Danish Society for Tunnels and Underground Works

NoDig Infra
Opgravningsfrie løsninger

Industry guideline

Work in tunnels with a diameter under 2 metres



Ensuring the working environment in pipe jacking,
with special focus on ergonomics and emergency preparedness

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1 Purpose and background

This guideline targets tunnels with internal diameters from Ø1200 to Ø1800 mm, where personnel are required inside the tunnel during construction.

The initiative for this guideline was taken following an enforcement notice from the Danish Working Environment Authority on a project involving Ø1600 and Ø1800 tunnels. The enforcement notice was issued due to insufficient documentation of appropriate ergonomic working positions and evacuation routes.

Many of the recommendations described in this guidance were implemented as part of complying with the Danish Working Environment Authority's enforcement notice.

This industry guideline has been prepared by a working group in collaboration between NoDig Infra and the Danish Society for Tunnels and Underground Works (DFTU), consisting of representatives from clients, consultants, and contractors.

The purpose has been to establish a common reference framework and shared understanding of challenges in small-diameter tunnels.

The guideline provides recommendations for constructing tunnels with internal diameters from Ø1200 to Ø1800 mm. It does not constitute a complete list of requirements but offers guidance on ensuring good ergonomics and safe escape and evacuation routes.

A separate document, "Machine Operations", has also been prepared, detailing specific work steps. The purpose of the document "Machine Operations" is twofold: firstly, to clarify how the various operations can be carried out with due consideration for the working environment and best practice; secondly, to confirm that the recommendations and guidelines presented in the industry guidance are practically feasible.

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2 Ergonomics in work and movement within tunnels and TBM

For tunnel dimensions in which personnel cannot move through the tunnel in an upright position, it must be considered during the design phase how personnel and other transport operations can be carried out safely. As the tunnel serves both as an access route and an escape route, designs requiring personnel to walk in a bent-over posture are not acceptable, as this places unnecessary ergonomic strain on the individual. Working postures in the tunnel will, for the majority of the time, be inappropriate, as one or more of the body's joints will be in an abnormal or strained position. This may for example include working above head height, below knee height, with outstretched arms, kneeling, squatting, or with a forward-bent back, etc. Therefore, it is particularly important in small tunnels to ensure that personnel can carry out the work in the most appropriate way, including the use of suitable technical aids where possible.

2.1 Working time in tunnel and TBM

Due to the low standing height, the Danish Working Environment Authority requires that working time is reduced to a maximum of 4 hours per day per person. These 4 hours apply to all work, presence, and movement inside the tunnel and TBM, including transport to and from the work site in the tunnel. This means that even if the operator/pilot is sitting in a good working position at the TBM control panel, the 4-hour limit still applies. Once an employee has spent a total of 4 hours during a working day inside the tunnel and/or TBM, they may complete the remainder of the working day with other tasks on the construction site, provided there is full standing height.

2.2 Personnel transport in tunnel

Transport in the tunnel must, as previously described, not be carried out in a bent-over position over longer distances. It is acceptable to pass obstacles in a bent-over posture, provided that the main transport route can be completed in an ergonomically relaxed position, i.e. without walking in a bent-over position.

Therefore, electric vehicles should be used for personnel transport, where the person is seated in a relatively relaxed position. When selecting an electric vehicle for tunnel use, consideration must be given to ensuring that it is easy to change the direction of travel of the vehicle, either by physically turning the vehicle or by reversing the control panel and seat. Reversing is not considered a change in direction of travel, as it results in other unnecessary loads and risks.



Figure 1: Electric personnel transport vehicle

Ergonomics in work and movement within tunnels and TBM ...

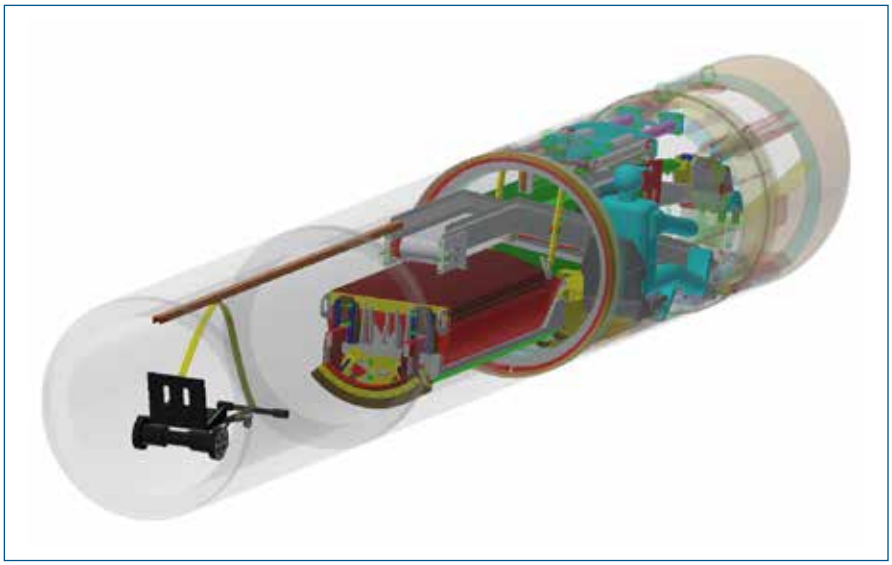


Figure 2: Rail installed at the crown of the tunnel for suspension of the vehicle.

It only becomes meaningful to use a vehicle when the tunnel reaches a reasonable length, so that the handling of the vehicle does not outweigh the strain associated with the distance travelled. Therefore, an overall assessment of distance and tunnel diameter should determine whether its use is beneficial.

It is recommended that electric vehicles are always used for distances longer than:

- Ø1200: 25 meters
- Ø1400: 25 meters
- Ø1600: 30 meters
- Ø1800: 40 meters

Immediately in front of the controls for the TBM, an area shall be established for turning and parking the vehicle without interfering with tunnel work operations. This may, for example, be achieved by suspending the vehicle on the wall or on a rail system installed at the crown of the tunnel.

If two persons are required to work in the tunnel simultaneously, two vehicles shall likewise be used, and sufficient space shall be provided for turning and storing both vehicles.

Charging of electric vehicles should, as far as possible, take place outside the tunnel to avoid the risk of fire in the battery. If battery charging inside the tunnel is necessary, it should be carried out when no personnel are present in the tunnel. The charging station shall always be positioned so that it does not obstruct the escape route i.e. it shall not be located between employees and the exit.

For longer sections where a slurry booster pump is required, a personnel transport vehicle is required on each side of the booster pump. In addition, a safe passage shall be established allowing personnel to pass the booster pump safely, as well as a procedure for stretcher evacuation of an injured person. If this requires additional equipment, it shall be positioned on site and ready for use.

Ergonomics in work and movement within tunnels and TBM ...

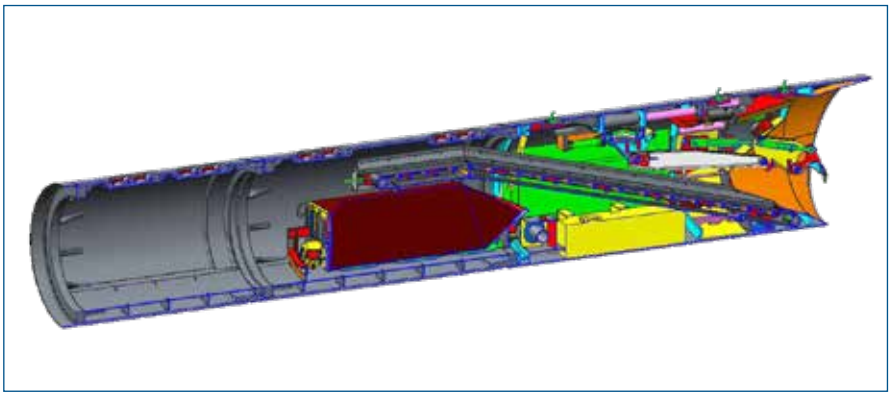


Figure 3: Extended TBM shield to increase the internal diameter.



Figure 4: Transport trolley for smaller equipment.

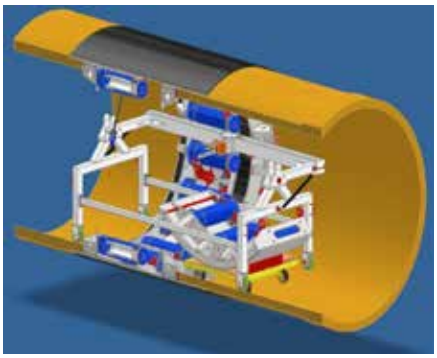


Figure 5: Lifting equipment designed for the tunnel dimensions.

2.3 TBM Arrangement

In order to improve the working environment during execution, it is recommended that the TBM shield is extended with extra steel sections installed behind the TBM. This allows personnel transport past, for example, conveyor belts, muck cars, transformers and other equipment to be carried out in a safe manner. The increased "clear diameter" also means that various tools and spare parts can be stored immediately behind the TBM prior to the start of tunnelling, while at the same time providing better spatial conditions for employees who need to stay and move around in the area.

2.4 Supervision

In order to minimise physical presence of personnel in the TBM and the tunnel, cameras (video/audio) should be installed at all locations in the tunnel where daily supervision would normally be required. The sole purpose of the cameras is to reduce physical access and presence in the tunnel. Each camera shall be monitored from surface level, so that supervision is carried out from above ground and not within the tunnel itself.

