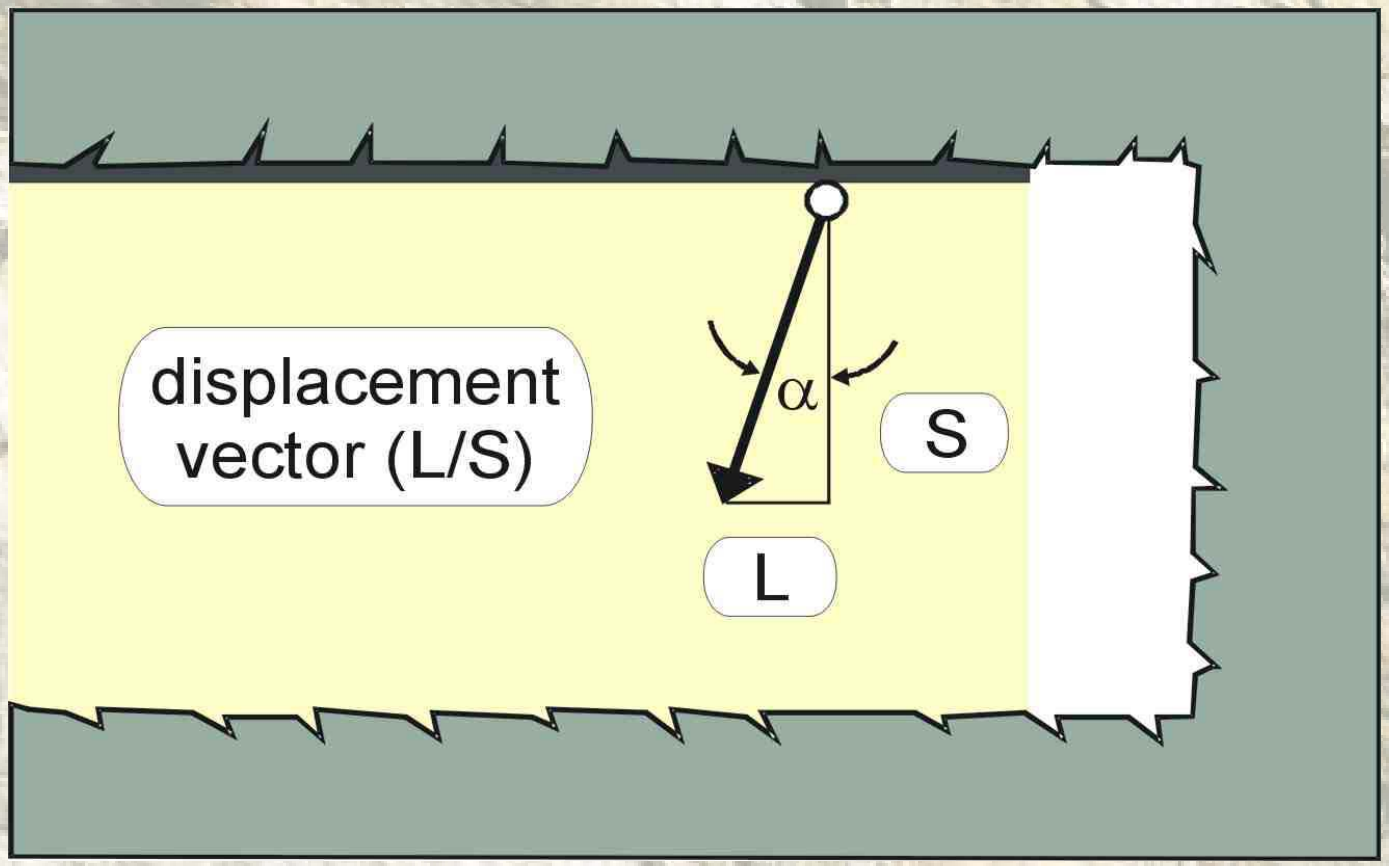
MONITORING / SHORT–TERM PREDICTION

DISPLACEMENT VECTOR ORIENTATION



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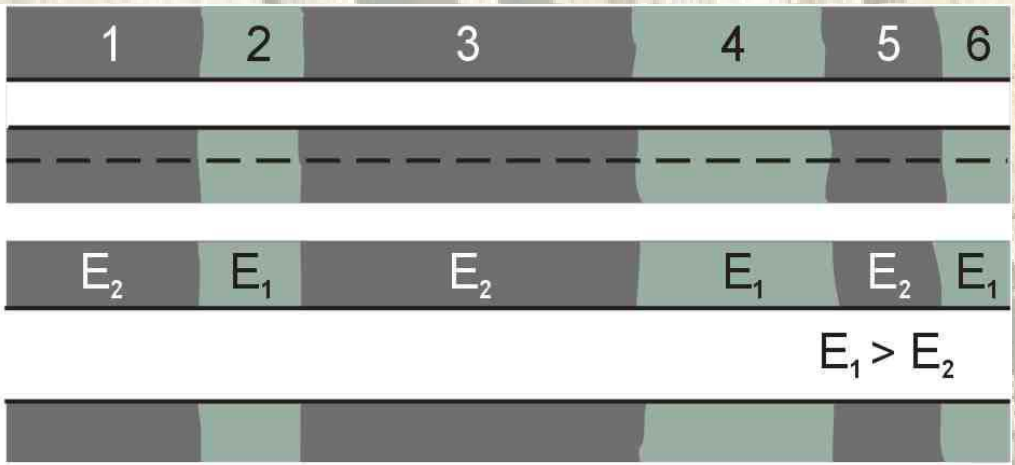
MONITORING / SHORT–TERM PREDICTION

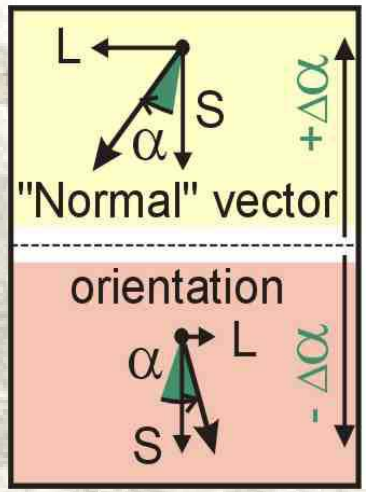
HETEROGENEITY – VECTOR ORIENTATION

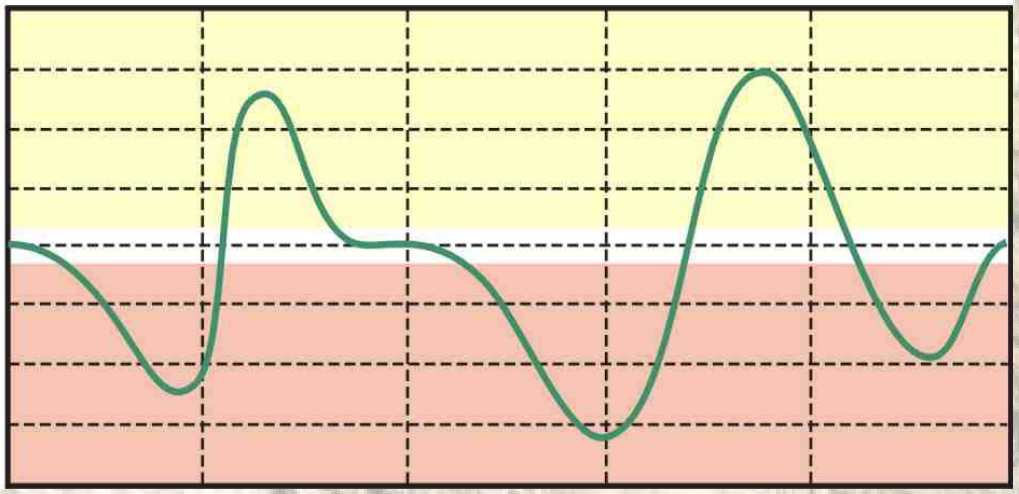
Longitudinal section

Geological situation

Plan view







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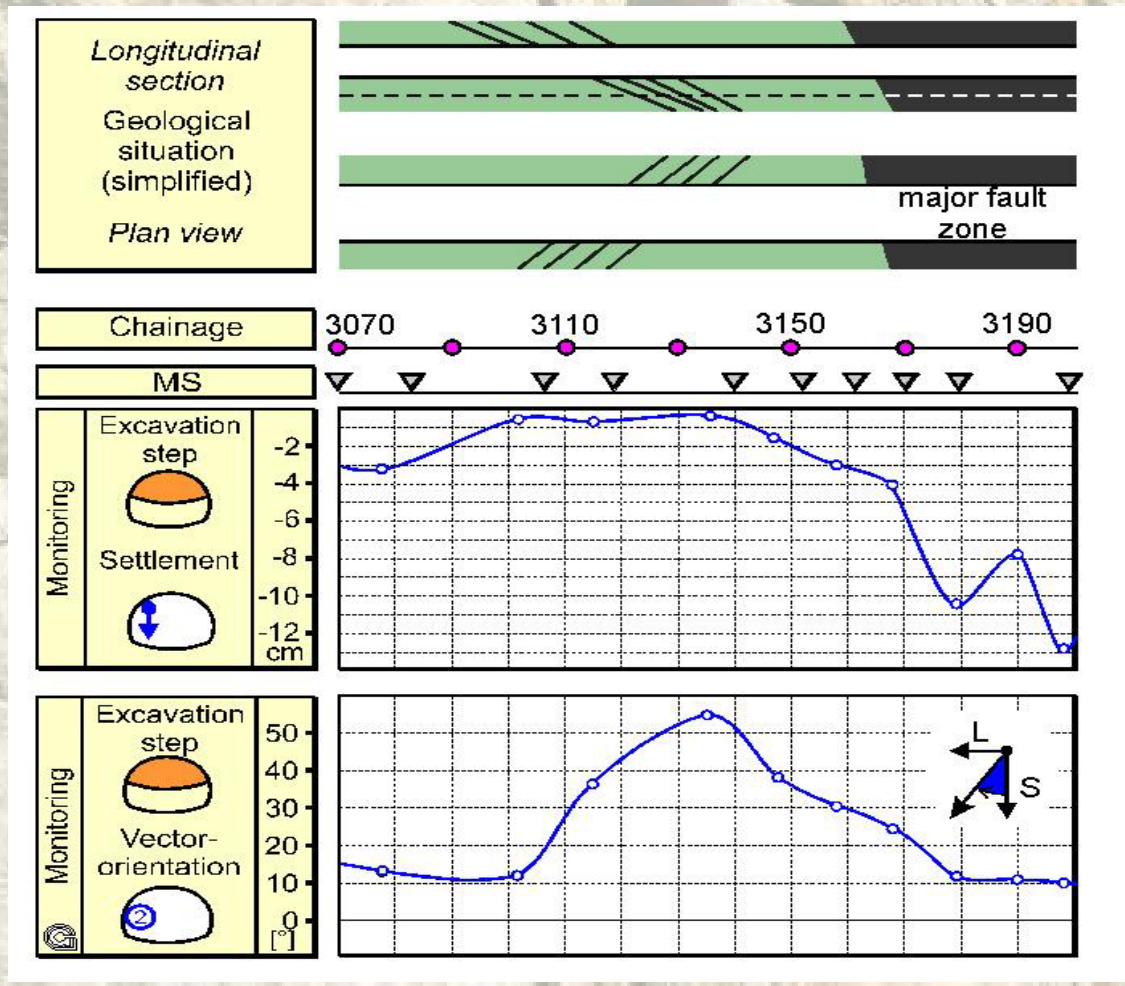
MONITORING / SHORT–TERM PREDICTION

