Herrenknecht Mining | Pioneering Underground Technologies

Mechanized Shaft & Raise Excavation Webinar

22nd January, 2020 – Patrick Rennkamp & Danny Harquail
Introduction Herrenknecht and Mining
Overview of Shaft Boring Machines and references
Boxhole Back Reaming Developments
Questions?
Founded in 1977
Site area: 199,800 m²
18 Assembly workshops for different product applications
Today around 4,600 employees worldwide, 2,000 in Schwanau & around 200 young people in training
Herrenknecht | Global
– 76 Locations: represented on all continents
– 4,100 Projects worldwide
Herrenknecht | Business Units

TRAFFIC TUNNELLING
- Roads
- Railroad
- Metro
- Water
- Sewage
- Hydropower
- Electricity

UTILITY TUNNELLING
- Communication
- Water
- Sewage
- Hydropower
- Electricity
- Oil gas
- Shafts

EXPLORATION
- Onshore
- Offshore
- Geothermal energy

MINING
- Exploration
- Production
All Around Tunneling Solutions | Core Products for Traffic Tunneling

- EPB Shield
- Mixshield
- Gripper TBM
- Single Shield TBM
- Double Shield TBM
THE BRENNER BASE TUNNEL
Lot 2-3 Mauls / Mules
TUEN MUN – CHEK LAP KOK LINK
All Around Tunneling Solutions | Core Products for Utility Tunnelling

- AVN Machine
- Partial-face Excavation Machine
- Auger Boring Machine
- HDD Rig
- Direct Pipe®
- Shaft Sinking Machine
Conventional D&B Shaft Sinking

https://www.youtube.com/watch?v=xpehTws0nUc
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<thead>
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<th></th>
<th>Mechanized</th>
<th>Drill &amp; Blast</th>
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<td><strong>Excavation</strong></td>
<td>Cutting Tools</td>
<td>Explosives</td>
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<td><strong>Mucking</strong></td>
<td>Pneumatic / Slurry</td>
<td>Cactus Grab</td>
</tr>
<tr>
<td><strong>Advance Rate</strong></td>
<td>3-4 meter/day</td>
<td>1-2 meter/day</td>
</tr>
<tr>
<td><strong>Process</strong></td>
<td>Continuous</td>
<td>Cyclic</td>
</tr>
<tr>
<td><strong>Lining</strong></td>
<td>Shotcrete/Cast in Place/Tubbing</td>
<td>Shotcrete/Cast in Place/Tubbing</td>
</tr>
<tr>
<td><strong>Hoisting</strong></td>
<td>Bucket</td>
<td>Bucket</td>
</tr>
</tbody>
</table>
**Mechanical Cutting**

- The basic rock cutting tools for mechanical excavation include:
  - Drag Cutter
  - Picks
  - Disc Cutters
  - Roller Cutters
  - Button Cutters

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**Fig. 22.1.1.** Rock cutting techniques (after Roxborough and Rispen, 1970).
History of Mechanized Shaft Sinking | The Full Face Blind Shaft Borer 1978, Robbins

- Self supporting machine (gripper systems)
- Full face excavation with disc cutterhead
- Chain and bucket conveyors as primary mucking system
History of Mechanized Shaft Sinking |
Shaft Boring Machine, Robbins 1984

- Self supporting machine (gripper systems)
- Partial face excavation with disc cutter drum
- Clam bucket as primary mucking system
History of Mechanized Shaft Sinking | V-MOLE, WIRTH

- Shaft enlargement works
- Self supporting machine (gripper systems)
- Full face excavation with disc cutterhead
- Muck discharge through pre shaft
History of Mechanized Shaft Sinking | Herrenknecht Shaft Sinking Machine 1986

- Self supporting machine (gripper systems)
- Partial face excavation with roadheader boom
- Muck discharge through pre-shaft
Reasons for a Mechanized Approach | General

