NTNU

Norwegian University of Science and Technology

The NTNU method

(The NTNU prediction model for hard rock TBM tunneling)

Amund Bruland

TBM Applications III
Trondheim 5 November 2019

The NTNU method

Prediction model for TBM performance in hard rock conditions

- Basic penetration (mm/rev)
- Net penetration rate (m/h)
- Cutter life (h/cutter ring)
- Machine utilization (h/km)
- Gross advance rate (m/week)
- Cutter cost (NOK/m^3)
- Excavation cost (NOK/m)

- Based on data from more than 300 km of TBM tunnels

The NTNU method

Laboratory testing of rocks

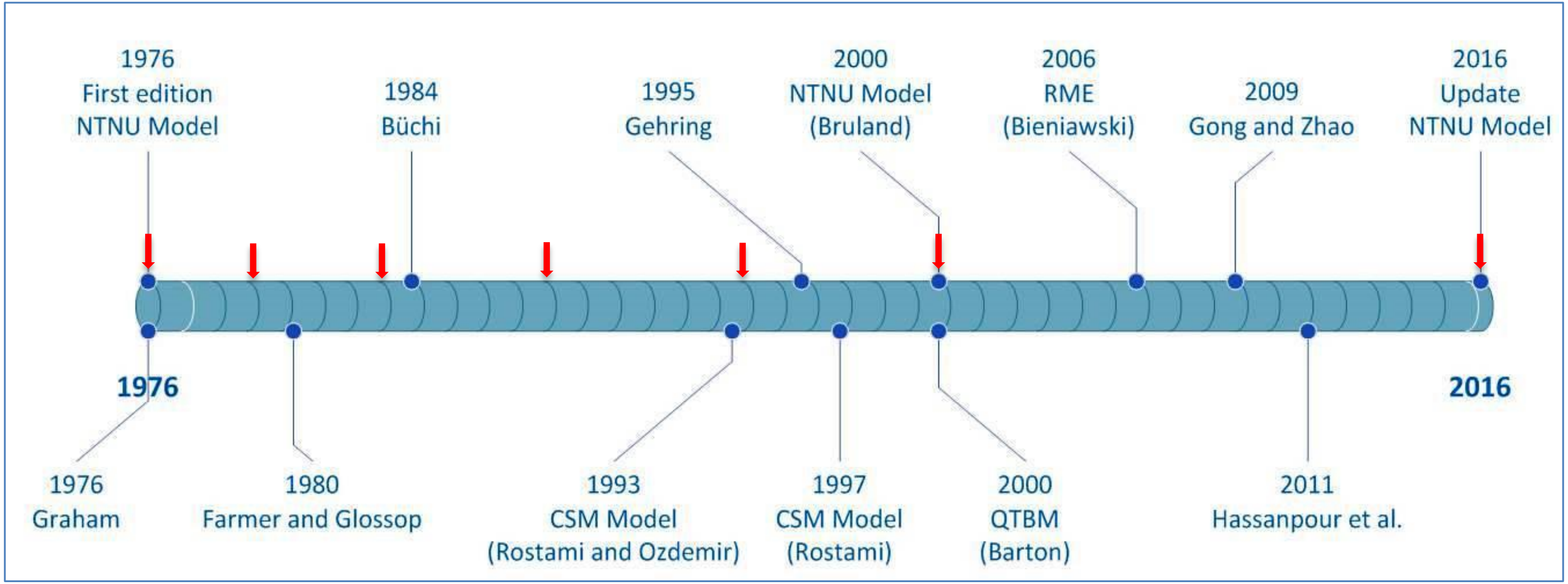
- Drilling Rate Index – DRI™
  - The Brittleness Value S20 (*Matern & Hjelmér 1943*)
  - The Sievers' J-Value SJ (*Sievers 1950*)
- Cutter Life Index – CLI™
  - The Abrasion Value Steel
  - The Sievers' J-Value SJ

Rock mass classification system

- Degree of fracturing – Fracturing Class 0 – 7
  - Classes based on fracture spacing