SETTLEMENT & VECTOR ORIENTATION TRENDS



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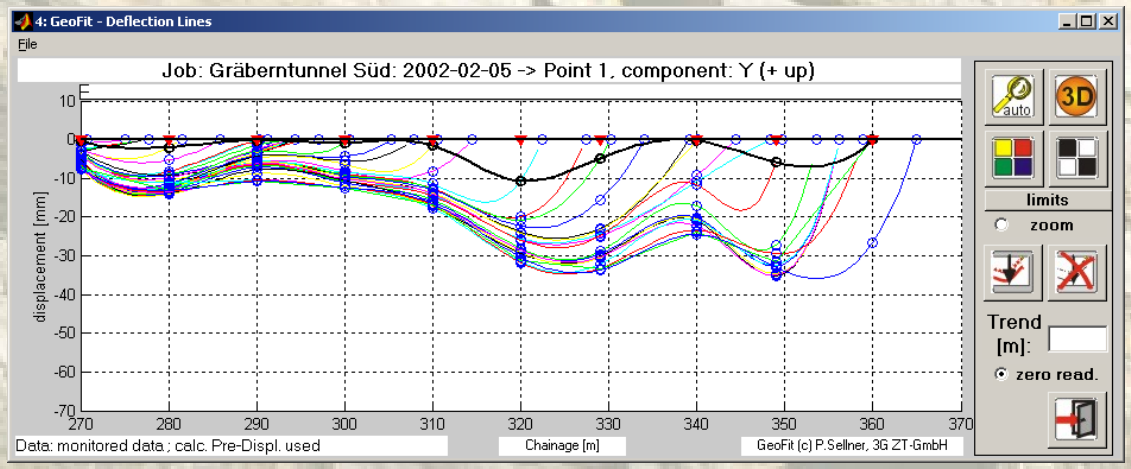
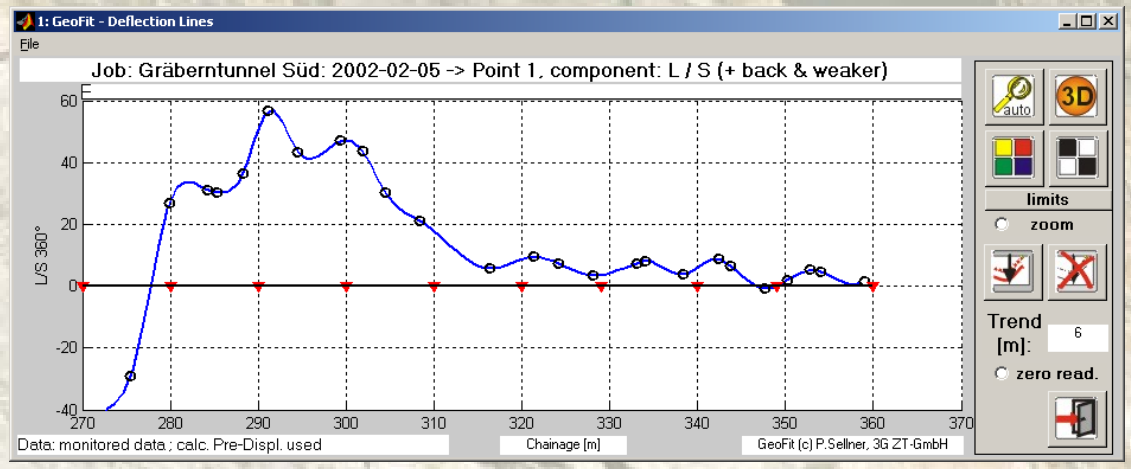
MONITORING / SHORT–TERM PREDICTION

DEFLECTION CURVE & VECTOR ORIENTATION TRENDS





Gräbern Tunnel, Austria

Construction

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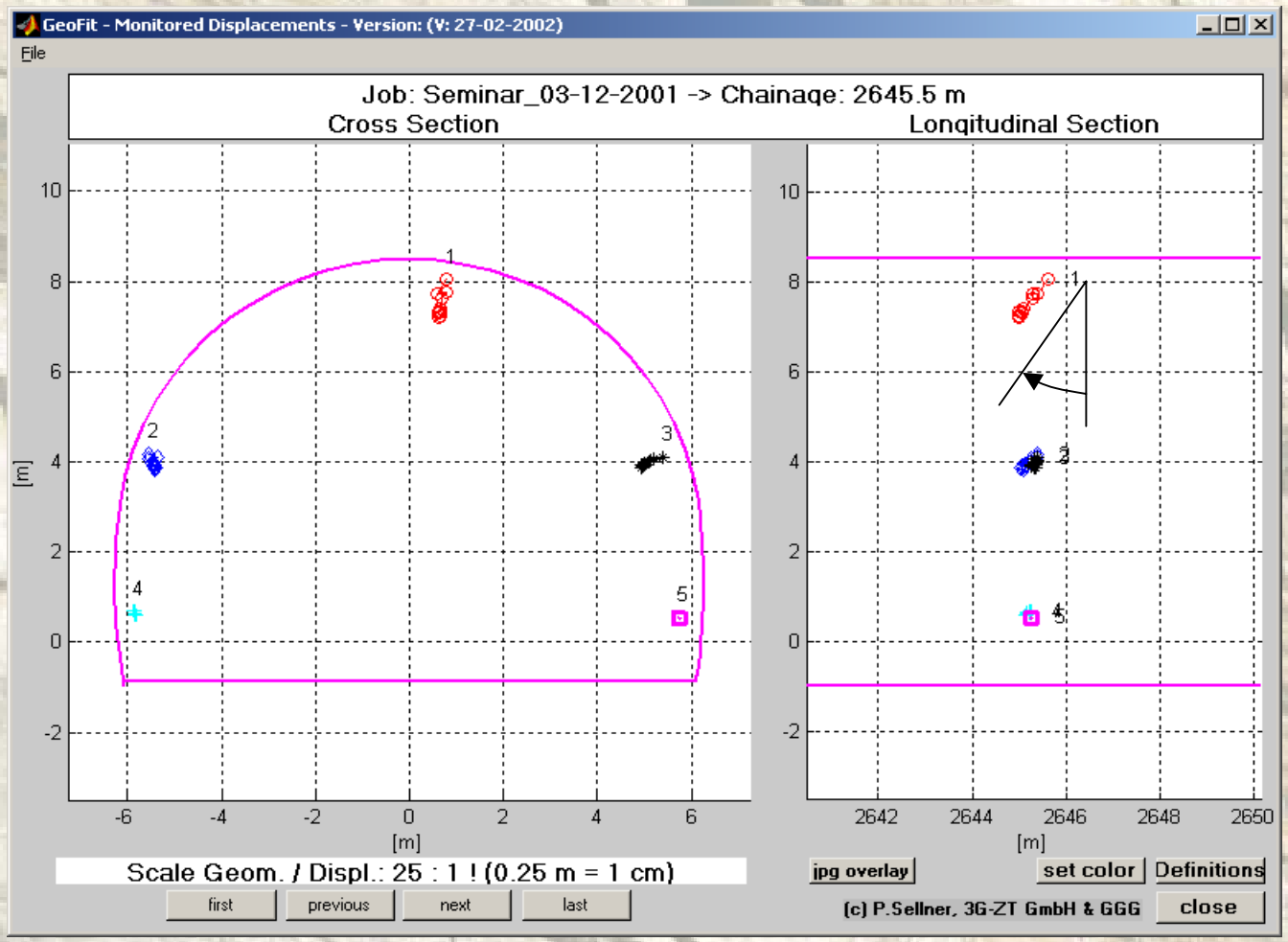
MONITORING / SHORT–TERM PREDICTION

DISPLACEMENT VECTORS



Inntal Tunnel, Austria

Construction

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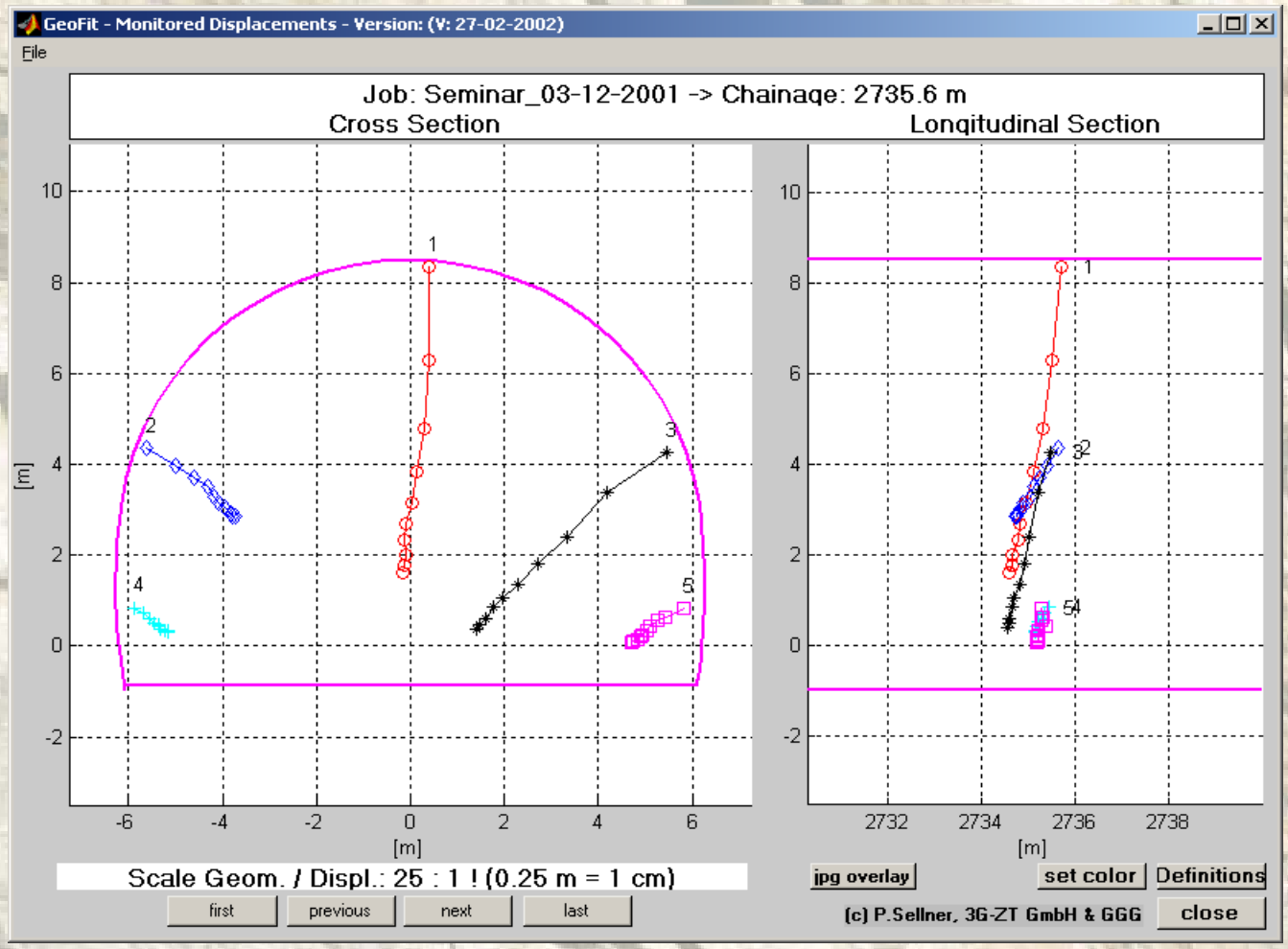
MONITORING / SHORT–TERM PREDICTION

