

Application of Drilling Monitoring Parameters in Tunnelling

With focus on excavation damage, rock mass characterisation and rock support design

Användning av borrarparameterna i Tunneldrivning Med fokus på sprängskador, bergmassakarakterisering och bergförstärkningsdesign

Jeroen van Eldert

Project conclusions: **2015-2019**

- Blast damage can be measured during tunnel excavation, by:
 - Ground Penetration Radar
 - Fracture density of drill cores
 - P-wave velocity along drill cores
- Drill monitoring in tunnel construction has potential to:
 - Improve the accuracy of rock mass characterisation
 - Improve rock support design process
 - Predict the extent of blast damage

BeFo Project 344

Problem statements:

- Actual blast damage is not measured during tunnel excavation
- Site investigations in tunnelling projects provide limited knowledge on actual rock mass conditions
- Project aims:
 - Measuring the extent of blast damage
 - Drill monitoring for rock mass quality assessment
 - Implement drill monitoring for improving rock support design process
 - Drill monitoring to predict blasting damage

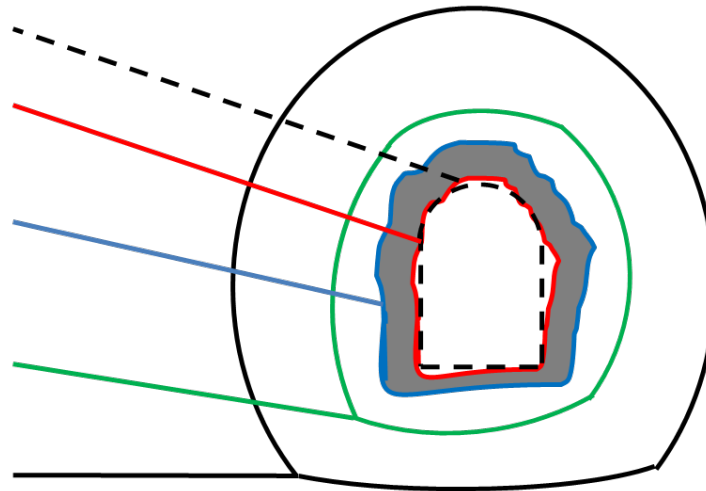
Planned Profile

Over-break

Blasting Induced
Damage

Stress Induced
Damage

Stress Influence



Excavation damage is defined as “an irreversible damage to the rock resulting from the creation of an opening” (Martino and Chandler 2004)

The excavation damage zone can be split in the different areas, the over-break, blasting induced damage and stress induced damage. The focus of this project was to determine the blasting induced damage.

Measurement While Drilling Technology

Drill monitoring data

- Continuously recording by the drill rig
- Objective data (machine data)
- Technology developed in the 1990s
- Available on AMV, Epiroc and Sandvik rigs
- Processing with e.g. Underground manager MWD, iSure, Rockma's GPM+ and Bever Team 3

Measurement While Drilling Indices

- Hardness Index: "Drillability" of the rock mass
- Fracture Index: "Heterogeneity" of the rock mass
- Water Index: "Water loss" in fractures during drilling