Examples of camera installation locations:

- Along the entire tunnel, at critical installations which, based on experience, may leak or fail.
- At each intermediate jacking station, so that cylinders, flexible hoses and crossover plates can be monitored.



Photo 1: Remote-controlled electric transport vehicle for material transport.

- At the transition from tunnel to TBM, covering all hoses, pipes and cables.
- At the pilot/operator position in the TBM (particularly relevant in cases of lone working).
- Pressure chamber.

2.5 Material transport

Trolleys and lifting equipment used for transport of equipment (such as electrical cables, slurry pipes, air pipes, and bentonite pipes) shall be designed for the relevant conditions and dimensions.

Similarly, a special trolley and lifting equipment are required for dismantling operations, e.g. of intermediate jacking stations.

For transport of heavy items in the tunnel, a mobile electric lift may be used to move items and raise them to the required height.

When using a mobile electric lifting device, the personnel transport vehicle can be suspended on steel trailing pipes during tunnelling, thereby ensuring that it is ready when personnel need to return. See photo 1.

2.6 Repair and maintenance work

In order to minimise the workload associated with repair and maintenance activities, the contractor should use fully refurbished or new equipment, including all backup systems and installations in the tunnel.

For repair and maintenance of larger equipment, a plan shall be in place describing how the component can be removed from the tunnel, repaired in the shaft, and subsequently transported back into the tunnel and reinstalled, so that major works do not need to be carried out inside the tunnel.

For all repair and maintenance work, as well as removal of obstructions at the tunnel face, on the TBM, or within the tunnel itself, a minimum of two persons shall be present.

Ergonomics in work and movement within tunnels and TBM ...

▶ Sliding rails for cutter tools through the pressure chamber.

▶▶ Example of a trolley hoist for passing obstacles in the tunnel.





2.7 Replacement of cutting tools in the cutterhead (interventions)

For ergonomic reasons, transport of cutting tools through the tunnel should be kept to a minimum. Therefore, cutting tools expected to be replaced during tunnelling shall be stored on the TBM and/or immediately behind the TBM prior to the start of tunnelling.

Replaced cutting tools should likewise be stored on the TBM and/or immediately behind the TBM, and be disposed when the tunnel boring machine arrives at the reception shaft.

Handling of cutting tools on the TBM shall be planned to avoid manual handling. For this purpose use of, for example, sliding rails or hoists located in the crown of the tunnel is recommended.

2.8 Maintenance of excavation/cutting tools (open face)

Maintenance of excavation/cutting tools during open-face tunnelling is recommended to be carried out in areas where the tunnel face is stable and where no water ingress has been identified. In this connection, the shield shall be pushed as far forward as possible in order to secure the face to the greatest extent possible.

Before personnel proceed to the excavation face, it shall be ensured that the face is stable by confirming that the excavation shield has been advanced to its maximum position and that no more soil has been excavated than necessary. As the work is typically carried out in a kneeling position, the work shall be planned with working periods suited to the nature of the task (potentially involving multiple shifts with regard to working time limitations).

2.9 Removal of obstructions from the excavation face (open face)

Obstructions that cannot be removed using the excavating arm or cutter during open-face tunnelling shall be removed manually. This may, for example, include splitting larger stones, removing crossing utilities, or removing structures left in the ground. Before personnel proceed to the excavation face, it shall be ensured that the face is stable by confirming that the excavation shield has been advanced to its maximum position and that no more soil has been excavated than necessary. As the work is typically carried out in a kneeling position, the work shall be planned with working periods suited to the nature of the task (potentially involving multiple shifts).

2.10 Dismantling of intermediate jacking stations

The work shall be planned so that manual handling of the jacks is not required at any stage.

The lower jacks may be lifted using a hoist fixed to the crown of the tunnel. The upper jacks may be dismantled using a hoist mounted at the crown and lowered directly onto a transport trolley. It shall be ensured that the jacks do not swing sideways when released.

The jacks shall be placed on a transport trolley and transported out of the tunnel to the shaft.

2.11 Dismantling of booster pumps

Booster pumps shall be designed to allow dismantling with minimum work required inside the tunnel itself. Booster pumps should be mounted on wheels so that they can be pulled out of the tunnel using, for example, a winch.

2.12 Clearing the tunnel

Where cables are handled manually, heavy cables shall be divided into sections, e.g. 3–5 m lengths, so that manual handling requirements can be complied with. The cables shall be removed from the racks and be capable of being placed directly onto a trolley transporting the equipment out of the tunnel.

When removing heavy items that must not be handled manually, lifting equipment shall be used. Primarily, two different types of lifting equipment may be used in smaller tunnels.

Chain hoist: A chain hoist may be installed at the crown of the tunnel pipe by drilling and installing an anchor with an internal thread. An eye bolt is inserted into the thread, to which the chain hoist is attached. The chain hoist can then be used to lower various pipes and hoses from the racks.

Crane: A specially manufactured crane adapted to the relevant tunnel diameter may be procured. The crane shall be approved for mounting on, for example, a vehicle, unless already mounted on wheels. The crane shall be mounted on a vehicle and be able to lift items and place them on an associated trolley for transport to the shaft.

2.13 Back grouting of pipes

Overcut grouting around the pipes may be carried out using manual or automatic valves. During tunnelling, these are used for bentonite grouting, while after completion of tunnelling they are used for back-grouting. Prior to back-grouting, automatic valves shall be replaced with manual valves. During manual grouting, including manual opening and closing of the valves, vehicles should be used for transport within the tunnel, as full standing height is not available.

The positioning of grouting valves shall be considered with regard to both the working environment and execution of tunnelling works, including ensuring that the crown of the tunnel is fully back grouted.

If the valves are positioned at the 1 o'clock and 11 o'clock positions, the working environment is improved by maximising the available height in the centre of the pipe. This reduces the likelihood of, for example, safety helmets colliding with the technical installations connected to the valves.

The selected positioning shall always be assessed by the contractor based on both technical and occupational health and safety considerations.

3 Accidents and incidents

3.1 Emergency preparedness – escape and evacuation

Work in tunnels and on TBMs are defined by the Danish Working Environment Authority as particularly hazardous work. The work is considered particularly hazardous due to confined working conditions, the presence of only one access/escape route, the underground environment, and that individuals frequently work alone.

Particularly hazardous work shall always be subject to a risk assessment prior to execution, and employees shall receive thorough and adequate instruction for the work.

Before work commences, an emergency response plan shall be prepared describing how incidents in the tunnel are to be managed, including how personnel are to be rescued from the tunnel. This emergency response plan shall be known by all relevant personnel at the construction site.

3.2 Collapse of soil (open face)

The stability of the tunnelling face is generally ensured by means of sand shelves, the shield, and, where applicable, bulkheads that can close off as much of the face as possible. In small diameters, there is typically insufficient space to install bulkheads.

It shall be ensured that no personnel are present at the face in the event of suspected loss of stability.

If unstable soil layers are encountered, these may collapse into the machine and flow over the lower edge and down the sand shelf. In such cases, the TBM pilot shall leave their position and exit the boring machine. At the same time, the main and intermediate jacking stations shall push the pipe string and TBM as far forward as possible in order to prevent further soil inflow. Once the situation has been stabilised, the machine shall be cleared of soil that has passed beyond the shield.

3.3 Medical incident in connection with work in the tunnel

In connection with the preparation of the emergency response plan for evacuation of persons from the tunnel, ergonomic conditions shall be taken into consideration.

▶ **Photo 4: Tunnel face with sand shelf and hydraulic bulkheads**



▶▶ **Photo 5: Tunnel face with sand shelf**





Figure 6: Obstructions in the tunnel where a stretcher must be transported over

A stretcher shall be available on the TBM and, where relevant, also in the shaft. The stretcher shall be capable of being transported through the tunnel in an appropriate manner, for example by being attached as a trailer to the electric vehicle.

The stretcher shall also be suitable for vertical transport, allowing the injured person to be lifted out of the shaft/excavation.

3.4 Medical incident during lone working on the TBM (e.g. drilling operator)

It is recommended to install cameras at several locations in the tunnel and at the face in order not only to reduce the need for physical supervision, but also to enable personnel outside the tunnel to monitor workers inside the tunnel, particularly at the excavation face.

If obstructions are present in the middle of the tunnel, it may be necessary to have a stretcher and a vehicle on both sides of the obstruction.

3.5 Passage of booster pumps or other obstructions with a stretcher

For all obstructions that may be present in the tunnel, consideration shall be given to how stretcher evacuation can be carried out. This shall be described in the emergency response plan.

When passing booster pumps in the tunnel, it may be necessary to install a trolley hoist above the pump so that the stretcher can be transported over the obstruction using the hoist system. It would be particularly difficult to manually lift a stretcher over a major obstruction in the tunnel due to the stretcher's centre of gravity combined with limited accessibility.

If a trolley hoist is installed above a major obstruction, it may also be used to transport various materials past the obstruction, so that it is not necessary to manually lift items over, for example, a booster pump.