DISPLACEMENT VECTORS



Inntal Tunnel, Austria

Construction

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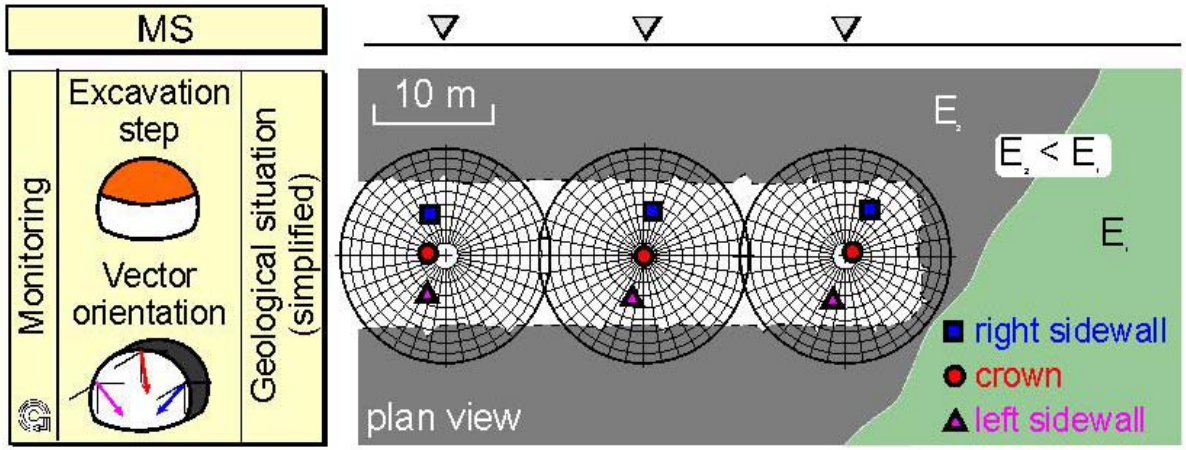
MONITORING / SHORT–TERM PREDICTION

SPATIAL DISPLACEMENT VECTOR



Construction

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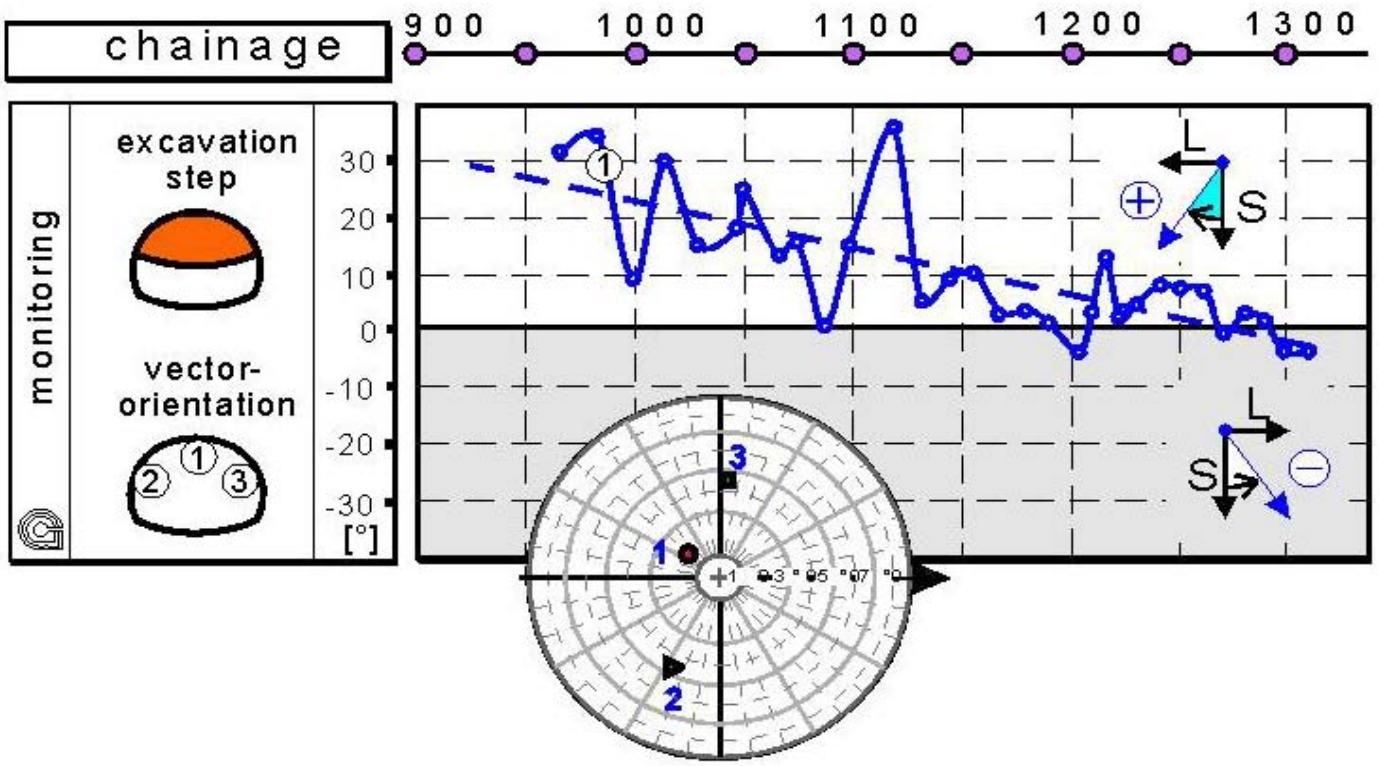
MONITORING / SHORT–TERM PREDICTION

VECTOR ORIENTATION - TREND



Hinterberg Fault Zone, Galgenberg Tunnel, Austria

Construction

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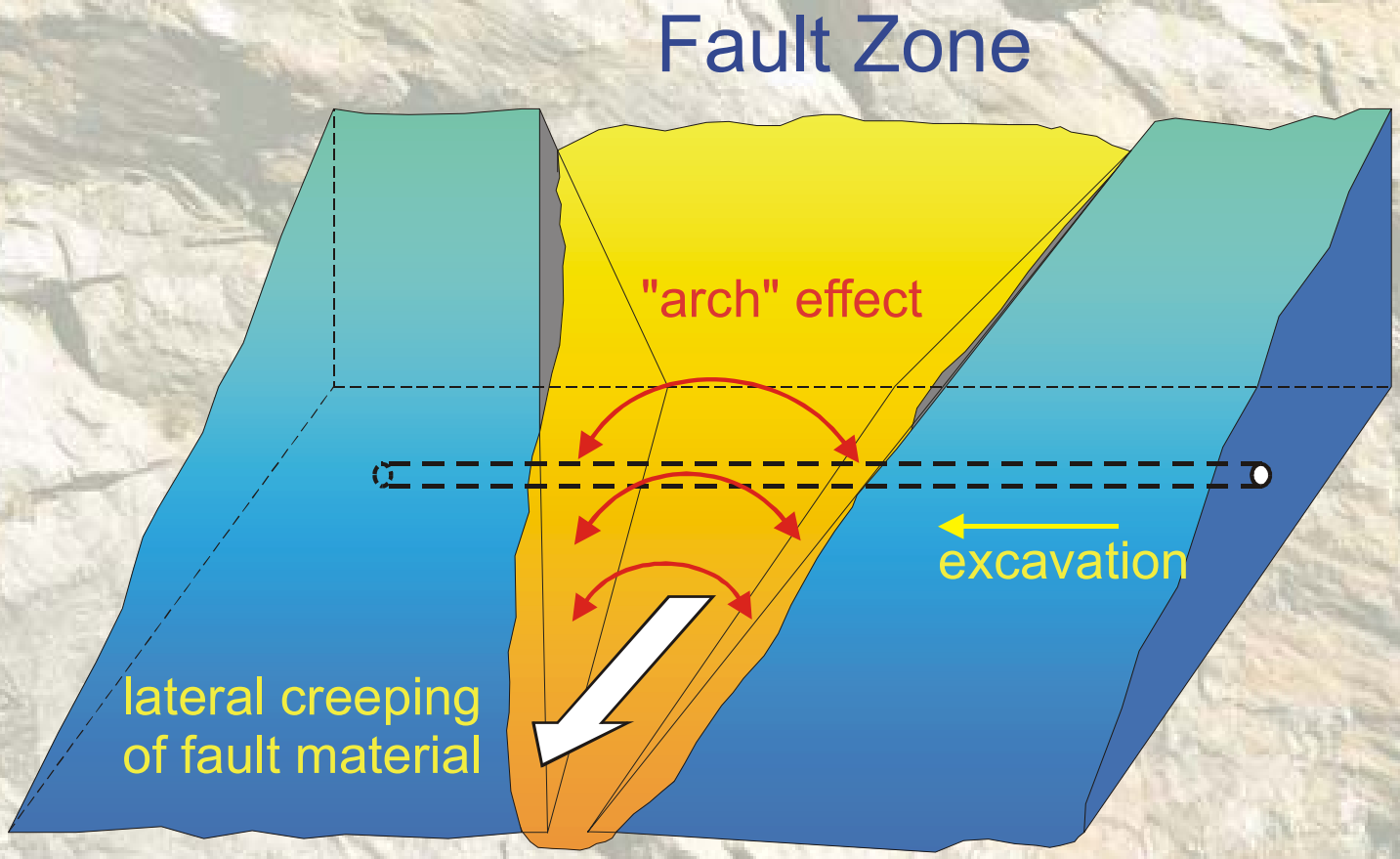
MONITORING / SHORT–TERM PREDICTION

ARCH EFFECT



Hinterberg Fault Zone, Galgenberg Tunnel, Austria

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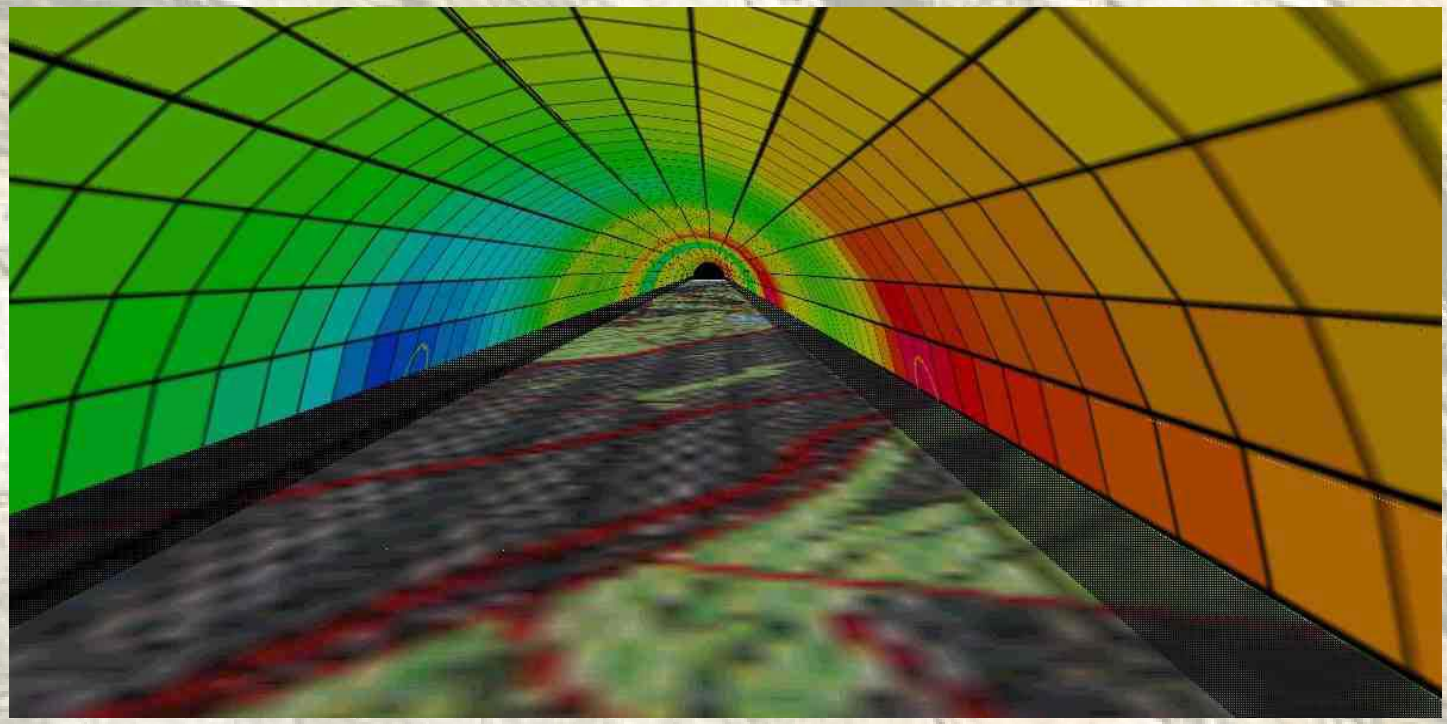
MONITORING / SHORT–TERM PREDICTION