- Increased level of Health & Safety
- **Mechanical excavation** systems provide greater advantages compared to drill & blast methods for the shaft design
- Cleaner, improved and modern **working environment**
- An increased level of **digital automation**
- Generates **real-time data acquisition** and ready reporting analysis – for full transparency
- Higher logistical efficiency due to greater accuracy in excavation parameters
- Opportunity for **concurrent work activities**
Process and Involvement for Successful Shaft Sinking Projects

- The owner is the most important decision maker and ultimately has the final call on the project.
- The owner has to be supported by every team member below to achieve their vision.
- The owners' effort to be balance the costs associated with a project can be offset by reaching the ore body more quickly & without incident.

Buy in by the owner required.
Webinar | Mechanical Shaft Excavation - 22nd January 2020

- Introduction Herrenknecht and Mining
- Overview of Shaft Boring Machines and references
- Boxhole Back Reaming Developments
- Questions?
# Herrenknecht Shaft Sinking Machines | Overview

<table>
<thead>
<tr>
<th>Type</th>
<th>SBM</th>
<th>SBR</th>
<th>SBC</th>
<th>SBE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>Shaft Boring Machine</td>
<td>Shaft Boring Roadheader</td>
<td>Shaft Boring Cutterhead</td>
<td>Extension Shaft Boring Machine</td>
</tr>
<tr>
<td><strong>Geology</strong></td>
<td>Hard rock</td>
<td>Soft/medium hard rock</td>
<td>Hard rock</td>
<td>Hard rock</td>
</tr>
<tr>
<td><strong>Shaft diameter</strong></td>
<td>10 – 12 m</td>
<td>8 – 12 m</td>
<td>8.1 – 8.6 m</td>
<td>7.5 – 9.5 m</td>
</tr>
<tr>
<td><strong>Shaft depth</strong></td>
<td>~ 2000 m</td>
<td>~ 1000 m</td>
<td>~ 1000 m</td>
<td>~ 3000 m</td>
</tr>
<tr>
<td><strong>Machine height</strong></td>
<td>60 m</td>
<td>40 m</td>
<td>35 m</td>
<td>20 m</td>
</tr>
<tr>
<td><strong>Machine weight</strong></td>
<td>3000 t</td>
<td>350 t</td>
<td>350 t</td>
<td>350 t</td>
</tr>
<tr>
<td><strong>Mucking method</strong></td>
<td>Mechanical</td>
<td>Slurry / Pneumatic</td>
<td>Slurry</td>
<td>Pilot hole</td>
</tr>
</tbody>
</table>

*Herrenknecht. Pioneering Underground Technologies*
SBM - Shaft Boring Machine

- **Geology**: hard rock (~280 MPa)
- **Shaft diameters / depth**: 10 - 12m / ~2000 m
- **Machine height / weight**: 60m / 3000t
- **Suspension**: gripping system
- **Mucking method**: mechanical
- **Rock Support/Lining**: rock bolts, shotcrete
- **Net excavation**: ~10.5 m/d

*Developed with Rio Tinto – Mine of the Future™*
Target of Rio Tinto

- “Civil Technology” with high mechanization level to be combined with “Mine Development Technology”, which has a lower mechanization level

HK Approach

- Excavation System: Combination of full-face cutter head and cutting drum
- Primary Mucking System: Bucket Wheel and Continuous Vertical Conveyor
- Support and Thrust System: Single Gripper and Support Shield
- Rock Support: Permanently Installed Rock Bolters and Shotcrete Robot
- Pre-Excavation Drilling: Permanently installed rock drill (L≈3 m)
**SBM | Basic Assembly Units**

1. Cutterhead
2. Dust shield
3. Rock bolters
4. Gripper system
5. Vertical conveyor

VSM - Vertical Shaft Sinking Machine | System Overview

- Shallow shafts (~ 120 m)
- Shaft Ø 4.5 – 16m
- Blind sinking method
- Soft rock
- Water bearing soils
- Heterogeneous geological conditions
- Hydraulic mucking system
- Pre-cast liner system
- Submerged operation
- Remote controlled
- High shaft accuracy
VSM reference | Ballard Siphon Replacement Project