In addition, it is recommended that for longer tunnel sections requiring a booster

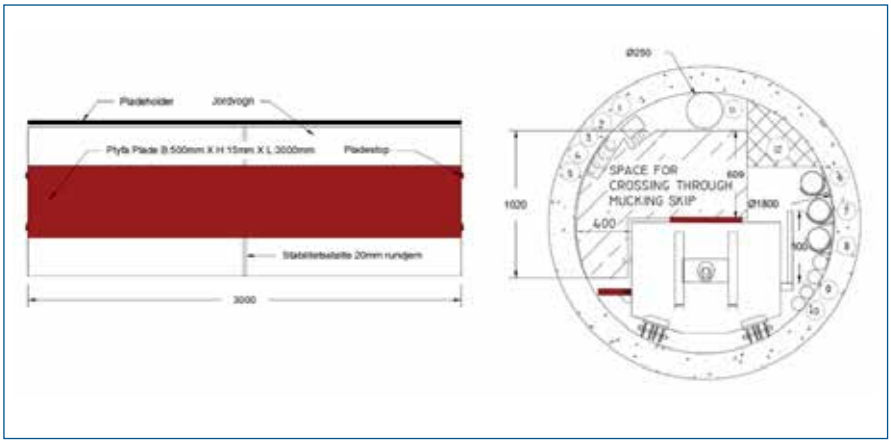


Figure 7: Cross-section of both muck car and tunnel illustrating passage past the vehicle

pump, personnel transport vehicles are placed on both sides of the pump. A safe means of passage for personnel shall also be established.

3.6 Passage of intermediate jacking stations with a stretcher

To facilitate all transport in the tunnel, the invert at intermediate jacking stations shall be equipped with a crossover plate with the same curvature as the tunnel pipe. The plate shall be fixed on one side of the intermediate jacking station within the tunnel pipe, so that it continuously covers the level difference at the intermediate jacking station.

The plate shall be designed to allow easy passage over it with a stretcher and other transport equipment.

3.7 Passage of muck car with a stretcher

The muck car shall be designed to allow personnel to pass it in the tunnel, for example by providing a small side walkway on the vehicle. It may be necessary to reduce the height and/or width of the muck car to enable safe passage past it.

The muck car should also be equipped with plates that can be placed over the vehicle, allowing a stretcher with a person to be transported over the muck car in an emergency evacuation situation. The plates shall be readily available and may be stored either on the vehicle or immediately outside the tunnel. Once installed, the plates shall be securely fixed to the vehicle so that they cannot shift during transport.

If the plates are stored in the shaft rather than on the vehicle, a plan shall be in place for how they can be quickly and safely transported to the muck car.

3.8 Fire in the tunnel

Due to the difficult escape routes in small tunnels, it is essential to ensure that sufficient time and possibility exist for evacuation from the tunnel and TBM to the shaft. The contractor shall always prepare an emergency response plan prior to the start of tunnelling, in which fire scenarios are also included.

In the event of a fire in the tunnel, the technical installations connecting the tunnel boring machine are not considered a significant fire risk, as they comply with all

applicable technical and safety requirements for electrical installations. This assessment also applies to intermediate jacking stations within the tunnel, regardless of whether these stations are pressurised from a hydraulic station located either in the TBM or in the launch pit.

If the execution of the project requires the installation of a hydraulic station within the tunnel itself in order to ensure the necessary hydraulic pressure during operation, this hydraulic station shall in particular be protected against fire risk. Such protection may be achieved by equipping the hydraulic station with thermal cut-outs preventing overheating of components, as well as establishing a real-time monitoring system of the equipment's condition. The thermal protection will prevent components from reaching a temperature at which the surface could ignite hydraulic oil from any damaged hoses, while real-time monitoring, for example via video link to the drilling operator or control centre, enables continuous visual inspection of the equipment's operational status and safety condition. Similar safety measures shall be implemented for other technical equipment, such as slurry booster pumps, installed within the tunnel.

The primary fire risk during the construction phase is considered to arise during repair work on equipment located inside the tunnel. In such situations, it is crucial that personnel pay particular attention to operational procedures when using potentially fire-generating tools such as angle grinders and cutting torches, especially in the vicinity of intermediate stations and installed technical equipment, including hydraulic stations and slurry booster pumps. After completion of repair work, it is essential to ensure that all spilled oil is thoroughly removed, and that used and oil-contaminated rags are disposed of safely. This is due to the risk of spontaneous ignition of oil-soaked rags under certain environmental conditions, which represents a significant fire safety concern.

To reduce the risk of fire incidents, fire enclosures may be installed at carefully selected critical locations where there is an increased risk of fire or fire propagation.

For precautions regarding charging and storage of batteries, see sections 2.2 and 3.9.

3.9 Fire on the TBM

It is a fundamental requirement that the temperature of all electric motors in the tunnel boring machine is continuously monitored in order to prevent overheating and thereby reduce the risk of fire and malfunction. Monitoring may, for example, be carried out using thermal cut-outs or by integrating functions into the TBM control software, which can automatically deactivate motors in the event of a detected temperature exceedance.

To minimise fire risks, the installation of the following measures should be considered:

- A fire alarm system that automatically sends signals to the drilling operator by the controls. In cases where the TBM is controlled directly from the machine itself, the fire alarm shall be connected so that both personnel in the launch pit and at surface level are promptly and effectively informed of a potential fire incident.

Accidents and incidents ...

- Placement of fire extinguishers at strategic locations throughout the TBM to ensure rapid access to firefighting equipment in the event of a fire.
- A fire suppression system consisting of sprinklers installed at the crown of the TBM, designed to create a water curtain that can limit or extinguish a fire in its initial stages and help contain smoke.
- Fire enclosures may be installed at carefully selected critical locations where there is an increased risk of fire or fire propagation.
- Pressure cylinders, e.g. oxygen and gas cylinders used during repair work on the TBM, shall be removed immediately after the work has been completed and before tunnelling resumes. This is to reduce the risk of incidents related to fire or explosion hazards.
- Batteries for transport vehicles intended for personnel transport inside the tunnel shall be removed from the TBM before tunnelling is initiated and operated unmanned. In cases where the TBM is manned, such as an Earth Pressure Balance (EPB) machine, batteries may however remain in the machine while personnel are present inside it. Reference to Section 2.2 Personnel transport in tunnels.

4 Tunnelling methods

The tables below provide schematic overviews of the main tasks associated with different tunnelling methods.

4.1 Typical work operations

Typical work operations	AVN	EPB	Open face	Open face with compressed air
TBM operator in the machine		X	X	X
Normal access through the tunnel	X	X	X	X
Control measurements	X	X	X	X
Alignment surveyor	X	X	X	X
Pressurised work	X	X		X
Regular inspections	X	X	X	X
Minor repairs	X	X	X	X
Passage of intermediate jacking stations	X	X	X	X
Passage of booster pump	X			
Passage of muck car		X	X	X
Dismantling of tunnel equipment	X	X	X	X
Grouting of the overcut	X	X	X	X
Repair of pipe damage	X	X	X	X

4.2 Ergonomics in tunnel and TBM

Manual work	AVN	EPB	Open face	Open face with compressed air
Personnel transport in tunnel	X	X	X	X
Replacement of cutting tools in the cutterhead	X	X		
Maintenance of excavation and cutting tools			X	X
Transport of tools and cutterhead disc through tunnel	X	X		
Removal of obstructions at excavation face			X	X
Dismantling of intermediate jacking stations (Ø1600–Ø1800 for lengths above approx. 200 m)	X	X	X	X
Dismantling of booster pumps (lengths above approx. 500 m)	X			
Repair of damage	X	X	X	X
Breakdowns and emergency repair of tunnelling equipment	X	X	X	X
Dismantling of hydraulic pump	X	X	X	X
Clearing of the tunnel	X	X	X	X
Overcut grouting	X	X	X	X
Transport of various items for maintenance	X	X	X	X
Tunnel cleaning	X	X	X	X

4.3 Emergency preparedness and evacuation from the tunnel and TBM

Incidents and accidents	AVN	EPB	Open face	Open face with compressed air
Ground collapse at the excavation face			X	X
Ground collapse into the cutterhead	X	X		
Injury during pressurised work at the excavation face	X	X		X
Medical incident during work in the tunnel	X	X	X	X
Medical incident during lone working on the TBM (e.g. TBM operator)		X	X	X
Passage of intermediate jacking stations with a stretcher	X	X	X	X
Passage of booster pumps or other obstructions with a stretcher	X	(X)	(X)	(X)
Passage of muck car with a stretcher		X	X	X
Fire in the tunnel	X	X	X	X
Fire on the TBM	X	X	X	X

Appendix 1 – Machine operations

Machine operations

Working environment in AVN and EPB-machines

Martin Winther Vede

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Appendix ...

2 Machine operations AVN og EPB

2.1 Introduction

This appendix serves as a comprehensive guide to the operational procedures and safety protocols governing machine and tunnel activities associated with AVN and Earth Pressure Balance (EPB) tunneling methods. Given the complexity and inherent hazards of tunnel construction, particularly in mechanized tunneling environments, ensuring safety and regulatory compliance is paramount. The focus of this document is to provide detailed, step-by-step procedures addressing both machine operations and tunnel operations, with an emphasis on occupational health and safety management.

Throughout tunneling activities, a wide range of operational scenarios present unique risks that require vigilant oversight by contractors to ensure adherence to occupational health legislation and to safeguard the well-being of personnel. The document systematically outlines specific safety measures, emergency response protocols — such as fire incidents and personnel rescue — as well as practical guidelines for the transport of personnel and materials within confined tunnel environments.

Moreover, the document details the coordination of complex tasks such as the maintenance and replacement of drilling tools under compressed air, intermediate station repairs, dismantling operations, and the installation of critical equipment like slurry booster pumps and grouting systems. These components are essential for maintaining operational efficiency and structural integrity, while promoting a safe workplace.

Each section not only presents operational instructions but also integrates comprehensive safety checks, including ventilation and air quality verification, electrical and hydraulic system inspections, and the use of specialized safety equipment ranging from fresh air masks to emergency communication systems. The document also clarifies personnel requirements, rescue preparedness, and equipment handling protocols, reflecting best practices and compliance with relevant safety standards.