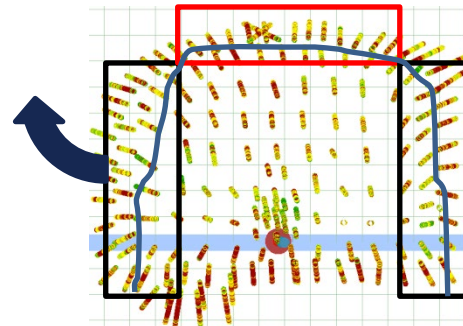
Drill rig for data collection



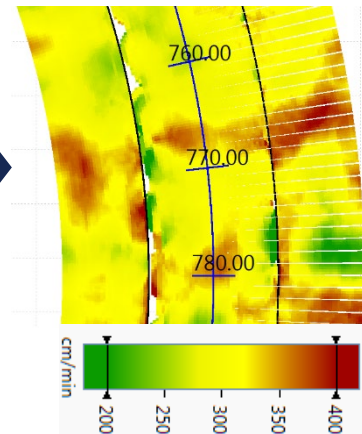
Collected MWD data

```
Time: 0.00  
Drill Type:   
Drill ID: 001_01_01_01_01_01  
Drill Length: 1000  
Drill Diameter: 100  
Drill Speed: 1000  
Drill Feed: 100  
Drill Torque: 100  
Drill Power: 100  
Drill Pressure: 100  
Drill Temperature: 100  
Drill Vibration: 100  
Drill Noise: 100  
Drill Acceleration: 100  
Drill Deceleration: 100  
Drill Jerk: 100  
Drill Shock: 100  
Drill Impact: 100  
Drill Force: 100  
Drill Moment: 100  
Drill Torque: 100  
Drill Power: 100  
Drill Pressure: 100  
Drill Temperature: 100  
Drill Vibration: 100  
Drill Noise: 100  
Drill Acceleration: 100  
Drill Deceleration: 100  
Drill Jerk: 100  
Drill Shock: 100  
Drill Impact: 100  
Drill Force: 100  
Drill Moment: 100
```

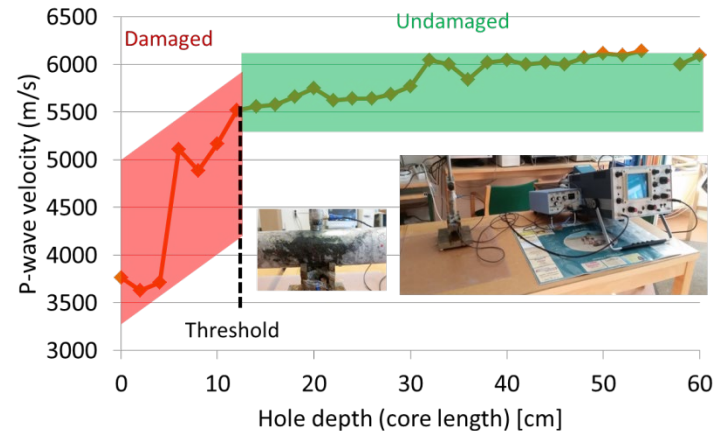
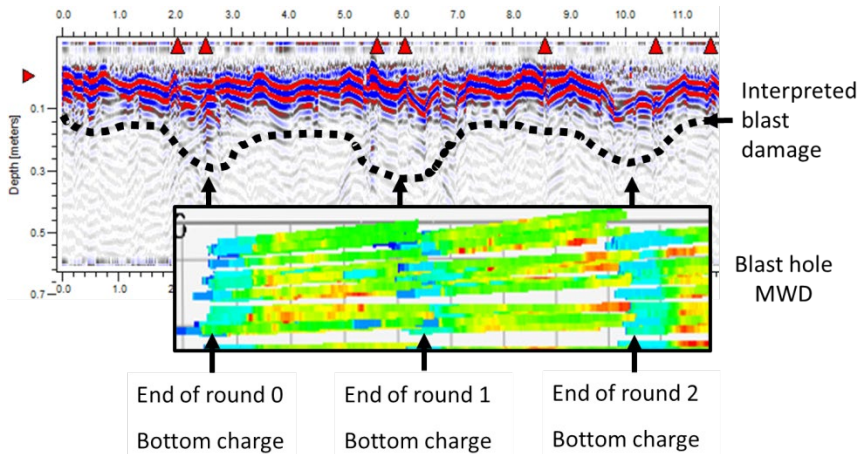
Visual portrayal of the MWD data



Interpolated MWD data along the Tunnel walls

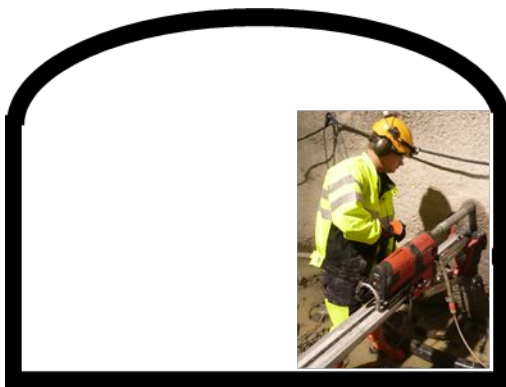


Measurements of blast damage



Ground Penetration Radar, used to determine micro fracture (dispersion) and macro fracture (reflections). The depth of reflections used to determine the extent of the blast damage zone

P-wave velocity, micro fractures (blast induced) in the rock mass reduce the P-wave velocity. Based on the development of the P-wave velocity along the drill core at threshold could be determined, which was defined as the extent of blast damage.