VISUALIZATION OF MONITORED DATA



Hinterberg Fault Zone, Galgenberg Tunnel, Austria

Construction

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BIMROCK EFFECTS

- Mixed face conditions require different excavation methods on the same section
- Strong variation of rock mass quality
- Stress redistribution and deformations extremely influenced by arrangement of blocks and matrix
- Prediction of displacements and lining utilization extremely difficult
- Danger of brittle failures in blocks
- Difficulty to determine proper support

Construction

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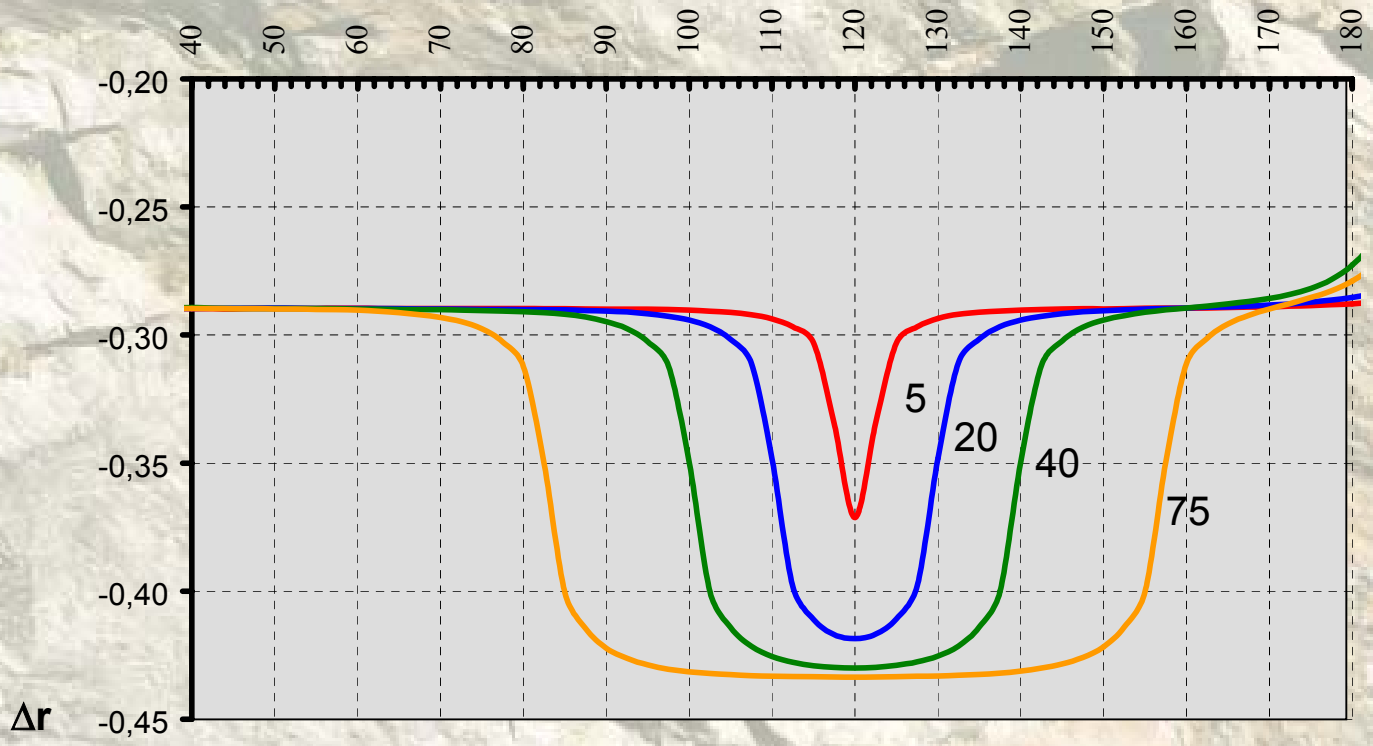
BIMROCK EFFECTS

DISPLACEMENTS IN MATRIX IN RELATION TO BLOCK DISTANCE PROBLEMS

- Displacements depend on the length of the weak zone between two stiff blocks



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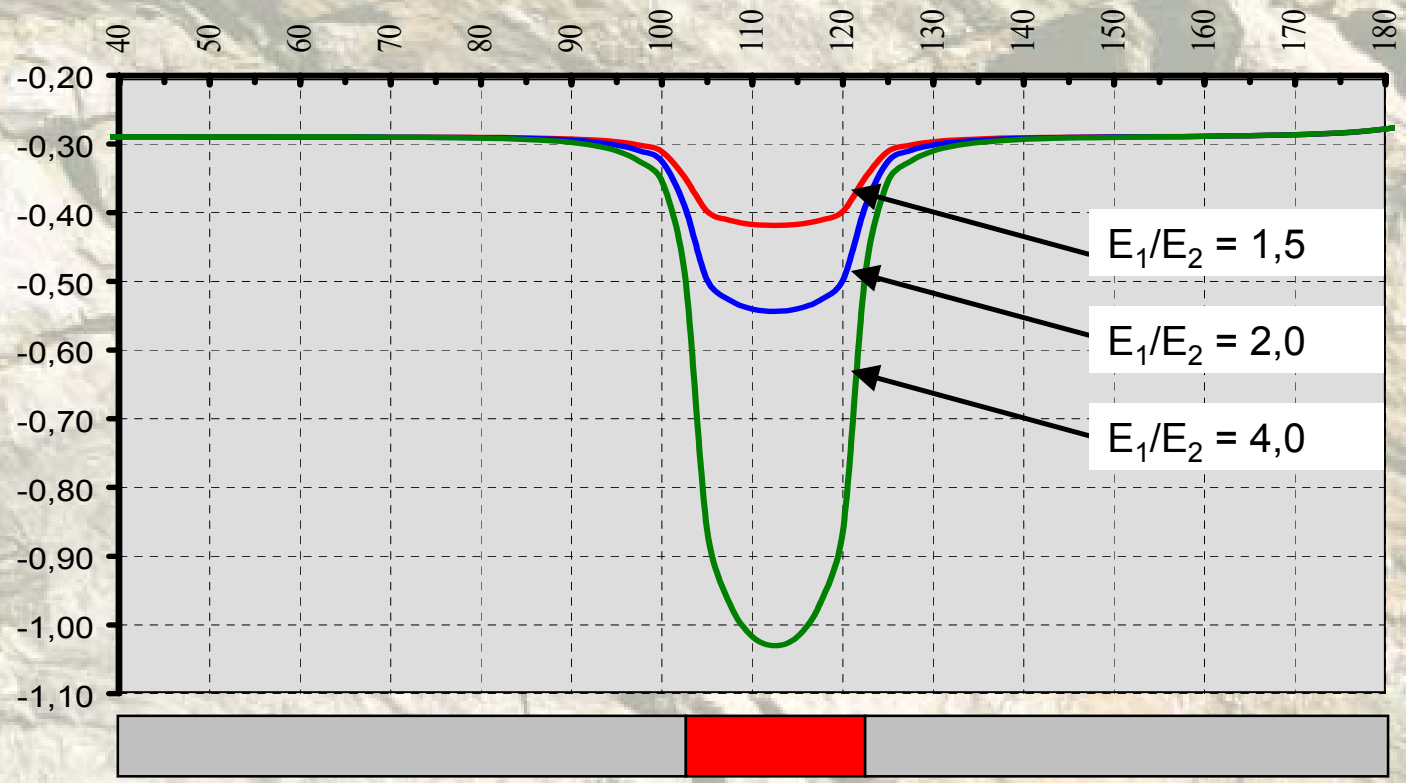
BIMROCK EFFECTS

DISPLACEMENTS

- Final displacements influenced by zone length and stiffness contrast



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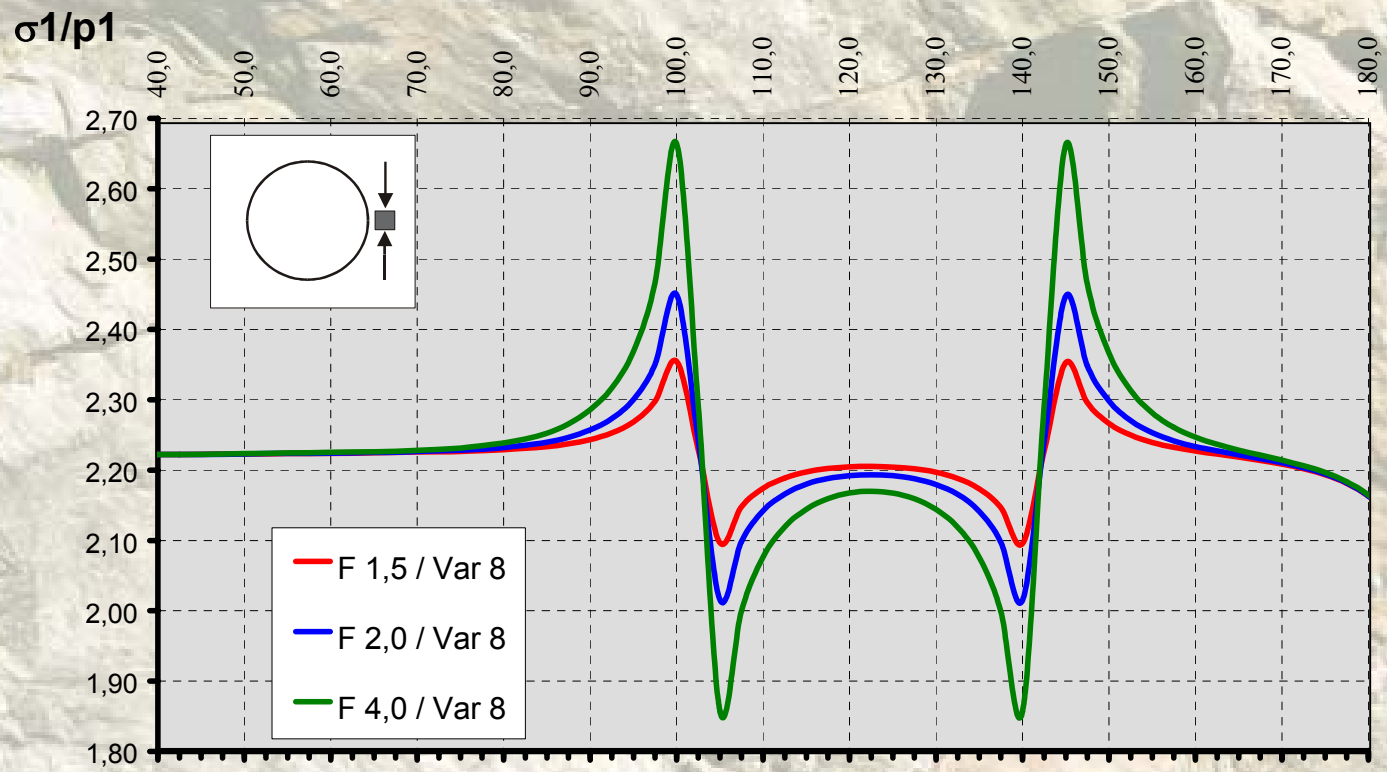
BIMROCK EFFECTS

STRESS DISTRIBUTION

- Stress concentation in blocks depend on stiffness contrast and distance between blocks