- 45 meter-deep launch shaft for microtunnelling
- Advance rates of up to 2.6 meters per shift
- High level of worker safety, low noise emission and reduced construction time compared to conventional methods
- Shaft sinking below groundwater possible
Herrenknecht VSM Development | From Submerged to Dry Excavation

2004 - Kuwait
- Shaft depth: 30 m
- Shaft diameter: 8 m
- Max. excavation rate: 3.5 m/shift
- Material transport: pneumatic

2004 - Indonesia
- Shaft depth: 100 m
- Shaft diameter: 2.5 m
- Max. excavation rate: 2 m/shift
- Material transport: rope excavator

2006 - Israel
- Shaft depth: 160 m
- Shaft diameter: 6.9 – 9.3 m
- Max. excavation rate: 5 m/shift
- Material transport: pilot hole
SBR - Shaft Boring Roadheader

- Geology: soft/medium hard rock (~120 MPa)
- Shaft diameters / depth: 8 - 12m / ~1600 m
- Machine height / weight: 40 - 70m / ~400t
- Suspension: Headframe / ropes
- Mucking method: slurry, pneumatic
- Rock Support/Lining: per requirement
- Net excavation: ~3 m/d
SBR | Built-In Safety

Location of workplaces and equipment on the SBR

- Work Decks
  - Infrastructural components
  - Control cabin
  - Permanent work places
  - Pneumatic Mucking System (PNM)
  - Position of sheaves
  - Personal and material logistic

- Rock support area
  - Shotcrete application and rock bolting unit

- Excavation chamber
  - Boom with cutting drum and muck intake hopper
  - Access during maintenance time only
**SBR | Excavation and Mining Cycle**

Steps of Mining Cycle:
1. Cut trench in 120° clock
2. Move boom to center position
3. Slew a few degrees clockwise
4. Cut next trench
5. Repeat until in 120° clock position
6. Extension of the boom
7. Re-start of the cutting cycle
8. When 1m of the bench is cut, the SBR will be lowered 1m and the mining cycle starts again…

**SBR | Pneumatic Mucking System**

- Air Flow per. Blower: 7800 m³/h
- Tank Capacity: 4.5 - 7 m³
- Vertical Distance: 25 m
- Number of Blowers: 1 - 3

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SBR References
MI-003 & MI-004
BHP Jansen Project Overview

- Potash mine in Canada
- DMC contractor
- Blind shafts for Service and Production
- Shaft depth up to 1,005m,
- Diameter between 8-12m
- Lining: shotcrete, cast in place and bolt & mesh
- 2 x SBR
- Geology: medium hard rock (~120 MPa)
- Frozen ground up to 700m depth
Initially planned rock support: Screen mesh support in combination with shotcrete

https://www.herrenknecht.com/de/produkte/productdetail/shaft-boring-roadheader-sbr/
SBR | Jansen | Rock Support / Lining

- **Actual rock support:** Fibre reinforced concrete cast in place using shaft forms

- **Rock support in the Blairmore layer (-430 to -480m):** Segmental steel lining rings installed with Blairmore Ring Erector.

- **Rock support below -828 m:** PET, geo grid and split set bolts.
SBR | Jansen | Rock Support / Lining
Bolt and Mesh
Thanks to the machines’ ability to excavate variable diameters, large-mini hitches were excavated into the shaft wall throughout the length of the shafts to improve liner friction.
The Famous Blairmore Layer of Saskatchewan

Saskatchewan’s massive potash reserves were discovered in the 1940s, but were inaccessible because of a 100-meter layer of underground salt and water called the Blairmore Formation. Early attempts to mine the deposits, which are almost one kilometer below the surface, were flooded out.