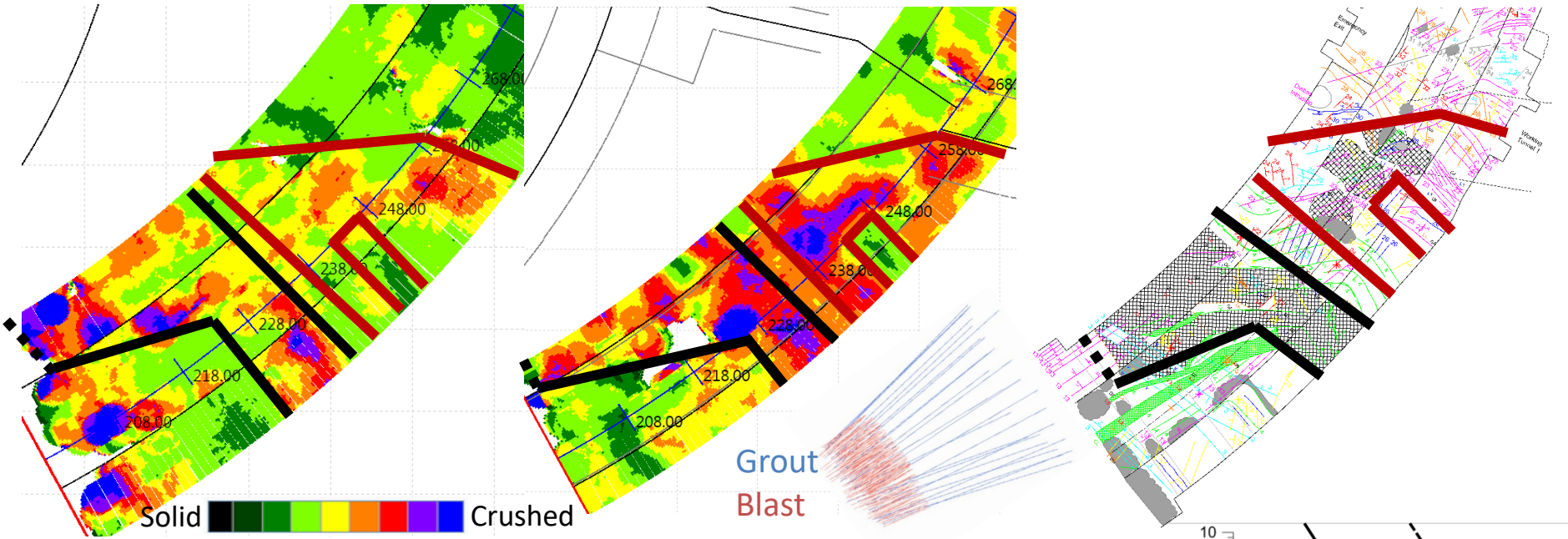
A Hilti DD200 was used to extract drill cores perpendicular to the tunnel wall. These cores were investigated for fracture density. The part of the core which is heavily fractured is most likely be damaged by blasting and can be used to determine the extent of the blast damage zone.