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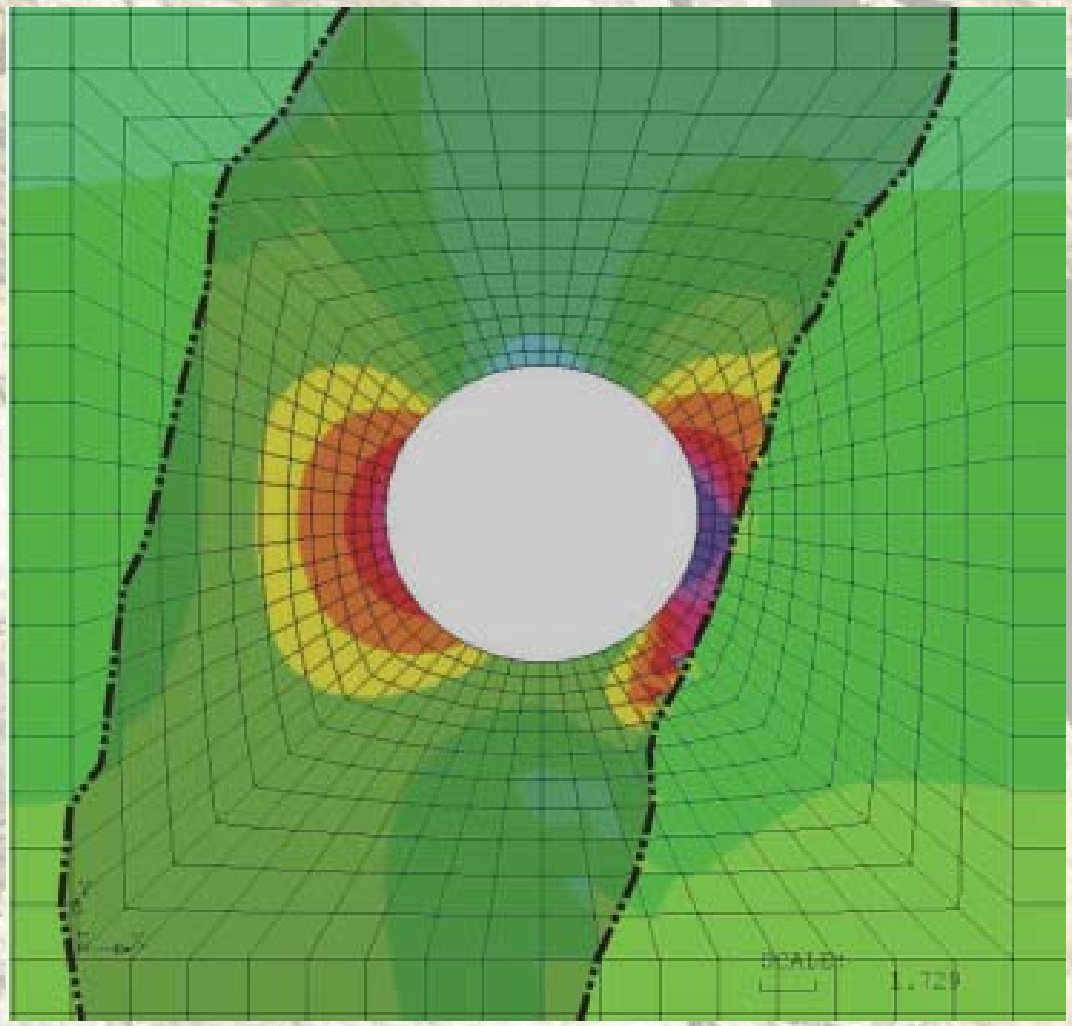
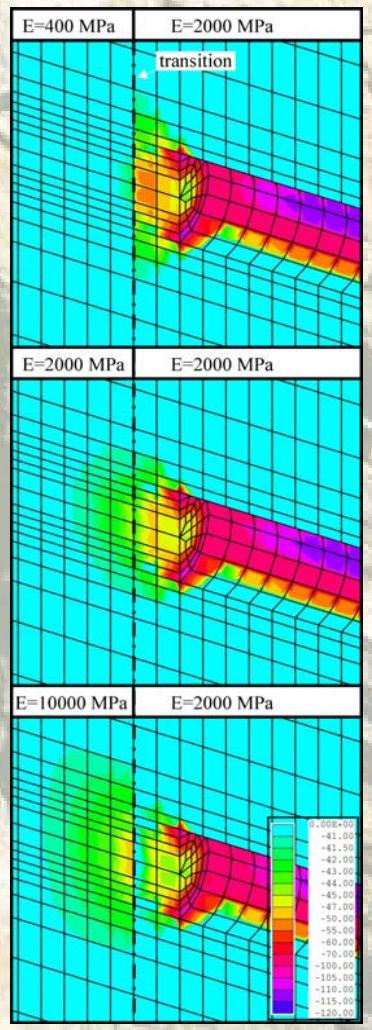
BIMROCK EFFECTS

STRESS CONCENTRATIONS





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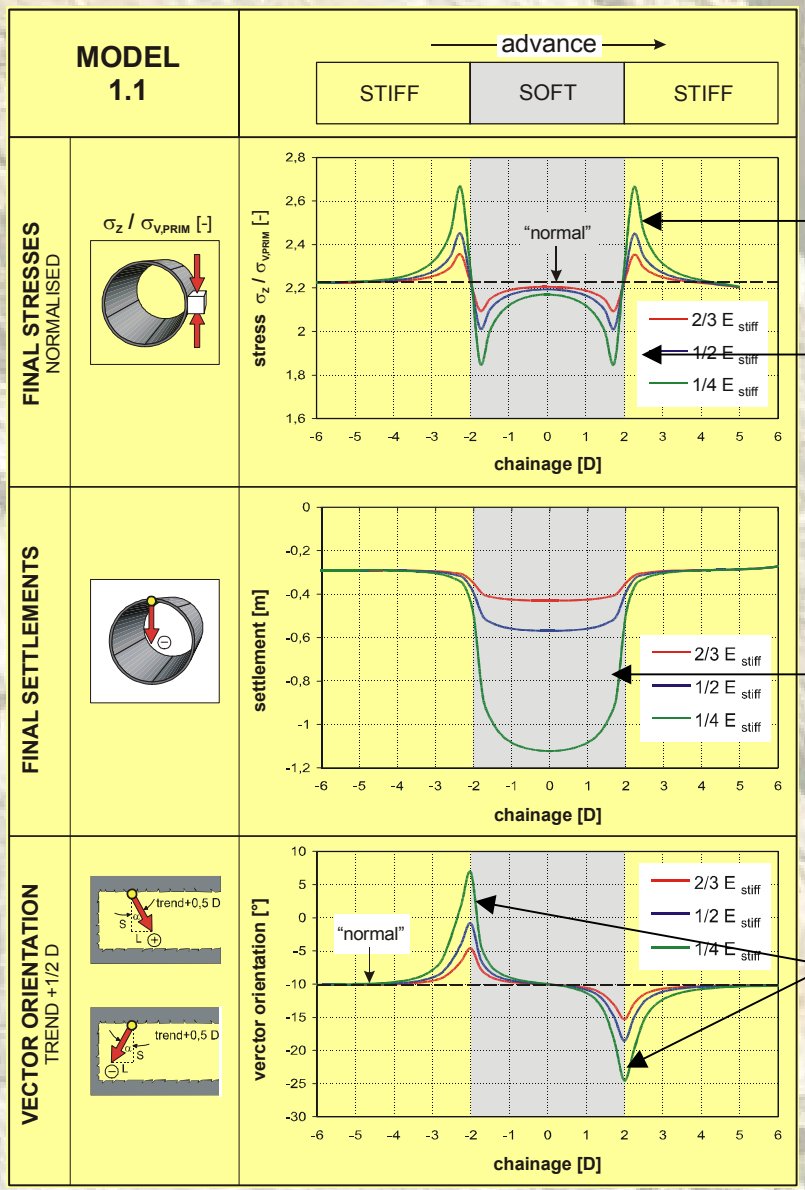
BIMROCK EFFECTS



STIFF-SOFT-STIFF

Relative stress increase in stiff material

Relative stress decrease in soft material

Trough shaped displacement

Change of displacement vector orientation near transition

Construction

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BIMROCK EFFECTS

BLOCK REINFORCEMENT

- Stress concentrations can cause brittle failure in stiff blocks
- Resulting stress redistribution leads to additional displacements in the matrix material

- Knowledge of the spatial distribution of blocks and matrix essential to properly estimate stress situation
- Short term prediction and prediction of displacements extremely important
- Support / reinforcement of blocks necessary to avoid brittle failure and long term stress redistribution, frequently mistaken for creeping

Construction

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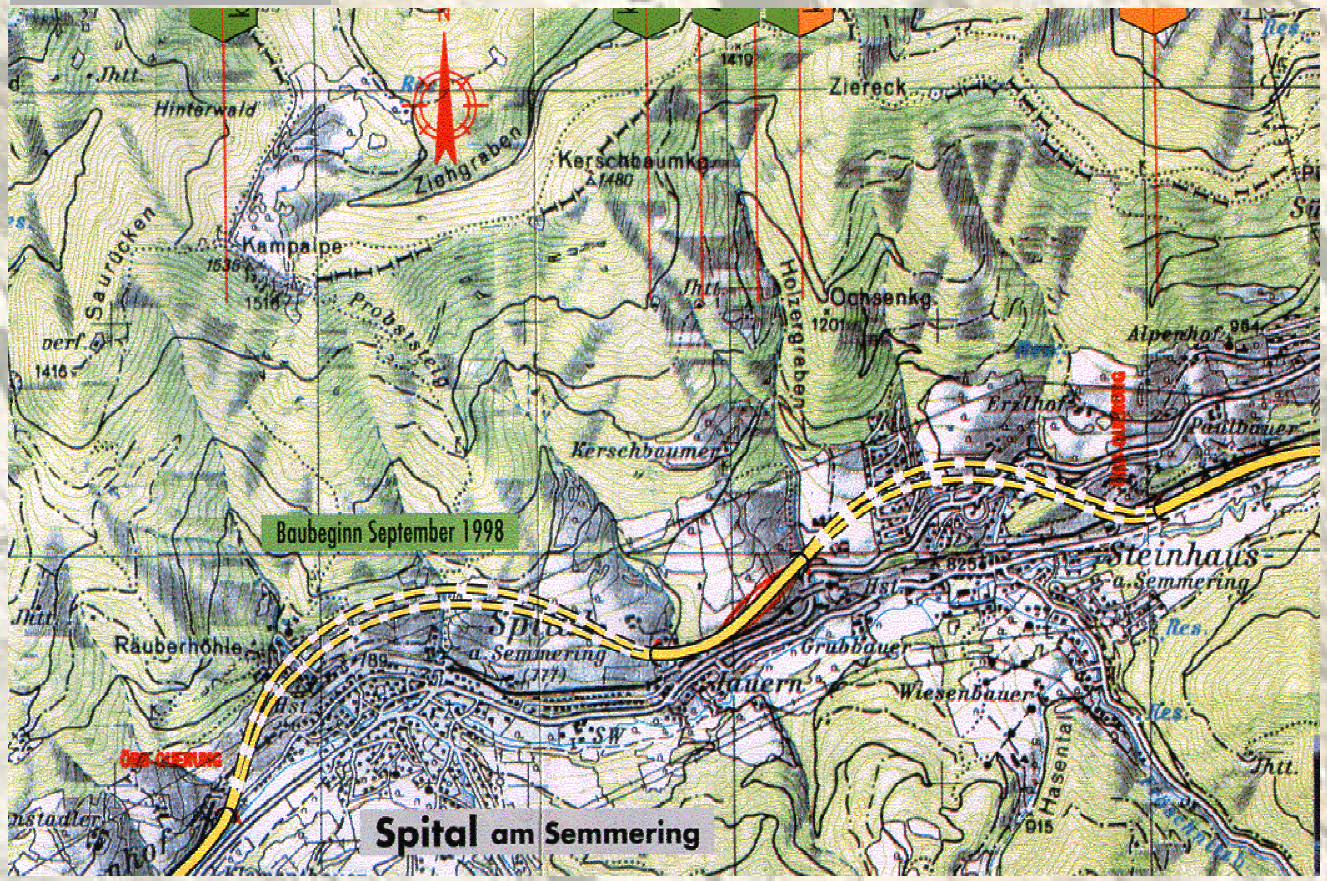
BIMROCK EFFECTS