In the early 1960s, the Blairmore Ring provided the key to unlocking the potential of Saskatchewan’s potash industry. After temporarily freezing the underground water formation, miners dug through the frozen mass a few feet at a time. The cast-iron rings were inserted and sealed to create a water-tight wall for the mine shafts. This allowed miners to safely reach deposits and return one to the surface.

The Blairmore Ring has become a symbol of the innovation, commitment and perseverance of the many people who developed Saskatchewan’s first potash mines. That spirit lives on today in the thousands of people who work to ensure our province remains the world leader in this important industry.
SBR | Jansen | Rock support / Blairmore Ring Erector

- Lower Cretaceous Blaimore formation extends over the whole of Southern Saskatchewan.
- Innovative Blairmore Ring Erector technology allowed for a fully mechanized installation of 8.35 m ID rings with minimal open wall exposure.
- 16 pieces of tubbing weighing 2 tonne each forming one ring.
- Doubled the expected performance for ring installation as planned.
Excavation chamber equipment removed and replaced by a support platform

- SBR brought up to the sub-collar
- SBR’s support platform connected to the sub-collar with Ø82,5 mm structural strands
- With SBR fully supported by the structural strands and using stabilizers at three elevations, the winch ropes removed from the SBR
- The machine removed from the shaft in five major lifts ranging from 35 t to 90 t.
The Jansen Potash project has been a proof of the SBR concept and showed that shaft sinking using purely mechanical excavation can safely and efficiently accomplish the BHP vision.

With a high degree of accuracy and top-level planning, the two shafts at the Jansen Mine demonstrate that mechanical excavation of deep shafts is possible and brings several benefits not achievable by conventional means.

Using the success and lessons learnt from Jansen, the next generation of SBRs are already active and producing at a high level of efficiency with more on their way.
SBR | Second Generation

Overall height: 50m

- Work Deck 11
- Work Deck 10
- Work Deck 9
- Work Deck 8
- Work Deck 7
- Work Deck 6
- Work Deck 5
- Work Deck 4
- Work Deck 3
- Work Deck 2
- Work Deck 1

Sheave Deck
Filter
Blower
Concret distribution
Control Cabin
Stabilisation
Excavation chamber
Shaft Boring Roadheader | References
Slavkaliy ordered two SBRs: MI-029/30

- Delivery time 11/12 months after workshop commissioning
- Client: Deilmann-Haniel Dortmund (Redpath group)
- Potash Plant in Nezhinsky, Belarus
- Production of 2 Mio. Tpd of potash in 2024
- Sinking of two shafts with two SBR machines (725m & 698m)
SBR | Slavkaliy | Overview
First cut, December 11th, 2018
SBR | Slavkaliy | Belarus shaft sinking record.
Herrenknecht. Pioneering Underground Technologies

SBR | Slavkaliy
Shaft Boring Roadheader | References
MI-035 & MI-036
DMC UK ordered two SBR
for the North Yorkshire Polyhalite Project

- Owner: SIRIUS MINERALS
- Contractor: DMC UK
- Two shafts with two machines
- 1600m depth
SBR | Sirius | Project overview

1. MINE SITE DEVELOPMENT
2. MINING
3. MINERAL TRANSPORT SYSTEM (MTS)
4. MATERIALS HANDLING FACILITY (MHF)
5. PORT
6. OTHER CONSENTED SHAFTS

Average depth 250m

Crushing Granulation Finished Product Storage

MTS

To Berth
SBR | Sirius | Jobsite overview

- Production Shaft | MI-36
- Service Shaft | MI-35
- MTS Shaft | V-006
SBR | Sirius | Grounding
Jumbos in the Excavation Chamber

The main functions are:

- Initial grouting program
- Potential probe drilling
- Ground support installation
- The 2 jumbos can be dismantled and operated independently
- WASSARA hammer drills
SBR | Sirius | Workshop Assembly in Schwanau
Herrenknecht. Pioneering Underground Technologies
# Shaft Boring Roadheader | Comparison

<table>
<thead>
<tr>
<th></th>
<th>MI-003/04</th>
<th>MI-029/30</th>
<th>MI-035/36</th>
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</thead>
<tbody>
<tr>
<td><strong>Project Name</strong></td>
<td>Jansen</td>
<td>Slavkaliy Nezhinsky</td>
<td>North Yorkshire Polyhalite</td>
</tr>
<tr>
<td><strong>Project Owner</strong></td>
<td>BHP</td>
<td>Slavkaliy</td>
<td>Sirius Minerals PLC</td>
</tr>
<tr>
<td><strong>Country</strong></td>
<td>Canada</td>
<td>Belarus</td>
<td>United Kingdom</td>
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<tr>
<td><strong>Client</strong></td>
<td>DMC mining services</td>
<td>Deilmann-Haniel GmbH</td>
<td>DMC UK</td>
</tr>
<tr>
<td><strong>Shaft depth &quot;Service Shaft&quot;</strong></td>
<td>1000,0 m</td>
<td>698,0 m</td>
<td>1562,0 m</td>
</tr>
<tr>
<td><strong>Shaft depth &quot;Production Shaft&quot;</strong></td>
<td>1000,0 m</td>
<td>726,0 m</td>
<td>1600,0 m</td>
</tr>
<tr>
<td><strong>Finished Inner diameter</strong></td>
<td>8,0 m</td>
<td></td>
<td>6,8 m</td>
</tr>
<tr>
<td><strong>Maximum cutting diameter</strong></td>
<td>12,3 m</td>
<td>10,1 m</td>
<td>10,5 m</td>
</tr>
<tr>
<td><strong>Total height SBR</strong></td>
<td>45,0 m</td>
<td>45,0 m</td>
<td>50,0 m</td>
</tr>
<tr>
<td><strong>Total weight SBR</strong></td>
<td>380 to</td>
<td>400 to</td>
<td>350 to</td>
</tr>
<tr>
<td><strong>Type of mucking method</strong></td>
<td></td>
<td></td>
<td>Pneumatic Mucking System</td>
</tr>
<tr>
<td><strong>Filter system</strong></td>
<td></td>
<td></td>
<td>Dry filter system</td>
</tr>
<tr>
<td><strong>Forzen shaft</strong></td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td><strong>Tubbing Installation</strong></td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td><strong>Ring Erector in excavation chamber</strong></td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td><strong>Ring Erector on rock support deck</strong></td>
<td>optional</td>
<td>manual</td>
<td>yes</td>
</tr>
<tr>
<td><strong>Bolt and Mesh</strong></td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td><strong>Concrete Liner System</strong></td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>
SBR | The Path Forward for Herrenknecht SBR’s

The future of shaft sinking is moving toward automation while ensuring the highest levels of safety possible. As Herrenknecht we want to ensure the SBR will meet if not exceed our client’s expectation and to achieve this:

1. Increase simultaneous working processes
2. Modular format for individual client customization & quicker delivery times
3. Increase machine torque / advance rates
4. Capability to mine in harder geologies

Herrenknecht developed the 2nd generation of SBR based on lessons-learned from Jansen:
- More power at the cutting drum
- Better stabilization
- Improved PNM system
- Sheave deck on top
SBC - Shaft Boring Cutterhead

- Geology
- Shaft diameters / depth
- Machine height / weight
- Suspension
- Mucking method
- Rock Support/Lining
- Net excavation

Hard Rock (~200MPa)
8.1 – 8.6m / ~1000 m
35m / 350t
Headframe / Ropes
Slurry
Per. Requirement
~3 - 6m/d
SBC | Concept Finished up to Detailed Design
SBC | Slurry Mucking System