By consolidating these procedures and safety considerations into a singular, accessible reference, this document aims to support contractors, engineers, safety officers, and all involved personnel in the secure and effective execution of DN1600 AVN and EPB tunneling projects. Ultimately, this ensures both project success and the highest standards of occupational health and safety are maintained throughout all phases of tunnel construction.

Appendix ...

3 AVN Machine operations

	Machine operations (AVN DN1600)		Tunnel operations (AVN DN1600)
1	Work in the tunnel/machine itself	1	Before Work in the tunnel/machine itself
2	Fire at the machine	2	Fire in the tunnel
3	Transport through the tunnel	3	Transport personnel through the tunnel
4	Rescue of personnel from the tunnel machine to terrain. Scenario heart attack.	4	Transport af loads in the tunnel
5	Compressed air, Replacement of drilling tools (Disc)	5	Work at intermediate stations repair/ dismantling
6	Slurry pump at the machine	6	Repair in the tunnel (Installation of a rubbering in the pipes, closing bentonite holes ex.
		7	Dismantling equipment in the tunnel. Pipes, cables, closing bentonite holes ex.
		8	Dæmmer/ grouting
		9	Installing Booster slurry pump

	Machine operations	Tunnel operations
1	**Before Work in the tunnel/machine itself** When work of extended duration is to be performed inside the Tunnel Boring Machine (TBM), all tunnel equipment obstructing free access to the machine must be removed. This specifically includes the Booster slurry pump, which must be extracted from the tunnel to ensure adequate space and a safe working environment for personnel. For tasks of shorter duration, the Booster pump may remain in place; however, personnel will be required to navigate around or pass over it during their activities. In such cases, a safe and stable passage must be established over the Booster slurry pump to facilitate secure access for personnel and to minimize the risk of accidents. It should be noted that the Booster slurry pump is mounted on wheels, enabling it to be easily relocated. The pump can be pulled out of the tunnel using a wire winch, facilitating efficient removal without significant difficulty.If work is to be carried out inside the TBM of long duration, the Booster slurry pump must be removed from the tunnel. For small work durations, the Booster pump will stay, and personnel will need to passit. (Booster pump is on wheels, and can be pulled out using a wire winch) Before any work in the machine startup, the following must be executed. Prior to commencing any work within the machine startup area, a series of preparatory procedures must be executed meticulously. These procedures are critical to establish a controlled and secure work environment while minimizing operational hazards during maintenance or inspection operations. Everyone who will be working in tunnel and TBM must have undergone a special safety introduction before the work can commence. Checklist prior to start work: • Site crane is ready for operations. • Site personnel is advised/instructed in the operations • The main power supply turns off • Air exchange and air quality ensured, Fresh air compressor checked – Backup fresh air compressor checked – Emergency generator checked • Emergency light is installed in the tunnel and TBM as described in TUN 101 with a back-up orientation light lasting for at least 30 min. • Safety equipment checked – Stretcher – First aid equipment – Fresh air masks for a minimum of 20 minutes or longer if the tunnel length requires it. – Fire extinguisher – Gas detector	**Before Work in the tunnel** If work of extended duration is to be carried out inside the tunnel, all tunnel equipment obstructing free access must be removed. For example it is mandatory to remove the Booster slurry pump from the tunnel to ensure unobstructed access and a safe working environment. In cases where the work duration is short, the Booster slurry pump may remain in place; however, personnel will be required to pass by or over the equipment during their tasks. In such instances, appropriate measures must be taken to establish a safe and stable passageway to facilitate secure and efficient movement of personnel around the pump. This precaution is essential to minimize potential risks and maintain operational safety within the confined tunnel space.If work is to be carried out inside the Tunnel of long duration, the Booster slurry pump must be removed from the tunnel. Small work durations, the Booster pump will stay, and personnel will need to passe it. **Staff** • Always minimum 2 people in the tunnel at a time • 1 Person in the shaft ready for rescue • 1 person on terrain ready for rescue Before any work in the tunnel startup, the following must be executed. • Site crane is ready for operations. • Site personnel is advised/instructed in the operations • The main power supply turns off • Air exchange and air quality ensured in the tunnel, – Fresh air compressor checked – Emergency generator checked • Main light checked • Bring emergency lighting • Safety equipment checked – Stretcher – First aid equipment – Fresh air masks for a minimum of 20 minutes – Fire extinguisher – Gas detector • Telephone landline is installed, Telephone at Shaft, all intermediate stations and the machine. • Trolly for transport of personnel and materials is checked. • Battery driven personnel transport is checked and used for entering the tunnel.

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	Machine operations	Tunnel operations
	• Telephone line is installed fx. on WiFi, so personnel can come in contact with their colleges at all time. • Trolly for transport of personnel and materials is checked. • Battery driven personnel transport is checked and used for entering the tunnel. • Main power supply switched off before personnel enter the tunnel • Hydraulic stations are switched off before personnel enter the tunnel • In the tunnel at then TBM there will be installed censors/monitoring for the following – Oxygen level – CO2 level – Methane gas – LEL and VOC. • Cameras is Checked before personnel enter the tunnel. • Tunnel lights – Stationary lighting in the tunnel run on separate light source.	
2	**Fire at the machine *** There is little risk of fire and smoke in an AVN TBM. If a fire or heavy smoke breaks out, the tunnel is to be evacuated. The workforce at the TBM will: • Use the Fresh air masks. • Call out to the shaft and report the situation. • Evacuating the TBM and tunnel using Battery driven personnel transports Water curtains at the TBM It is recommended that water curtains be installed exclusively at the exit of the Tunnel Boring Machine (TBM) and further inside the tunnel to prevent direct contact between the water spray and components that may be involved in an oil fire. The primary function of these water curtains is to retard smoke development, thereby creating a safer environment that enables personnel to evacuate the tunnel promptly and reach safety. This precaution is especially important because if water curtains spray water directly onto burning oil, the fire risk may escalate, potentially intensifying the flames or causing hazardous spread. By strategically positioning water curtains in these locations, the risk of exacerbating an oil fire is minimized while still providing an effective smoke barrier. This approach enhances overall safety by mitigating smoke propagation without increasing the risk of fire escalation within the TBM and tunnel environmentIt is recommended that because there is a risk, that the workforce do not know what started the fire or smoke development, the use of water curtains cannot be allowed at the TBM. If it is an oil fire, the use of water curtains can escalate the situation.	**Fire in the tunnel/tunnel equipment** There is little risk of fire and smoke in the tunnel. The materiel/Equipment mounted in the tunnel is the following. • Main power cable Modules a water prof (For the TBM) (Electricity) • Secondar power cable Modules a water prof (For the lightning and placed power boxes in the tunnel) (Electricity) • Tunnel light (Electricity) • Pipes/hoses for fresh air (Air) • Pipe/hoses for the slurry line (Water, bentonite and underground materials) • Pipe/hoses for bentonite lubrication (Bentonite) • Bentonite modules placed ad the bentonite holes. Modules a water prof (Modules run on low voltage 230V) • Data cable for the TBM Modules a water prof (Cobber or fiber) • Data cable for the TBM navigation Modules is waterproof (Cobber or fiber) • Hose for the TBM navigation (Freezing fluids) • Landline for the telephone Modules is waterproof (Cobber of fiber) • Hydraulic hoses (Hydraulic) • Hydraulic cylinders (Intermediate Stations) As indicated in the list above, the system involves both hydraulic oil and electrical components. The coexistence of these two elements under optimal operating conditions presents a potential fire hazard. For ignition to occur, a specific sequence of events must take place involving the activation of multiple system components. Initially, the hydraulic pump becomes operational, pressurizing the hydraulic fluid. Should there be a breach in the hydraulic hose, such as a small rupture or perforation, pressurized hydraulic oil can be expelled at high velocity directly onto an exposed or compromised electrical component. In this scenario, the combination of flammable hydraulic oil and an electrical source capable of generating sparks or sufficient heat creates a risk of ignition. Consequently, the hydraulic oil may ignite, potentially resulting in a fire. Seen in the above list, there isHydraulic oil and there iselectricity. Combine the two in aperfectcondition and there maybe a risk of fire. For a fire to start alle systems must be activated. The hydraulic pump is activatedand a small hole in the hydraulic hose spray oil direc-tlyat a damagedelectric component. And now there is a chance for the oil to ignite. If the electrical system becomes exposed to water infiltration or experiences an ignition event, electrical current may short circuit, causing the protective relay system to activate and subsequently cut off the power supply, similar to the safety mechanisms employed in standard residential electrical installations. Once the power is interrupted, the hydraulic pump ceases operation, resulting in no pressure being exerted on the hydraulic hoses. Consequently, the absence of pressurized hydraulic fluid eliminates the presence of any potential combustible source within the hydraulic lines. Moreover, the deactivation of the electrical system removes the ignition source entirely, thereby significantly reducing the risk of fire or further damage. This

* There is no registered fire in an AVN micro tunneling machineever. However, should an AVN TBM ignite during operation. Then let it burn!!!. There are no people at the AVN machine when it is in operation or in the tunnel. In the tunnel itself there is nothing for igniting a fire, hydraulic oil is fed in dense pressurized hoses. Electrical cables and lighting are switched off at transition, i.e. the sheath of a cable, for example, is exposed. Relay turns off the power. If manning is required into the tunnel, the oil engine for hydraulic oil shall be switched off and the main power supply is turned off.