CASE STUDIES

Location Map



Tunnel Spital, Austria

Construction

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BIMROCK EFFECTS

CASE STUDIES

Project data

- Twin 2,2 km long freeway tunnels in the Semmering region, eastern Austria
- Alignment along a major fault zone
- Excavation area 70 – 90 m2
- Underpassing of a railway line and built up area
- Maximum overburden 80 m

Tunnel Spital, Austria

Construction

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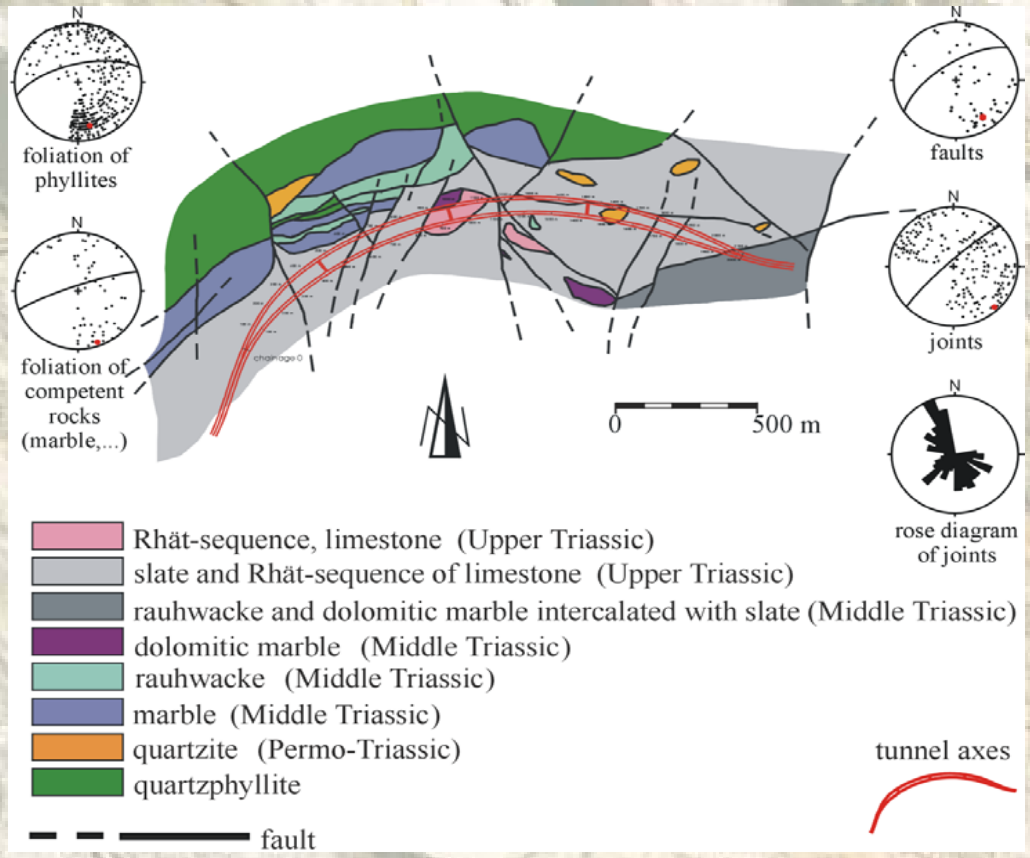
BIMROCK EFFECTS

CASE STUDIES

Geological overview



Tunnel Spital, Austria

Construction

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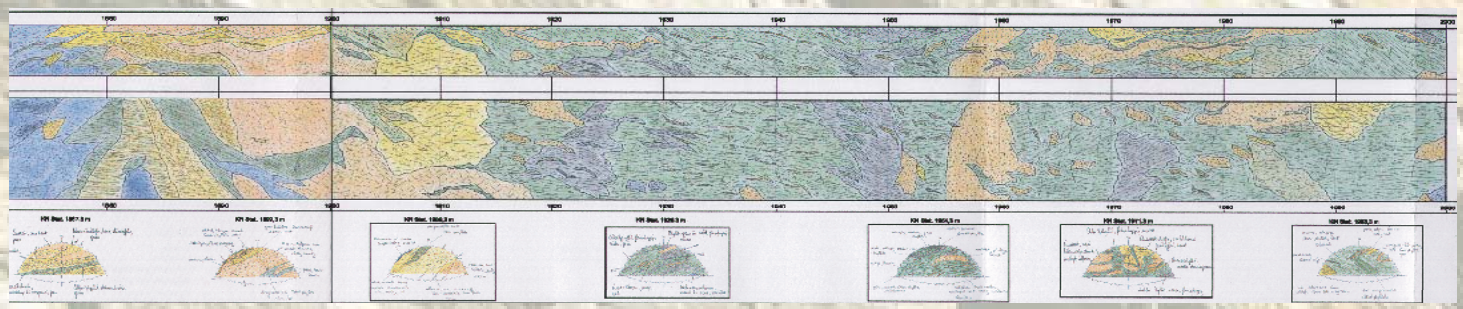
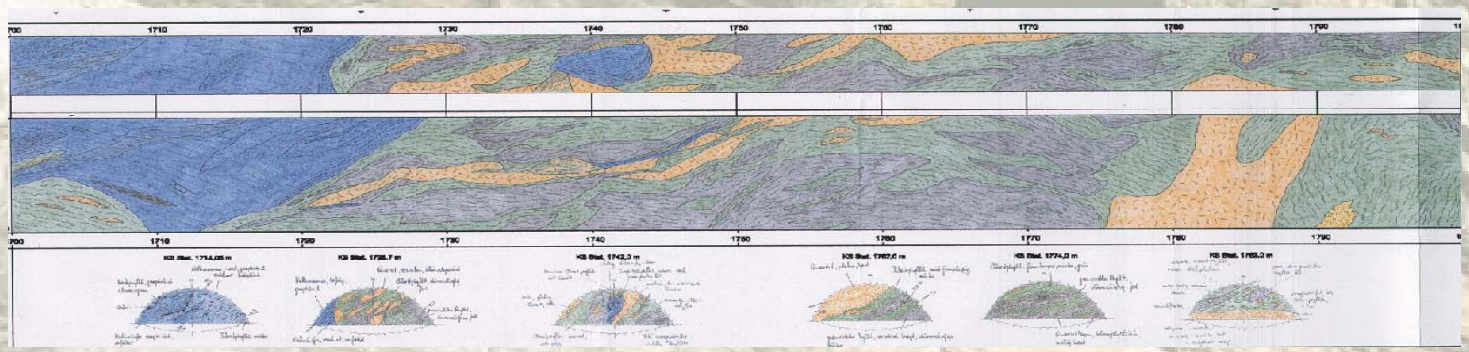
BIMROCK EFFECTS

CASE STUDIES

Geological overview



Nord tube: 1870-2000m



South tube: 1700-1800m

Tunnel Spital, Austria

Construction

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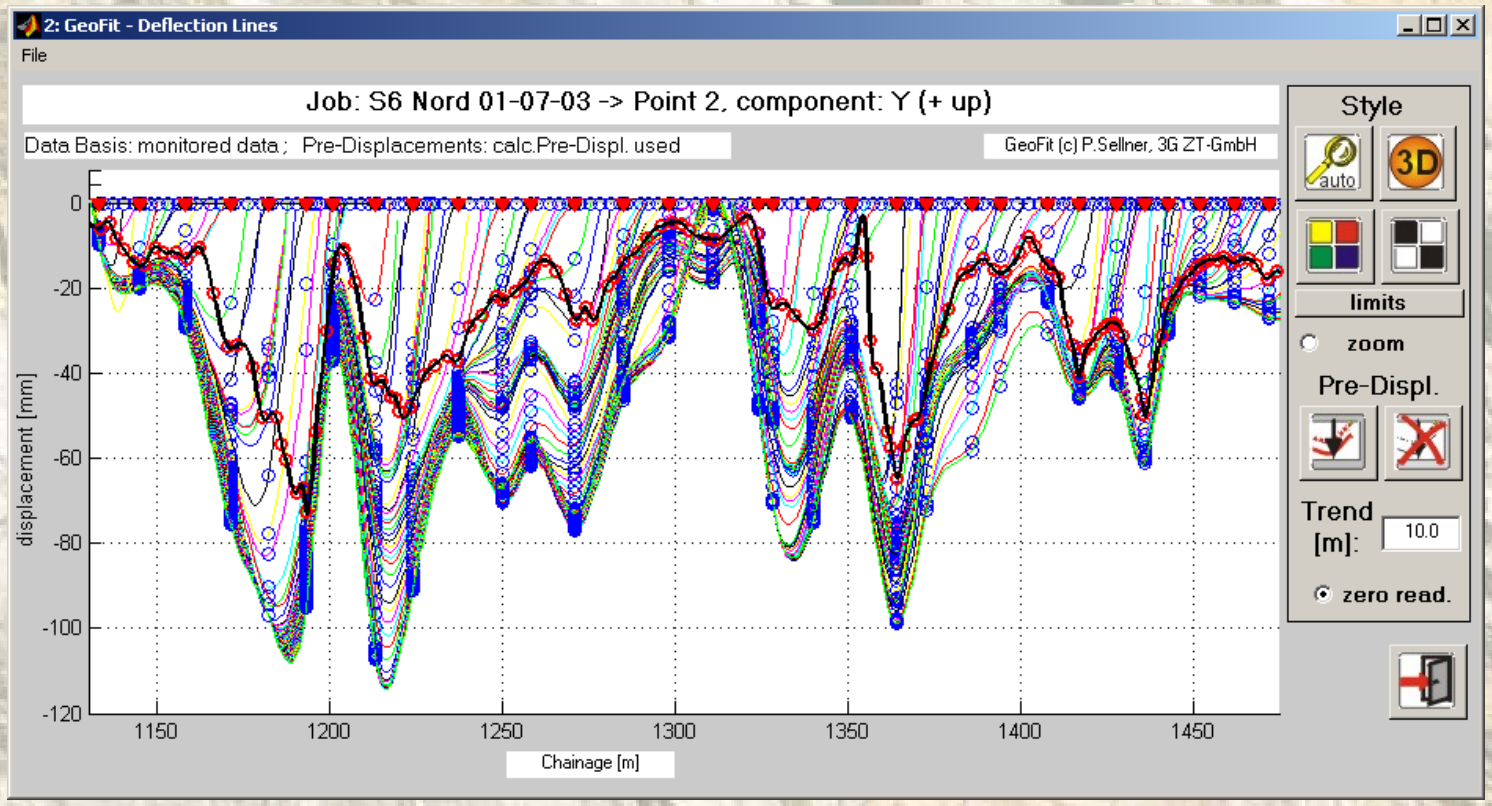
BIMROCK EFFECTS