- Feedbox with sieve
- Overflow pipe
- Underflow tank
- Muck bunker
- Material Kibble
- Slurry pump
- Telescopic slurry line
- Suction pipe
- Return flow line
- Seal water supply line
- 3 booster pump units
- Level sensor
- Dewatering pump
SBE - Shaft Boring Extension Machine

- **Geology**: Hard Rock (~200MPa)
- **Shaft diameters / depth**: 7.5 – 9.5m / ~3000 m
- **Machine height / weight**: 18m / 350t
- **Suspension**: Gripping System
- **Mucking method**: Pilot Hole
- **Rock Support/Lining**: Rock Bolts, Shotcrete
- **Net excavation**: ~6-10 m/d
SBE | Construction Procedure

Technology consists of 3 steps:

1. Directional drilling of pilot hole
2. Back reaming the pilot hole by Raiseboring
3. Extension of the raisebored hole to the final diameter by means of the shaftboring machine

[Image]

SBE | Advance

1. Starting position

2. Advance

1000 mm advance

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Pre-Sink requirements:

- Required pre-sink depth: 8 – 10 m
- Pre-sink diameter to match max. gripper stroke
- Cutterhead can be equipped with support structure for assembly

Picture left an example for breakthrough and lifting:

Before breakthrough the SBE will be attached to the strand jack system.

Lifting the SBE to surface by use of heavy duty lifting equipment like strand jack cylinders & long steel cables
Conclusion | Shaft Sinking Machines
Modular Concepts are Proven and Available!

Mucking Method:
- Pneumatic, Slurry, Conveyor Belt or via Pre-hole

Shaft Wall Support:
- Bolt and mesh, shotcrete, segmental liner
- Either on the bench or above stabilizer

Excavation Unit:
- SBR for medium soft rock
- SBC for hard rock
Webinar | Mechanical Shaft Excavation - 22nd January 2020

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- Boxhole Back Reaming Developments
- Questions?
Boxhole Back Reaming Machine | Combining Technologies for New Applications
BBR –
Boxhole Backreaming
Machine
BBM | Rapid Production of Shafts and Slot Holes With Small Diameters

- Boring of vertical and inclined shafts in hard rock conditions
- Shaft diameter up to 1.5 m
- Shaft depth up to 70 m
BBM | Setup in Open Drift

- Power pack
- Boring unit
- Cutterhead
- Hose drum
- Crawler
- Jacking frame
BBM | Advantages

- **System with the highest safety level**
  - Good control of falling material and small annular space
  - No exposure to falling rocks
  - Reduction of dust and noise
  - Highly mechanized operation. i.e. pipe installation, muck-removal, machine setup
  - PLC system: high level of control and safety interlocks
  - Accident-free excavation of more than 5,500m
BBR | New concept for creating ore passes and ventilation raises

- **Boxhole Boring**: Drilling upwards a raise drilled pilot hole
- **Reamer Installation**: Break through to upper level + reamer head installation
- **Reaming & Lining**: Reaming back down to final diameter + installation of Lining
- **Mobilization**: Completion of Lining and mobilization
BBR | Customer value

- Allows simultaneous drilling and lining
- Stabilizing shaft with thrust pipes and by steel liner, avoiding collapse of shaft and rework
- Reducing amount of activities in upper level during mine development
- Diameter up to 3.5m, drilling length up to 60m
BBR | Equipment Overview

- Hose drum
- Jacking frame + Machine
- Reamer- hoist device
- Lining- lowering Frame
- Steel liner (not in HAG scope)
- Reamer head
- Power pack
- Transport unit
BBR | Field Trial

Development of one ore pass in German mine

- Pass specifications (Ø 2.8m)
  - Length and angle (to vertical): 22m, 19°
  - Reaming rates up to 1.3m/h (Ø 2.8m)
  - Rock: Gneiss
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Thank you very much for your attention.
Please feel free to ask questions or give comments.

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