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	Machine operations	Tunnel operations
		automatic shutdown mechanism plays a critical role in maintaining overall system safety by isolating both the fuel and ignition components in the event of a fault. If anelectric system take in water or ignite,the current will cross and the relay will cut of the power. Just like in a normal house. When the power is turnedoff, there will be no pressure on the hydraulic hosesand therefore no component/source to burn. Furthermore, when the power is turnedoff, the source for igniting is removed.
3	**Transport personnel through the tunnel to the TBM *** The conveyance of personnel through the tunnel to the Tunnel Boring Machine (TBM) is to be conducted exclusively by means of battery-powered personnel transport vehicles. In adherence to safety protocols, each personnel transport unit is designated for a single occupant at a time; additionally, at least two individuals must be present within each designated work zone in the tunnel to ensure safety and provide mutual assistance in the event of an emergency.Transport of personnel, is by using bBattery driven personnel transport. One person pr transport and a minimum of 2 persons in the tunnel pr work zone. All battery-powered personnel transport vehicles must be stationed in the shaft when not in active use. In circumstances where the tunnel is partially obstructed—such as by the presence of equipment like the slurry booster pump—it may be necessary to position an equivalent personnel transport vehicle on the opposite side of the obstruction. This ensures continuous accessibility and maintains the flexibility required for safe movement of personnel throughout the tunnel, irrespective of physical barriers.Battery driven personnel transportare placed in the shaft and at on the other side of the slurry booster pump in the tunnel. See drawing 01must be placed in the shaft. If obstacles in the tunnel, it can be necessary to havea similar personnel transport on the other side of the obstacle. Fx slurry booster pump. Should personnel be required to undertake an inspection of the TBM and the tunnel, the following procedures must be executed:If personnel need to do inspection of the TBM and tunnel, the following will be performed: Personnel shall utilize battery-powered transport vehicles to facilitate safe and efficient travel within the tunnel environment.The personnel will use Bbattery driven transports, to drive in the tunnel. • Personnel drive in the tunnel to the booster slurry pump,. Tthis pump is often installed 400-500m into the tunnel. • Personnel pass the booster slurry pump, by using the pathway that is placed on the side or top of the pump. • There a placed 2 Battery driven transports on the other side of the booster slurry pump. Personnel use this to drive to the TBM. • At the booster slurry pump, the charging-station is placed for the transports. Because the charging is at the booster slurry pump, there will never be personnel in the tunnel, when the transports is charging.	**Transport personnel through the tunnel** Transport of personnel is by using a batterybattery driven personnel transport. One personOne-person pr transport and a minimum of 2 personspeople in the tunnel pr work zone. There are placed personnel transportstransport in the shaft and ttransportransports on the other side of the slurry booster pump in the tunnel. *Se drawing 01* If personnel need to do inspection of the TBM and tunnel, the following will be performed. The personnel will use Battery driven transports, to drive in the tunnel. • Personnel drive in the tunnel to the booster slurry pump, this pump is often installed 400-500m in the tunnel. • Personnel pass the booster slurry pump, by using the pathway that is placed on the side of the pump. • There is placed 2 Battery driven transports on the other side of the booster slurry pump. Personnel will use this to drive to the TBM. • At the booster slurry pump,the charging-station is placed for the transports. Becausethe charging is at the booster slurry pump, there will never be personnel in the tunnel,when the transports is charging.
4	**Rescue of personnel from the tunnel machine to terrain. Scenario: fainted personnel. TBM AVN** Scenario: 2 people work at the TBM, one person faints and has tomust be brought to terrain. • The personnel at the TBM contactscontact the personnel in the shaft, by using the installed telephone landline. The personnel in the shaft call emergency 112. • At the TBM the injured personnel is placed on at stretcher (by 2 persons) that is on a trolly and is pushed to the Booster Slurry Pump. • The personnel in the shaft prepares the trolly, that is placed in the shaft with the first aid kit. • 2 persons from the shaft enter the tunnel with the trolly, and go to the booster slurry pump. • At the Slurry booster pump, the injured personnel is lifted op by using a chain hoist and slides over the pump. • The injured personnel is now placed on the trolly from the shaft. • One person pushpushes the trolly to the shaft and the remaining 2 persons, drive out by using the 2 Battery driven personnel transport, the is placed at the slurry booster pump. • In the shaft, the injured personnel is lifted uplifted to terrain, by using the site crane. The stretcher is build for lifting.	**Transport of loads in the tunnel** **Transport from shaft to the Booster slurry pump** • Cutting tools are placed in boxes and transported on a trolly pulled by a wire/ hydraulicmotorhydraulic motor to the booster slurry pump • The boxes and trolly are lifted uplifted by using a chain hoist and slidesslide over the pump. • The boxes and trolly are put down • Personnel use the passage on the side of the pump **Transport from the Booster slurry pump to the TBM** Passing the slurry pump at the TBM (Personnel and Loads/materials). • The Box and trolly is pulled by a wire to the TBM • The Box is lifted op, by using a chain hoist and slides over the pump on the trolly line. • When the Box has passed the slurry pump, the load can be placed in the TBM for further handling. • Personnel use the passage on the side of the pump

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	Machine operations	Tunnel operations
5	**Compressed air. Compressed Air and Replacement of Disc Drilling ToolsReplacement by disk drilling tool** Prior to the commencement of tunnelling operations, cutting tools are pre-positioned at the Tunnel Boring Machine (TBM) to minimize the need for subsequent lifting and manual handling, thereby enhancing both efficiency and safety. This preparatory measure is designed to reduce the risk of injury and streamline the replacement process. In circumstances where it becomes necessary to transport cutting tools from the shaft to the TBM, the following procedural steps must be observed: Before the actual tunnelling starts, cutting tools are laid at the machine, this is to reduce lifting and handling. If cutting tolls is to be transported from the shaft and to the TBM there arefollowing steps: **Transport from shaft to the Booster slurry pump** • Cutting tools attools placed in boxes and transported on a trolly pushed by personnel through the tunnel, and to the slurry booster pump. • The boxes are sifted up, by using a chain hoist and slides over the pump. • The boxes are put down on the trolley, that is placed on this side of the pump. • Personnel use the passage on the side of the pump • The trolly is pushed to the TBM. **Transport from the Booster slurry pump to the TBM** Passing the slurry pump at the TBM (Personnel and Loads/materials). • The cutting tools on the trolley are placed next to the slurry pump. • The Cutting tools isare lifted op, by using a chain hoist and slides over the pump on the trolley line. • When the Cutting tools has passed the slurry pump, the load can be placed in the TBM for further handling. • Personnel use the passage on the side of the pump **Work with compressed Air** When the cutting tools need to be changed, the work is performed under compressed air. Before work with compressed air can start, personnel need to be medical approved, andapproved and trained in the equipment and procedures. Furthermore, the TBM needs to be equipped with a certain safety installation. • All personnel are dive approved (Medical approved) • All personnel are trained in the airlock systems. • The machine is installed with emergency locks, so that personnel that is working under compressed air, can get help. – Fresh air compressor • Air is pumped up in the air tank that acts as a main and backup tank., if thelf the pressure drops in this tank, the emergency compressor is automatically turned on. • Emergency fresh air compressor • Emergency generator – All systems are designed to initiate automatically. In the event that the compressors do not receive electrical power, the emergency generator will be activated to supply the necessary voltage and ensure uninterrupted operation of the compressors and associated systems.All systems are started automatically, if there is no voltage at the compressors and the emergency generator starts. • At a minimum, two individuals must be present within the pressure chamber to conduct the work. In addition, one designated operator is responsible for monitoring and controlling the pressure system at the Tunnel Boring Machine (TBM). Furthermore, a dedicated rescue team must be in place: one person positioned at the TBM, ready to initiate rescue operations if necessary; one individual stationed at the base of the shaft (in the pit), prepared to assist in rescue situations; and one person located on the surface (terrain), also prepared for immediate intervention. This arrangement brings the minimum total number of required personnel to six, thereby ensuring that both operational and emergency protocols can be implemented without delay in the event of an incident.When working under compressed air, the minimum personnel is 2in the pressure chamber, and1 person controls the pressure system at the TBM, 1 person is ready for rescue at the machine. 1 person stands in the pit ready for rescue. 1 person stands on terrain ready for rescue. In total6 persons. • When replacing cutting tools, chains and lifting equipment are used, so that the crew does not lift them directly.	**Work at intermediate stations repair/ dismantling** A variety of operations can be performed at the intermediate station, with the primary activities encompassing the repair and dismantling of hydraulic jacks located within the stationWhen working at the intermedia station a lot of different operations can be performed. Main categories is repair and dismantling of hydraulic jacks inthe station. **Repair** When repairs are conducted at the intermediate stations, the main electrical power supply is disconnected, and hydraulic pressure to the station is simultaneously relieved. This safety protocol effectively eliminates the risk of fire ignition within the tunnel equipment during maintenance activities. In cases where the repair work involves hot work operations, such as the use of angle grinders or blowtorches, personnel are required to comply with Danish safety regulations. Specifically, they must possess a valid certification for performing hot work and adhere to the European CFPA Guideline No. 12, which outlines best practices and safety measures for fire prevention during such tasks. If repair is performed in the stations, the main electric power is turned off, and the hydraulic pressure to the intermedia station is cut off. Now there is no risk for starting a fire on the tunnel equipment. If the work includeshot work, ex. Angel grinder or a blowtorch, the personnel need to follow the Danish instruction and have a valid Course certificate for this and it must follow the European CFPA Guideline nr. 12.. • The Personnel use the trolly that is placed in the shaft for materials. One person pushpushes the trolly and the college use the electric transport to the work Zone • When the personnel isare at the work zone, they either work on their knees, if the work is close to the bottom of the tunnel, or they site on the trolly if the work is placed higher. **Dismantling off the intermediate stations** The dismantling process of the intermediate station commences once the Tunnel Boring Machine (TBM) has arrived at and been removed from the end shaft. Additionally, the slurry booster pumps are extracted from the tunnel. Under these conditions, the tunnel attains unrestricted airflow, with no physical obstructions impeding movement, and two available exits providing safe egress routes. To facilitate the removal of equipment such as trolleys during dismantling, hydraulic winches may be installed at both the start and end shafts. These winches enable controlled pulling of the trolley in both directions, ensuring efficient and safe handling of heavy components within the tunnel environment. When the intermediate station is to be dismantled, the TBM have arrived and removed from the end shaft. The slurryboosterpumpswill also beremoved from the tunnel.Now there is free airflow in the tunnel,no obstaclesand there aretwoexits. (A hydraulic winch can be installed in the start, and end shaft to pull the trolly in both directions. • The personnel remove cylinders from the bottom and sides first, by lifting them with a chain hoist. This chain hoist is fixed to the cylinder in the top. This work is performed from the knees. • When the cylinders are removed from the bottom and sides and placed on the trolley, the trolley is pushed out to the shaft and emptied. • The trolley is now loaded with pallets, so the pallets hight, is about 30cm from top pipe (ID) • The trolly is now pushed in under the intermediate station cylinders, and the top cylinders is dismantled, and falls 30 cm down on the pallet, this work can be performed by personnel sitting on a chair. • When all ofall the cylinders a removed, the intermediate station is pushed together, with the main jacking cylinders in the shaft.