Drill monitoring for rock mass quality assessment

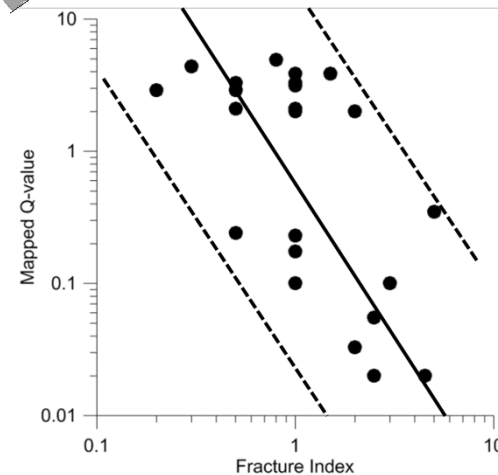
Grouting Holes

Blasting Holes

Mapping

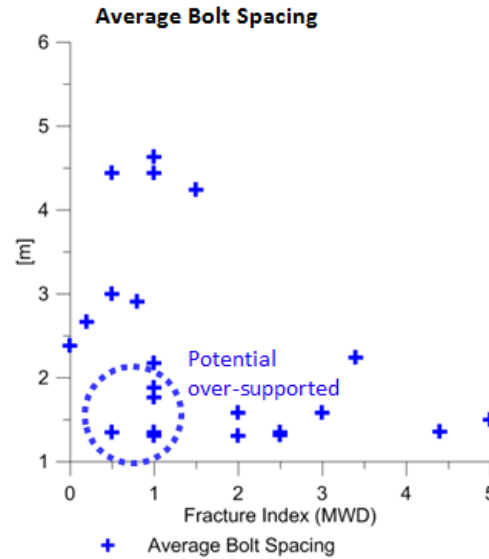
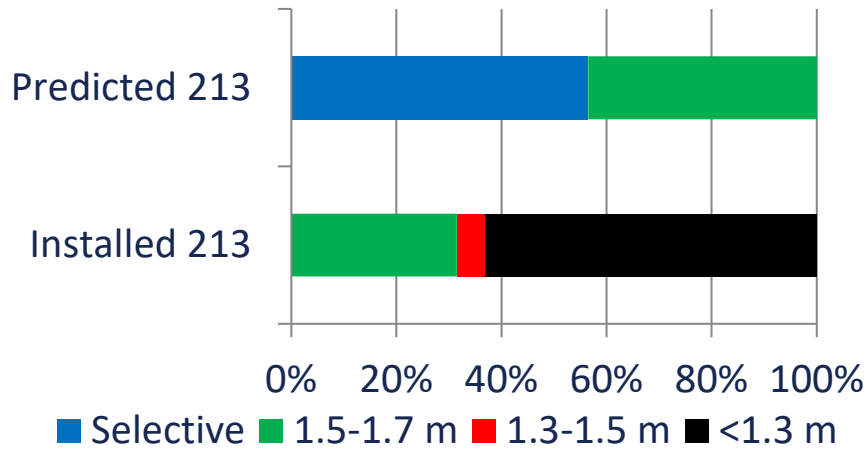


The MWD data shows it is capable to locate planes of weakness with in the rock mass along the tunnel path. The difference between the grout and blast holes can be explained by the drill geometry, blast holes within the tunnel perimeter and the grout holes up to 5m outside. The continuous measurement shows a good portrayal of the mapping of the rock mass and can therefore improve the rock mass characterisation.