Model history

From *Macias 2016*



= Editions of the NTNU model

The first version 1976

- Overall goal: *To develop a prediction model for advance rate, cutter life and excavation costs*
- Input parameters
  - Drilling Rate Index
  - Bit Wear Index (originally for drill bits)
  - Degree of fracturing: ≤ *5 cm, ~ 10 cm, ≥ 20 cm*
  - TBM diameter (i.e. cutterhead rpm)
  - Machine utilization of 40 %
- Rock strength have stronger influence than rock mass fractures
- Data from 2 tunnels in Norway and a few more from Europe and USA

The second version 1979

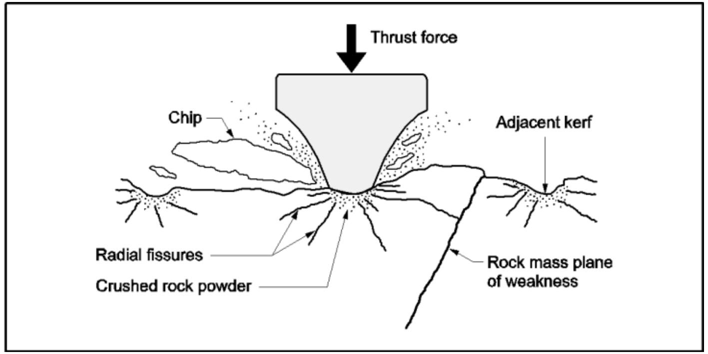
- Fracture classes I – IV, from 40 cm to 5 cm spacing
- Orientation of fractures
- Applied cutter thrust reduced with increasing degree of fracturing (torque limitation)
- Cutter spacing
- Rock mass fractures have stronger influence than rock strength
- Model for machine utilization
- Detailed model for excavation costs

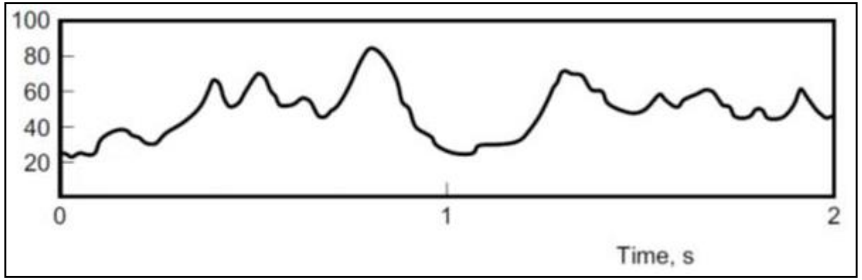
The third version 1983

- Non-fractured rock mass (Class 0)
- CLI and new laboratory test AVS
- Quartz content
- Cutter diameter
- Thrust limitations due to peak loads and vibrations
- Detailed model for machine utilization
- Analyses of performance data
  - Back-mapping procedures
  - Instantaneous cutter wear

The third version 1983

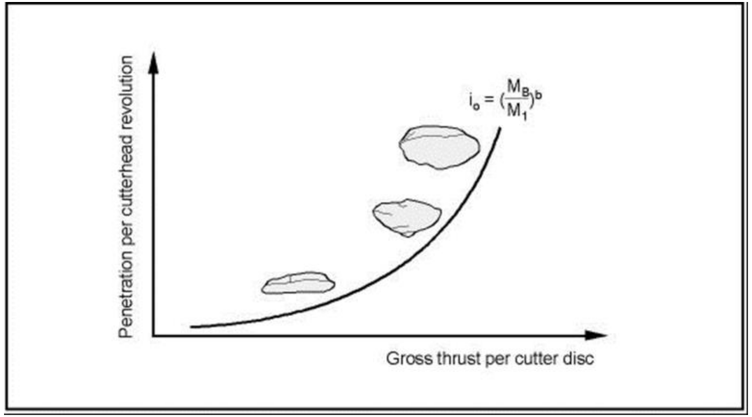
- Extensive discussions of the rock breaking process
- … and the cutter wear process
- Clear references to the penetration curve, but not really used in the prediction model
- Strong focus on chip analyses
- Peak loads break the largest chips