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	Machine operations	Tunnel operations
6		**Repair in the tunnel (Installation of a rubbering in the pipes, closing bentonite holes ex.** The Tunnel Boring Machine (TBM) has successfully arrived at and been removed from the end shaft, and the slurry booster pumps and other equipment have likewise been extracted from the tunnel. As a result, unobstructed airflow is now established within the tunnel, with all obstacles cleared and two accessible exits available. To facilitate the movement of trolleys during subsequent operations, hydraulic winches have been installed at both the start and end shafts. These winches allow for controlled and safe towing of the trolley in both directions, thereby enhancing operational efficiency and safety within the tunnel environment. TBM have arrived and removed from the end shaft and the slurry pumps areremoved from the tunnel. Now there is free airflow in the tunnel, no obstacles and there are two exits. A hydraulic winch isinstalled in the start, and end shaft to pull the trolly in both directions. The work positions will be the same in all work scenarios. • Personnel drive to the work zone, using the electric transports. • The trolley is pulled in loaded with tools and materials, for the work assignment • Personnel will work eighter on their knees or sitting on the trolly.
7		**Dismantling equipment in the tunnel. Pipes, cables, closing bentonite holes ex.** The Tunnel Boring Machine (TBM) has successfully arrived at and been removed from the end shaft, and the slurry booster pumps and other equipment have likewise been extracted from the tunnel. As a result, unobstructed airflow is now established within the tunnel, with all obstacles cleared and two accessible exits available. To facilitate the movement of trolleys during subsequent operations, hydraulic winches have been installed at both the start and end shafts. These winches allow for controlled and safe towing of the trolley in both directions, thereby enhancing operational efficiency and safety within the tunnel environment.TBM have arrived and removed from the end shaft and the 2 slurry pumps a removed from the tunnel. Now there is free airflow in the tunnel,no obstaclesand there are two exits. A hydraulic winch a installed in the start, and end shaft to pull the trolly in both directions. • Personnel drive to the work zone, using the electric transports. • The trolly is placed next to ex. hose that need to be dismantled, a person is standing on each side of the trolly • The personnel now lift the hose down from the rack and on the trolly. • When the trolly is loaded, personnel use the telephone installed at the intermedia station, to call personnel placed in the shaft. The load is pull out to the shaft. • When the personnel need to dismantle heavy equipment like electric cables, the cables is taken down 3-5meters at a time and put on the trolly. At this way, the workers is lifting a minimum. When the equipment is getting to heavy to lift by hand, the personnel will use eighter a chain hoist mounted I the top af the tunnelpipe. It is also possible of using af customized, electric crane mounted on the undercarriage af the trolly.
8		**Dämmer/ grouting** Upon completion of the tunneling process, the majority of the equipment within the tunnel is removed. One critical step in the finalization phase involves stabilizing the overcut surrounding the tunnel pipe. This stabilization is achieved by injecting grout material, specifically dämmer, into the overcut through bentonite injection nozzles. Bentonite pipes are installed throughout the tunnel at regular intervals, typically with every third pipe designated as a bentonite pipe. Each bentonite pipe is equipped with approximately three bentonite nozzles positioned along the circumference of the pipe to ensure even distribution of grout. The standard locations of these nozzles within the pipe are at approximately the 2 o'clock, 5 o'clock, and 7 o'clock positions. This systematic injection of dämmer through the bentonite nozzles plays a vital role in reinforcing the soil around the tunnel lining, thereby enhancing the structural stability and long-term integrity of the tunnel. When tunneling is finished, most of the equipment inside the tunnel is removed, and the overcut around the tunnel pipe must be stabilized. This is done by injecting dämmer into the overcut via the bentonite nozzles. Every third pipe in the tunnel stretch is a bentonite pipe, and each bentonite pipe have typically 3 bentonite nozzles. (Location of the nozzles in the pipe is kl.2…kl.5…kl.7.

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	Machine operations	Tunnel operations
		• The work processes,processes for this work assignment can be performed by this following steps. • The automatic bentonite system is dismantled, leaving only bentonite nozzles. • Personnel in the tunnel connect a 1 inch rubber hose to the bentonite nozzle. This hose is connected withrelates to the main bentonite line, which was previously used. • The tunnel staff contact the staff who mix and control the pumping of Ddämmer. Pumping is initiated. • The staff in the tunnel make sure the overcut is filled with dDämmer when the external pressure in the overcutter is sufficient. This is done visually via a pressure gauge, which is mounted on the 1inch hose • When the overcut is filled, the 1inch hose is removed and mounted on the next bentonite nozzle and work processes are started again. • When the entire tunnel section overcut is sufficiently filled, the remaining pipes are dismantled. See Dismantling equipment in the tunnel. Pipes, cables, closing bentonite holes ex.
9		**Installing Booster slurry pump** A slurry booster pump must be installed typically after the 400-500 meter tunnel is performed. This pump help maintain the pump pressure, so that the slurry materials can be pumped. The pump is installed from the pit and into the first tunnel pipe. • The pump is hoisted into the pit with the construction site crane. • The pump is pushed into the first tunnel pipe • Personnel connect the pump inside the tunnel approximately 2 to 3 meters inside. To connect the pump, one power cable and 2 Pcs 4-6 inch hoses is connected.

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4 EPB Machine operations

	Machine operations (EPB DN1600)		Tunnel operations (EPB DN1600)
1	Work in the tunnel/machine itself	1	Before Work in the tunnel/machine itself
2	Fire at the machine	2	Fire in the tunnel
3	Transport through the tunnel	3	Transport personnel through the tunnel
4	Rescue of personnel from the tunnel machine to terrain. Scenario heart attack.	4	Transport af loads in the tunnel
5	Compressed air, Replacement of drilling tools (Disc)	5	Work at intermediate stations repair/ dismantling
6	Soil cart at the machine	6	Repair in the tunnel (Installation of a rubbering in the pipes, closing bentonite holes ex.
		7	Dismantling equipment in the tunnel. Pipes, cables, closing bentonite holes ex.
		8	Dæmmer/ grouting

	Machine operations	Tunnel operations
1	**Before Work in the tunnel/machine itself** When work of extended duration is to be performed inside the Tunnel Boring Machine (TBM), all tunnel equipment obstructing free access to the machine must be removed. This specifically includes the soil cart, which is used to transport soil from the tunnel boring machine to the pit. This must be extracted from the tunnel to ensure adequate space and a safe working environment for personnel. For tasks of shorter duration, this also applies Prior to commencing any work within the machine startup area, a series of preparatory procedures must be executed meticulously. These procedures are critical to establish a controlled and secure work environment while minimizing operational hazards during maintenance or inspection operations. Everyone who will be working in tunnel and TBM must have a special safety introduction before the work can commence. Checklist prior to start work: • Site crane is ready for operations. • Site personnel is advised/instructed in the operations • The main power supply turns off • Air exchange and air quality ensured, Fresh air compressor checked – Backup fresh air compressor checked – Emergency generator checked • Emergency light is installed in the tunnel and TBM with a back-up orientation light lasting for at least 30 min. • Safety equipment checked – Stretcher – First aid equipment – Fresh air masks for a minimum of 20 minutes – Fire extinguisher – Gas detector • Telephone line is installed fx. on WiFi, so personnel can come in contact with their colleges at all time. • Trolly for transport of personnel and materials is checked. • Battery driven personnel transport is checked and used for entering the tunnel. • Hydraulic stations are switched off before personnel enter the tunnel • In the tunnel at the TBM there will be installed censors/monitoring for the following – Oxygen level – CO2 level – Methane gas – LEL and VOC. • Cameras is Checked before personnel enter the tunnel. • Tunnel lights – Stationary lighting in the tunnel run on separate light source.	**Before Work in the tunnel** If work of extended duration is to be carried out inside the tunnel, all tunnel equipment obstructing free access must be removed. For example it is mandatory to remove the soil cart from the tunnel to ensure unobstructed access and a safe working environment. For tasks of shorter duration, this also applies. This precaution is essential to minimize potential risks and maintain operational safety within the confined tunnel space. **Staff** • Always minimum 2 people in the tunnel at a time • 1 Person in the shaft ready for rescue • 1 person on terrain ready for rescue Before any work in the tunnel startup, the following must be executed. • Site crane is ready for operations. • Site personnel is advised/instructed in the operations • The main power supply turns off • Air exchange and air quality ensured in the tunnel, – Fresh air compressor checked – Emergency generator checked • Main light checked • Bring emergency lighting • Safety equipment checked – Stretcher – First aid equipment – Fresh air masks for a minimum of 20 minutes – Fire extinguisher – Gas detector • Telephone landline is installed, Telephone at Shaft, all intermediate stations and the machine. • Trolly for transport of personnel and materials is checked. • Battery driven personnel transport is checked and used for entering the tunnel.