CASE STUDIES

Heterogeneity - Displacements



Tunnel Spital, Austria

Construction

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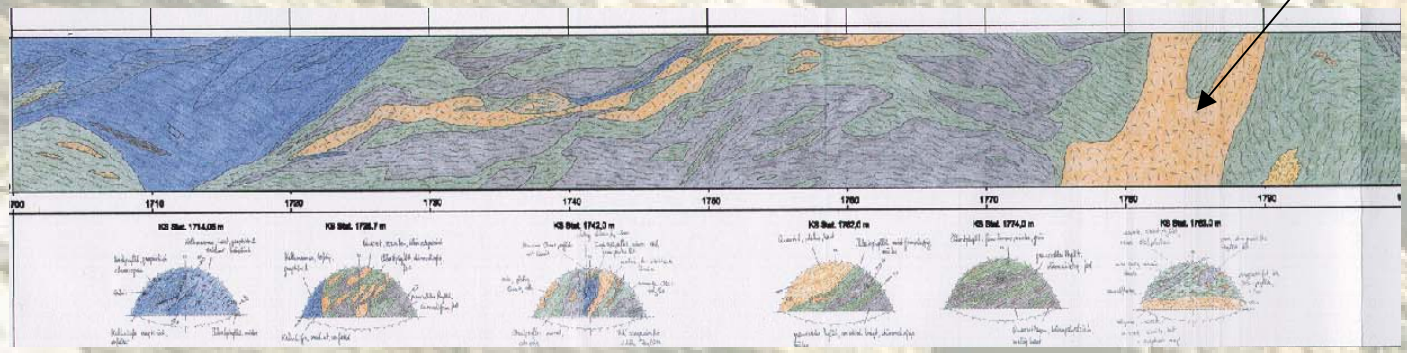
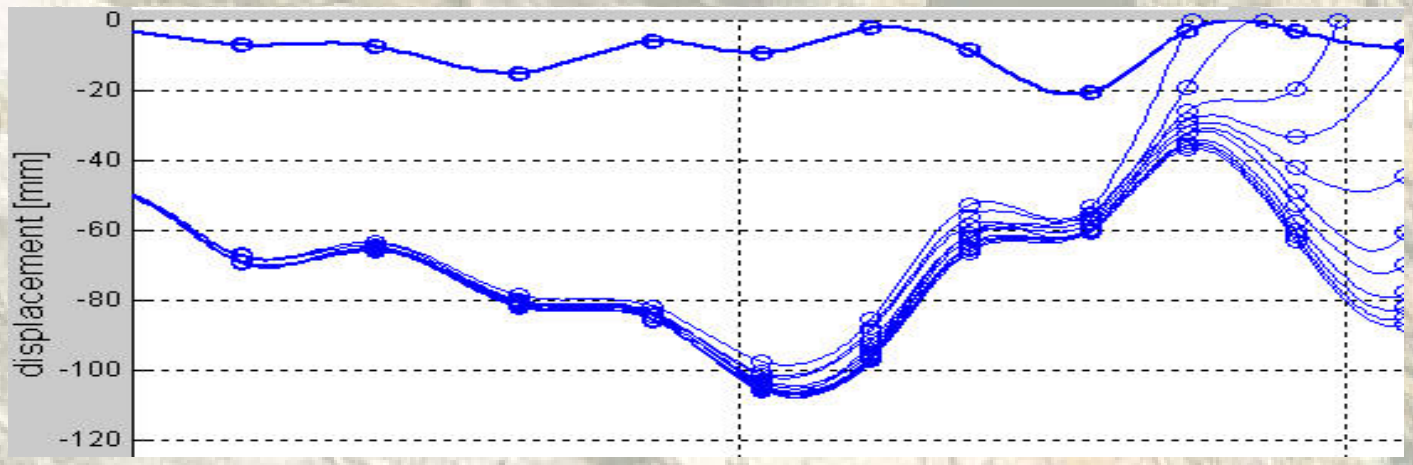
BIMROCK EFFECTS

CASE STUDIES

Block effect on displacement
settlement crown / top heading





Tunnel Spital, Austria

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BIMROCK EFFECTS

CASE STUDIES

Cross sections

1773

1777

1779

1785

1788

1790

Tunnel Spital, Austria

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BIMROCK EFFECTS

CASE STUDIES

Bench excavation

Tunnel Spital, Austria

Construction

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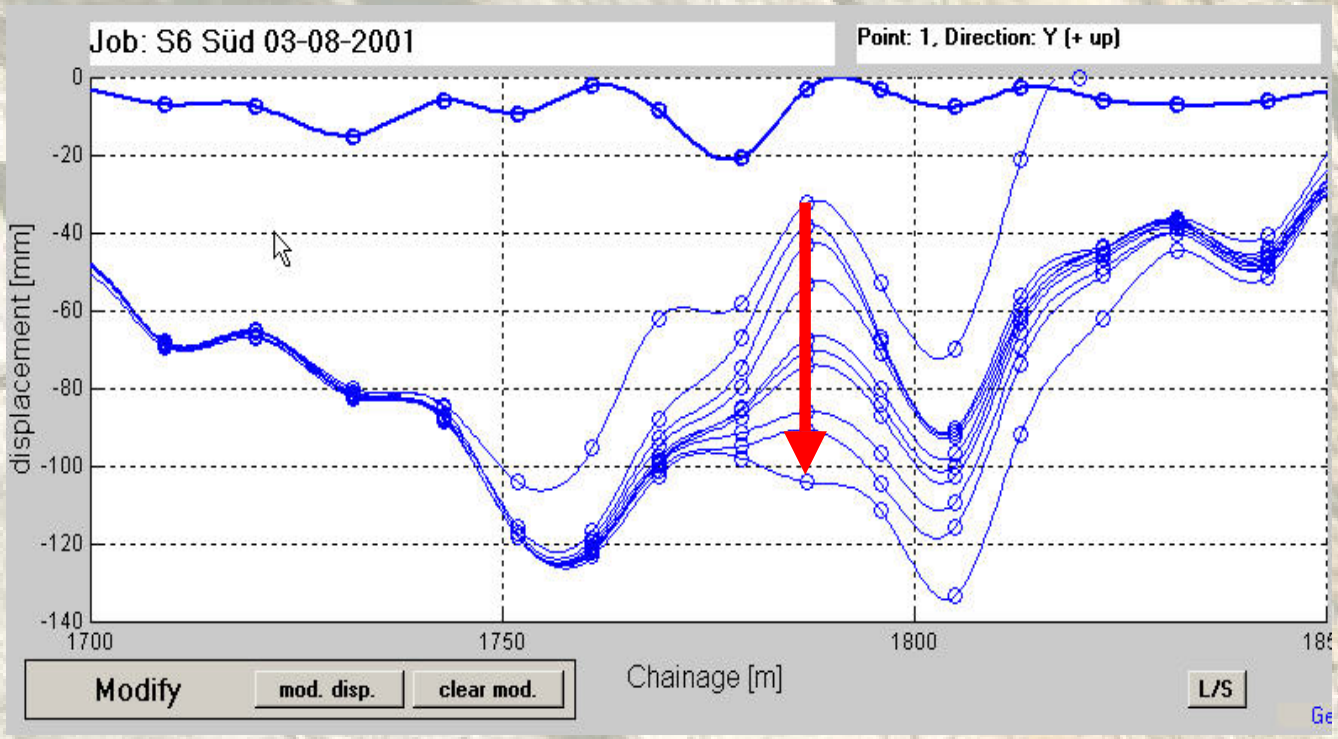
BIMROCK EFFECTS

CASE STUDIES

Failure of block

- During bench excavation the block fails, leading to additional 60 mm of settlement



Tunnel Spital, Austria

Construction

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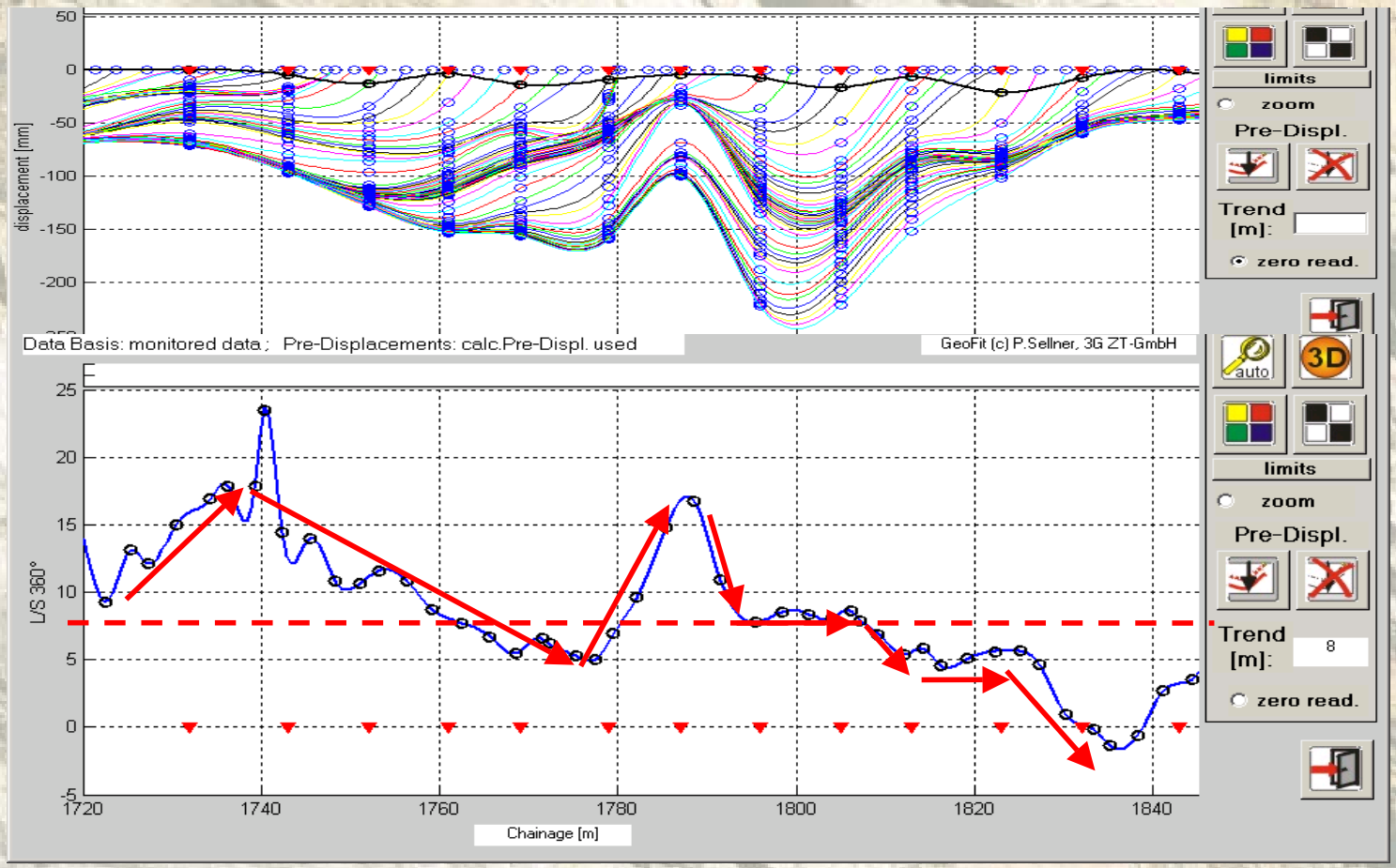
BIMROCK EFFECTS

CASE STUDIES

Final displacements & displacement vector orientation trend



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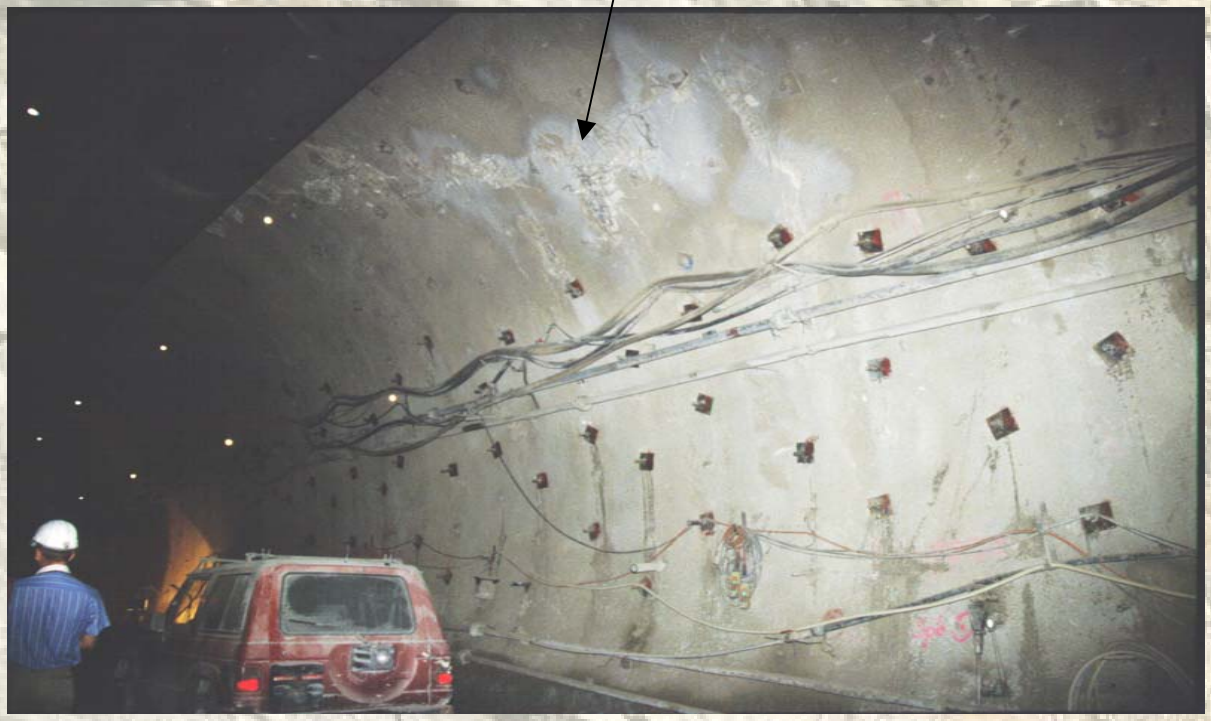
BIMROCK EFFECTS

CASE STUDIES

DAMAGES

cracks in the shotcrete on the southern sidewall



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BIMROCK EFFECTS

CASE STUDIES

Project Data

Single tube double track railway tunnel, length 5142 m, maximum overburden 260 m. Design from 1990 to 1992. The construction (three headings) started in June 1993 and was completed in April 1996.