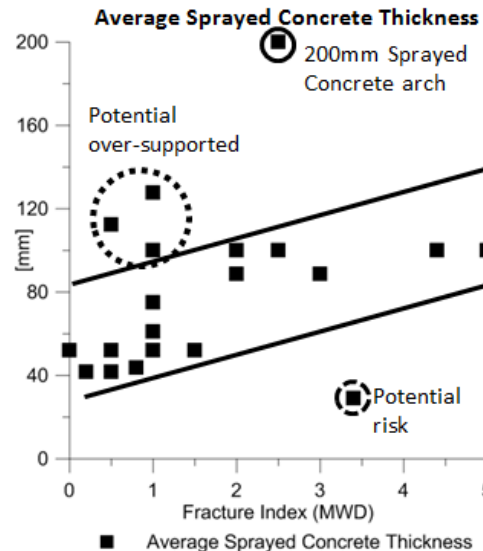
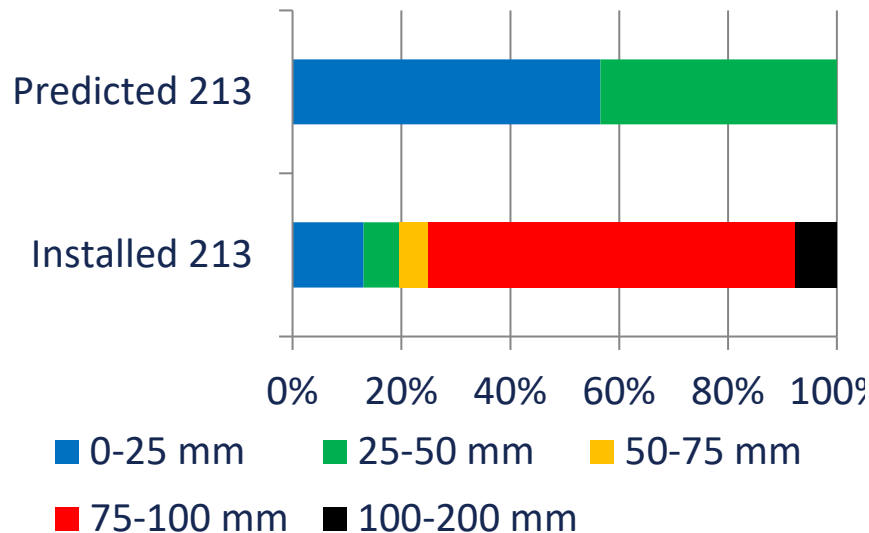
Drill monitoring and rock support

Bolt Spacing



During the site investigation the rock mass condition and support requirements were under-estimated, therefore more bolts and sprayed concrete was installed.


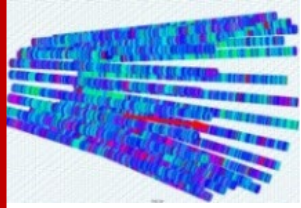
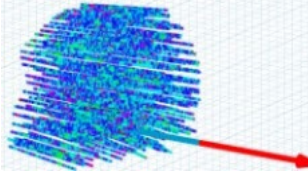
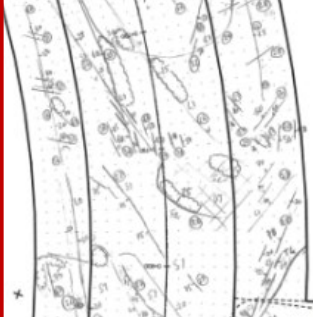
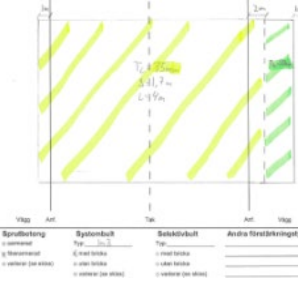
Sprayed Concrete Thickness



The usage of the MWD fracture Index show a correlation with the rock support requirements. In addition, the MWD data points out that several sections may be over-supported.

Drill monitoring in rock support design process

The study has shown that drill monitoring can predict rock mass conditions accurately. In addition, it has shown to be correlated to the rock support requirements. The traditional method were the site investigation is used for a preliminary rock support design, which is then redone or adjusted during the tunnel mapping. The proposed method includes both grout and blast hole MWD to make adjustments prior to the blasting. The MWD data will supply a continuous and objective data set, days to hours before the blast.

Process stage	Site investigation	Probing & Grouting	Drilling & Blasting	Rock quality investigation	Support decision
Example					
Application	Preliminary design/rock class	Adjustments	Minor adjustments	Rock Mass Classification & support adjustments	Support installation

Drill monitoring in blast damage prediction

- Multi Linear Regression was used to correlate the MWD parameters and operational parameters with the measured blast damage:
 - *Charge Concentration* - *Penetration Rate* - *Feed Pressure* - *Rotation Speed*
 - *Water Flow* - *Rotation Pressure* - *Rock Cover* - *Tunnel Area*
 - *Contour Spacing*
- The correlation with the data recorded by the ground penetration radar gave the best results ($R^2:0.67$). The model not include the type of initiation (pyro-technique or electronic, nor the effects of grains size and rock mass texture.