Appendix ...

	Machine operations	Tunnel operations
2	**Fire at the machine *** There is little risk of fire and smoke in an TBM. If a fire or heavy smoke breaks out, the tunnel is to be evacuated. The workforce at the TBM will: • Use the Fresh air masks. • Call out to the shaft and report the situation. • Evacuating the TBM and tunnel using Battery driven personnel transports Water curtains at the TBM It is recommended that water curtains be installed exclusively at the exit of the Tunnel Boring Machine (TBM) and further inside the tunnel to prevent direct contact between the water spray and components that may be involved in an oil fire. The primary function of these water curtains is to retard smoke development, thereby creating a safer environment that enables personnel to evacuate the tunnel promptly and reach safety. This precaution is especially important because if water curtains spray water directly onto burning oil, the fire risk may escalate, potentially intensifying the flames or causing hazardous spread. By strategically positioning water curtains in these locations, the risk of exacerbating an oil fire is minimized while still providing an effective smoke barrier. This approach enhances overall safety by mitigating smoke propagation without increasing the risk of fire escalation within the TBM and tunnel environment	**Fire in the tunnel/tunnel equipment** There is little risk of fire and smoke in the tunnel. The materiel/Equipment mounted in the tunnel is the following. • Main power cable Modules a water prof (For the TBM) (Electricity) • Secondar power cable Modules a water prof (For the lightning and placed power boxes in the tunnel) (Electricity) • Tunnel light (Electricity) • Pipes/hoses for fresh air (Air) • Pipe/hoses for the slurry line (Water, bentonite and underground materials) • Pipe/hoses for bentonite lubrication (Bentonite) • Bentonite modules placed ad the bentonite holes. Modules a water prof (Modules run on low voltage 230V) • Data cable for the TBM Modules a water prof (Cobber or fiber) • Data cable for the TBM navigation Modules is waterproof (Cobber or fiber) • Hose for the TBM navigation (Freezing fluids) • Landline for the telephone Modules is waterproof (Cobber of fiber) • Hydraulic hoses (Hydraulic) • Hydraulic cylinders (Intermediate Stations) As indicated in the list above, the system involves both hydraulic oil and electrical components. The coexistence of these two elements under optimal operating conditions presents a potential fire hazard. For ignition to occur, a specific sequence of events must take place involving the activation of multiple system components. Initially, the hydraulic pump becomes operational, pressurizing the hydraulic fluid. Should there be a breach in the hydraulic hose, such as a small rupture or perforation, pressurized hydraulic oil can be expelled at high velocity directly onto an exposed or compromised electrical component. In this scenario, the combination of flammable hydraulic oil and an electrical source capable of generating sparks or sufficient heat creates a risk of ignition. Consequently, the hydraulic oil may ignite, potentially resulting in a fire. If the electrical system becomes exposed to water infiltration or experiences an ignition event, electrical current may short circuit, causing the protective relay system to activate and subsequently cut off the power supply, similar to the safety mechanisms employed in standard residential electrical installations. Once the power is interrupted, the hydraulic pump ceases operation, resulting in no pressure being exerted on the hydraulic hoses. Consequently, the absence of pressurized hydraulic fluid eliminates the presence of any potential combustible source within the hydraulic lines. Moreover, the deactivation of the electrical system removes the ignition source entirely, thereby significantly reducing the risk of fire or further damage. This automatic shutdown mechanism plays a critical role in maintaining overall system safety by isolating both the fuel and ignition components in the event of a fault.
3	**Transport personnel through the tunnel to the TBM **** The conveyance of personnel through the tunnel to the Tunnel Boring Machine (TBM) is to be conducted exclusively by means of battery-powered personnel transport vehicles. In adherence to safety protocols, each personnel transport unit is designated for a single occupant at a time; additionally, at least two individuals must be present within each designated work zone in the tunnel to ensure safety and provide mutual assistance in the event of an emergency. All battery-powered personnel transport vehicles must be stationed in the shaft, when there is no personnel in the tunnel boring machine or in the tunnel. When the tunnel boring machine is in operation, here will also be a means of transport inside the tunnel boring machine, that the drill operator can use. In circumstances where the tunnel is partially obstructed—such as by the presence of equipment like the soil cart, Should personnel be required to undertake an inspection of the TBM and the tunnel because the tow wire is broken on the soil cart, the following procedures must be executed:	**Transport personnel through the tunnel** Transport of personnel is by using battery driven personnel transport. One-person pr transport and a minimum of 2 people in the tunnel pr work zone. There are placed personnel transport in the tunnel boring machine (If not remotely controlled) and in the pit. If personnel need to do inspection of the TBM and tunnel, the following will be performed. The personnel will use Battery driven transports, to drive in the tunnel. • Personnel must maintain communication with the machine operator and ensure that the soil cart is either driven out to the pit and only brought back in, after all personnel have left the tunnel, or that the soil cart remains securely positioned at the tunnel boring machine • Personnel drive in the tunnel to for their work tasks • If the soil cart is at the tunnel boring machine, the personnel will pass it by placing plates on top of the soil cart, and the personal pass over

* There is no registered fire in an micro tunneling machine. However, should an TBM ignite during operation. Ensure that all personnel are out of the tunnel boring machine and the tunnel itself. Do not attempt to extinguish the fire. Let it burn. In the tunnel itself there is nothing for igniting a fire, hydraulic oil is fed in dense pressurized hoses. Electrical cables and lighting are switched off at transition, i.e. the sheath of a cable, for example, is exposed. Relay turns off the power. If manning is required into the tunnel, the oil engine for hydraulic oil shall be switched off and the main power supply is turned off.

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	Machine operations	Tunnel operations
	Personnel shall utilize battery-powered transport vehicles to facilitate safe and efficient travel within the tunnel environment. • Personnel drive in the tunnel to the soil cart. This soil cart may risk stopping in case of a breakdown along the entire tunnel section. • Personnel can pass the soil cart, by laying plates over the soil cart if needed. • The Battery driven transports is lifted over the soil cart if necessary. • If the EPB is not remotely controlled, personnel from the tunnel boring machine can access the soil cart from the opposite side to assist with repairs, ensuring staff are positioned on both sides and eliminating the need to climb over the soil cart.	
4	**Rescue of personnel from the tunnel machine to terrain.** **TBM EPB** **Scenario 2** occurs during the work process when a loaded soil cart is pulled out to the shaft for unloading. On its way through the tunnel, the wheel on the soil cart is damaged to such an extent that the cart comes to a stop and cannot be pulled out by the wire. Personnel from the TBM and the shaft drive to the damaged soil cart to inspect the damage. The person positioned between the TBM and the soil cart slips, hits their head, and loses consciousness. The accident happens when the person dismounts the electric transport vehicle near the soil cart • Personnel in the shaft pull the soil cart out to the shaft, but the soil cart stops inside the tunnel. • Personnel in the shaft contact the drill operator and inform them about the situation. • Two people from the shaft call personnel on the surface, ensuring there is always staff in the shaft. Personnel from the shaft drive to the soil cart, and the drill operator also drives to the soil cart. • The drill operator dismounts the battery-powered transport vehicle, falls, hits their head, and loses consciousness. • Personnel now at the damaged soil cart, between the soil cart and the shaft, see their colleague lying in the tunnel pipe on the opposite side of the soil cart. • Personnel in the tunnel by the soil cart call the personnel in the shaft to inform them about the situation. • Personnel in the shaft call 112 (emergency) and bring a rescue stretcher and first aid kit into the tunnel to the soil cart. • Personnel already in the tunnel, between the soil cart and the shaft, immediately begin the rescue operation. Personnel use the two installed rescue planks found on the sides of the soil cart. • The rescue planks are placed on top of the soil cart so that they span from the front to the back of the soil cart. The rescue planks are equipped with lifting handles, which personnel use to handle them, and end stops that lock the planks onto the soil cart. (The planks are handled by one person.) – The rescue planks are lifted 20 mm at one end, over the shelf stop, and pulled out of the shelf. – When a rescue plank is pulled out, one end is lifted onto the cart with the end stop facing up. Then the opposite end of the rescue plank is lifted and pushed over the soil cart. When the rescue plank is placed on the soil cart, it is turned so the end stop faces down toward the soil cart and locks the ends in place. Two people climb over the soil cart and place the injured person on the brought-in rescue stretcher. The injured person is strapped onto the stretcher. There are now five people in the tunnel: one injured person, two people between the TBM and the soil cart, and two people between the soil cart and the shaft. • The rescue stretcher is lifted onto the rescue planks, first lifting one end so the front of the stretcher rests on the rescue planks. Then the back end of the stretcher is lifted onto the rescue planks. (Lifting the stretcher should be done in stages to minimize the burden on the rescuers.) • The injured person is pulled/pushed over the rescue planks by personnel on each side of the soil cart. • Personnel between the soil cart and the shaft receive the injured person and transport them to the shaft. Four wheels are mounted on the rescue stretcher, and the stretcher is pulled out to the shaft.	**Transport of loads in the tunnel** **Transport from shaft to the tunnelmashine** The soil cart must be removed from the tunnel to ensure clear passage between the pit and the tunnel boring machine • Cutting tools are placed in boxes and transported on a trolly pulled by a wire/ hydraulic motor to the tunnel boring machine. • When the equipment is at the tunnel boring machine, the equipment is lifted by using a chain hoist which is connected to an overhead beam. This beam is installed along the length of the tunnel boring machine