Tasks

Geological – geotechnical site investigation from the feasibility study to the tender design. Consultant services during construction

Geology

Paleozoic graphitic phyllite, greenschist and marble as well as Permo-Triassic quartzite, quartzphyllite and agglomerate were subjected to intense Alpine thrusting and Tertiary strike-slip faulting

Galgenberg Tunnel, Austria

Construction

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BIMROCK EFFECTS

CASE STUDIES

Collapse

A collapse with fatal accident happened on July 1994 at station 1330 m.
Eight meters of heavily supported tunnel section collapsed at the face.
A miner, including excavation equipment, was buried under the collapsed rock mass.
Redesign and maintenance work lasted for two months.
The excavation was resumed in October 1994.

Galgenberg Tunnel, Austria

Construction

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BIMROCK EFFECTS

CASE STUDIES

Collapse

Collapse caused by brittle failure of stiff rock outside of excavation

Galgenberg Tunnel, Austria

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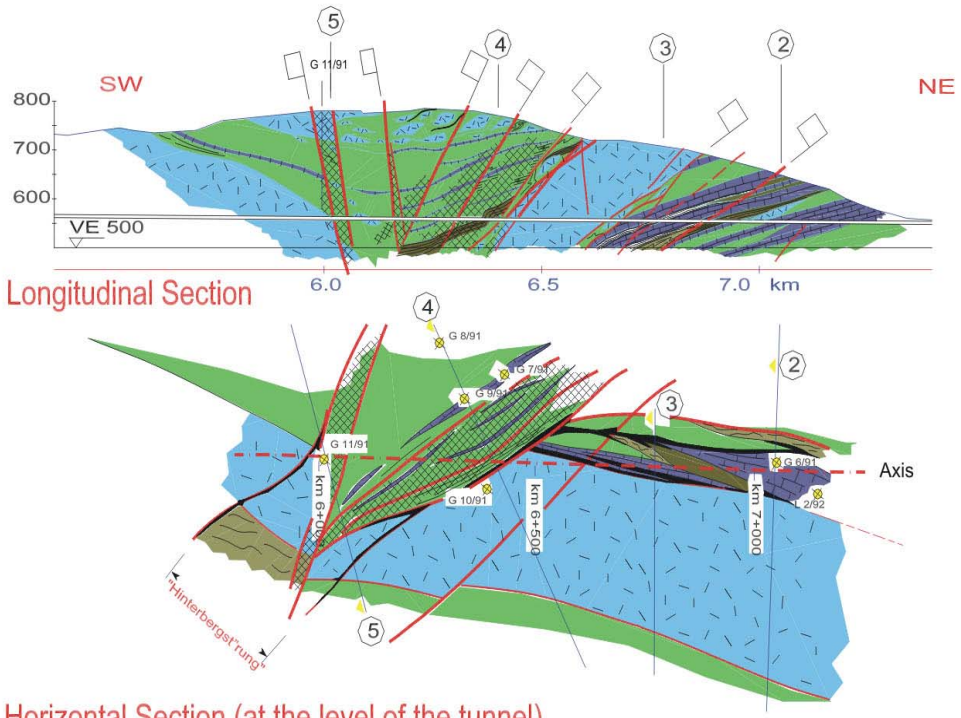
BIMROCK EFFECTS

CASE STUDIES

HINTERBERG FAULT ZONE
Prediction



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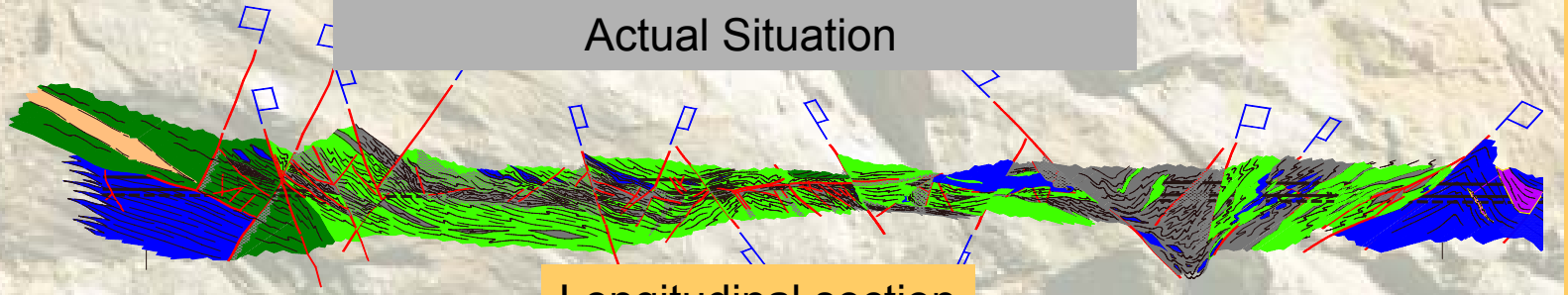
BIMROCK EFFECTS

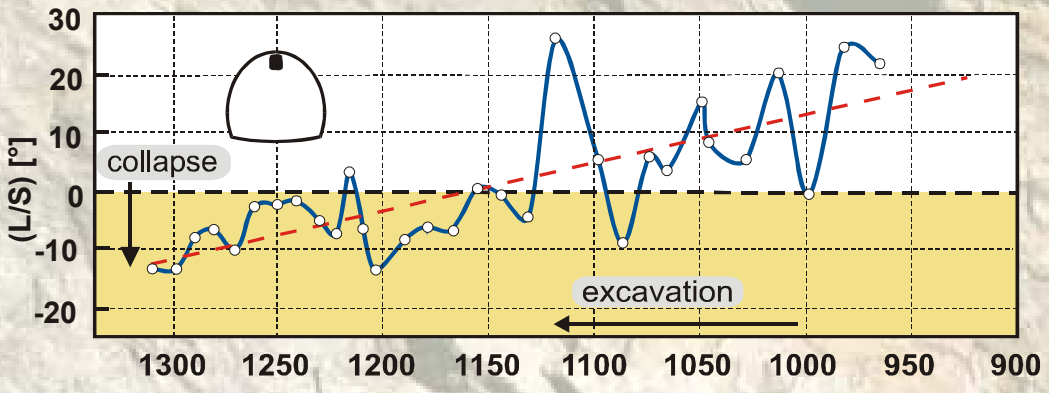
CASE STUDIES

HINTERBERG FAULT ZONE
Actual Situation



Longitudinal section

Plan view



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BIMROCK EFFECTS

CASE STUDIES

HABERL FAULT - IMPROVED PROCEDURE

Modification of excavtion and support – reduction of top heading heigth, yielding elements, regroutable rock bolts

Galgenberg Tunnel, Austria

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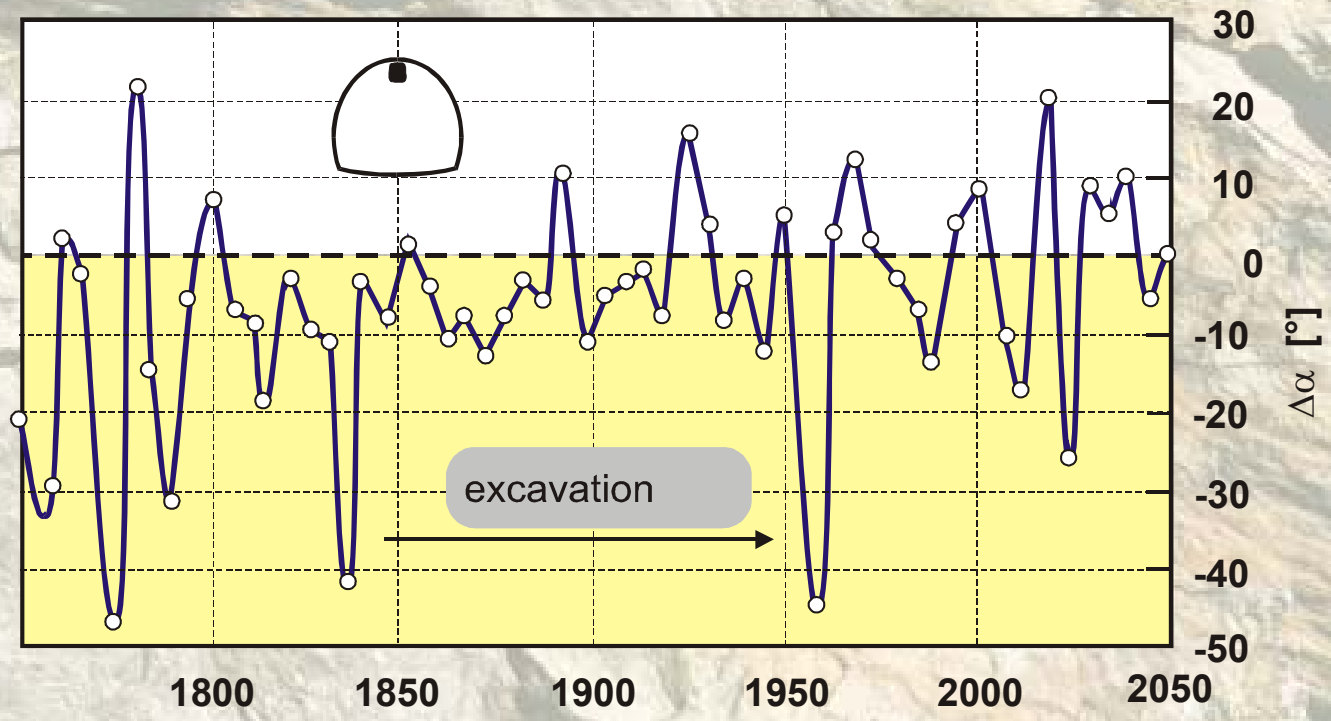
BIMROCK EFFECTS

CASE STUDIES

HABERL FAULT ZONE

Heterogeneity showing in strong variation of the vector orientation trend



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BIMROCK EFFECTS

CONCLUSION

- The complex spatial distribution of rock masses with different stiffness and strength makes prediction of behaviour difficult
- High displacments as well as differences in displacements can lead to severe damage of the (stiff) lining; thus flexible linings are required where bigger displacements are expected, and preferable even in shallow tunnels
- The analysis of the diplacement vector orientations can support the prediction of the location and distribution of blocks

Construction

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