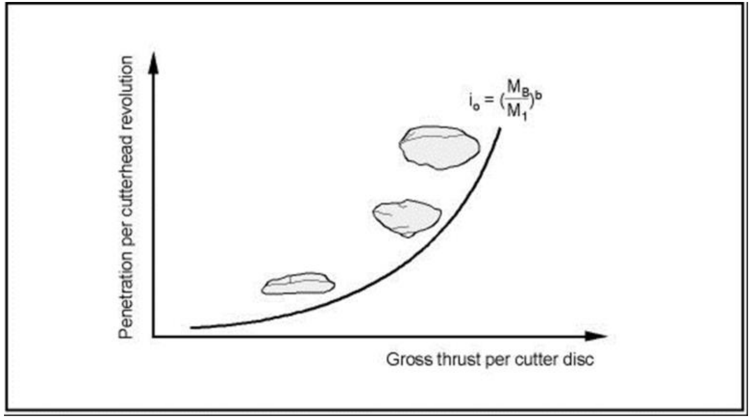
The fourth version 1988

- Basic penetration (mm/rev) based on the penetration curve
- Machine vs rock mass
  - M_1 from machine and rock parameters (thrust to achieve 1,0 mm/rev)
  - M_B applied thrust kN/cutter
  - *b* from M_1
- Influence of mica and amphibole content on cutter life
- Machine utilization based on h/km



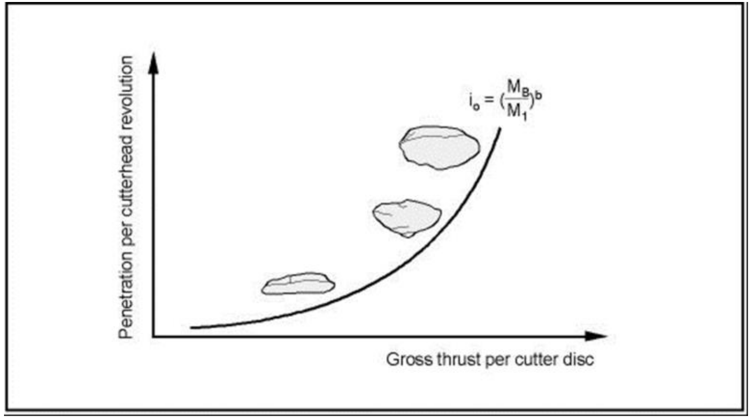
The fifth version 1994

- Machine vs rock mass is “reorganized”
  - M_{ekv} from machine parameters
  - M_1 and b from rock mass parameters (not shown)



The sixth version 2000

- Definition of “Hard rock conditions”
- Machine vs rock mass is “reorganized” once more
  - M_1 from rock mass parameters
  - M_{ekv} from machine parameters
  - *b* from rock mass parameters
- Detailing of
  - Site investigations
  - Aggregation of performance data
  - The rock breaking process



The seventh version 2016

- Influence of RPM
- Influence of cutter thrust on cutter life
- Influence of tunnel length on machine utlilization

Thanks to

- Odd Johannessen
- Olav Torgeir Blindheim
- Erik Dahl Johansen
- Steinar Johannessen
- Arne Lislerud
- … many more …

Some experience learning

- The penetration curve in combination with chip size and shape analyses offers possibilities to understand the rock breaking process
- The rock mass has a response time to thrust forces
- TBM parameters have strong influence on efficient rock breaking
- In hard rock: High vibration level necessary for efficient rock breaking
- The most important effect of rock mass fractures is the dynamic forces or peak loads.

Further development

- General improvement based on new data and new understanding
- Utilize the availability of digital performance data
- Site investigation methodology
- RIAT - rock test method
- Back-mapping in lined tunnels
- Improved software, including risk analyses and other prediction models
- … and more …

NTNU