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	Machine operations	Tunnel operations
5	**Compressed Air and Replacement of Disc Drilling Tools** Prior to the commencement of tunnelling operations, cutting tools are pre-positioned at the Tunnel Boring Machine (TBM) to minimize the need for subsequent lifting and manual handling, thereby enhancing both efficiency and safety. This preparatory measure is designed to reduce the risk of injury and streamline the replacement process. In circumstances where it becomes necessary to transport cutting tools from the shaft to the TBM, the following procedural steps must be observed: **Transport from shaft to the tunnel boring machine** • The soil cart is pulled out to the pit by a wire. • Cutting tools placed in boxes and transported on a trolly pulled by wire through the tunnel, and to the tunnel boring machine. • The boxes are lifted up, by using a chain hoist which is connected to an overhead beam. This beam is installed along the length of the tunnel boring machine • When the cases are at the pressure chambers, the cases are opened and the cutter disc is lifted with chain hoists attached inside the pressure chambers on the ceiling." **Work with compressed Air** When the cutting tools need to be changed, the work is performed under compressed air. Before work with compressed air can start, personnel need to be medical approved and trained in the equipment and procedures. Furthermore, the TBM needs to be equipped with a certain safety installation. • All personnel are dive approved (Medical approved) • All personnel are trained in the airlock systems. • The machine is installed with emergency locks, so that personnel that is working under compressed air, can get help. • Fresh air compressor • Air is pumped up in the air tank that acts as a main and backup tank. If the pressure drops in this tank, the emergency compressor is automatically turned on. • Emergency fresh air compressor • Emergency generator – All systems are designed to initiate automatically. In the event that the compressors do not receive electrical power, the emergency generator will be activated to supply the necessary voltage and ensure uninterrupted operation of the compressors and associated systems. • At a minimum, two individuals must be present within the pressure chamber to conduct the work. In addition, one designated operator is responsible for monitoring and controlling the pressure system at the Tunnel Boring Machine (TBM). Furthermore, a dedicated rescue team must be in place: one person positioned at the TBM, ready to initiate rescue operations if necessary; one individual stationed at the base of the shaft (in the pit), prepared to assist in rescue situations; and one person located on the surface (terrain), also prepared for immediate intervention. This arrangement brings the minimum total number of required personnel to six, thereby ensuring that both operational and emergency protocols can be implemented without delay in the event of an incident. • When replacing cutting tools, chains and lifting equipment are used, so that the crew does not lift them directly.	**Work at intermediate stations repair/ dismantling** A variety of operations can be performed at the intermediate station, with the primary activities encompassing the repair and dismantling of hydraulic jacks located within the station **Repair** When repairs are conducted at the intermediate stations, the main electrical power supply is disconnected, and hydraulic pressure to the station is simultaneously relieved. This safety protocol effectively eliminates the risk of fire ignition within the tunnel equipment during maintenance activities. In cases where the repair work involves hot work operations, such as the use of angle grinders or blowtorches, personnel are required to comply with Danish safety regulations. Specifically, they must possess a valid certification for performing hot work and adhere to the European CFPA Guideline No. 12, which outlines best practices and safety measures for fire prevention during such tasks. • the soil cart are extracted from the tunnel • The Personnel use the trolly that is placed in the shaft for materials. The trolly is pulled by wire and the college use the electric transport to the work Zone • When the personnel are at the work zone, they either work on their knees, if the work is close to the bottom of the tunnel, or they site on the trolly if the work is placed higher. **Dismantling off the intermediate stations** The dismantling process of the intermediate station commences once the Tunnel Boring Machine (TBM) has arrived at and been removed from the end shaft. Under these conditions, the tunnel attains unrestricted airflow, with no physical obstructions impeding movement, and two available exits providing safe egress routes. To facilitate the removal of equipment such as trolleys during dismantling, hydraulic winches may be installed at both the start and end shafts. These winches enable controlled pulling of the trolley in both directions, ensuring efficient and safe handling of heavy components within the tunnel environment. • The personnel remove cylinders from the bottom and sides first, by lifting them with a chain hoist. This chain hoist is fixed to the cylinder in the top. This work is performed from the knees. • When the cylinders are removed from the bottom and sides and placed on the trolley, the trolley is pulled out to the shaft and emptied. • The trolley is now loaded with pallets, so the pallets hight, is about 30cm from top pipe (ID) • The trolly is now pushed in under the intermediate station cylinders, and the top cylinders is dismantled, and falls 30 cm down on the pallet, this work can be performed by personnel sitting on a chair. • When all the cylinders a removed, the intermediate station is pushed together, with the main jacking cylinders in the shaft. There are also options to design a system yourself, where the cylinders are mounted on rolled plates, allowing 3-4 sections to be removed. With this solution, all cylinders are removed in 3 to 4 work steps, and there will be no grinding on the steel skirt that the intermediate station consists of
6		**Repair in the tunnel (Installation of a rubbering in the pipes, closing bentonite holes ex.** The Tunnel Boring Machine (TBM) has successfully arrived at and been removed from the end shaft, and the slurry booster pumps and other equipment have likewise been extracted from the tunnel. As a result, unobstructed airflow is now established within the tunnel, with all obstacles cleared and two accessible exits available. To facilitate the movement of trolleys during subsequent operations, hydraulic winches have been installed at both the start and end shafts. These winches allow for controlled and safe towing of the trolley in both directions, thereby enhancing operational efficiency and safety within the tunnel environment. The work positions will be the same in all work scenarios. • Personnel drive to the work zone, using the electric transports. • The trolley is pulled in loaded with tools and materials, for the work assignment • Personnel will work eighter on their knees or sitting on the trolly.

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	Machine operations	Tunnel operations
7		**Dismantling equipment in the tunnel. Pipes, cables, closing bentonite holes ex.** The Tunnel Boring Machine (TBM) has successfully arrived and been removed from the end shaft, and the soil cart been extracted from the tunnel. As a result, unobstructed airflow is now established within the tunnel, with all obstacles cleared and two accessible exits available. To facilitate the movement of trolleys during subsequent operations, hydraulic winches have been installed at both the start and end shafts. These winches allow for controlled and safe towing of the trolley in both directions, thereby enhancing operational efficiency and safety within the tunnel environment. • Personnel drive to the work zone, using the electric transports. • The trolly is placed next to ex. hose that need to be dismantled, a person is standing on each side of the trolly • The personnel now lift the hose down from the rack and on the trolly. • When the trolly is loaded, personnel use the telephone installed at the intermedia station, to call personnel placed in the shaft. The load is pull out to the shaft. • When the personnel need to dismantle heavy equipment like electric cables, the cables is taken down 3-5meters at a time and put on the trolly. At this way, the workers is lifting a minimum. When the equipment is getting to heavy to lift by hand, the personnel will use eighter a chain hoist mounted I the top af the tunnelpipe or a customized, electric crane mounted on the undercarriage af the trolly.
8		**Dämmer/ grouting** Upon completion of the tunneling process, the majority of the equipment within the tunnel is removed. One critical step in the finalization phase involves stabilizing the overcut surrounding the tunnel pipe. This stabilization is achieved by injecting grout material, specifically dämmer, into the overcut through bentonite injection nozzles. Bentonite pipes are installed throughout the tunnel at regular intervals, typically with every third pipe designated as a bentonite pipe. Each bentonite pipe is equipped with approximately three bentonite nozzles positioned along the circumference of the pipe to ensure even distribution of grout. The standard locations of these nozzles within the pipe are at approximately the 2 o'clock, 5 o'clock, and 7 o'clock positions. This systematic injection of dämmer through the bentonite nozzles plays a vital role in reinforcing the soil around the tunnel lining, thereby enhancing the structural stability and long-term integrity of the tunnel. The work processes for this work assignment can be performed by this following steps. • The automatic bentonite system is dismantled, leaving only bentonite nozzles. • Personnel in the tunnel connect a 1 inch rubber hose to the bentonite nozzle. This hose relates to the main bentonite line, which was previously used. • The tunnel staff contact the staff who mix and control the pumping of Dämmer. Pumping is initiated. • The staff in the tunnel make sure the overcut is filled with Dämmer when the external pressure in the overcutter is sufficient. This is done visually via a pressure gauge, which is mounted on the 1inch hose • When the overcut is filled, the 1inch hose is removed and mounted on the next bentonite nozzle and work processes are started again. • When the entire tunnel section overcut is sufficiently filled, the remaining pipes are dismantled. *See Dismantling equipment in the tunnel. Pipes, cables, closing bentonite holes ex.*

Industry guideline



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