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Mechanized cross passage construction in tunnelling projects

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ABSTRACT: As demand increases for safer road and rail tunnels, more cross passages are needed to connect parallel tunnel tubes or link tunnels to vertical shafts. These cross passages serve important safety functions, such as emergency escape routes and access for rescue teams. Traditionally, cross passages have been constructed using manual or semi-mechanized techniques, but in difficult ground conditions or under high groundwater pressure, these methods can be risky, slow, and expensive. Mechanized construction methods, especially pipe jacking with tunnel boring machines (TBMs), offer a more efficient and safer alternative. A key advantage of mechanized cross passage construction is that excavation and lining are done in one continuous process. The most commonly used machines are slurry-type microtunnel boring machines (MTBMs), such as AVN systems, which use a slurry circuit for the removal of the excavated soil. These machines are well-suited for water-bearing ground and can crush obstacles like rocks and boulders during excavation. Compact launch and reception designs allow TBMs to be used even in tight tunnel environments.

1 MECHANIZED CROSS PASSAGE CONSTRUCTION

With rising demand and higher safety standards, more cross passages will be required in road and rail tunnels in the future. Several approaches for rescue purpose are available. For a twin tunnel arrangement, a typical application in discussion is the provision of cross passages to link parallel tunnels, whether in new construction or in existing tunnels already in operation. Apart from the connection between two tunnels, the connection of a shaft and a tunnel is another concept for emergency exit, often used for train and metro double line tunnels or traffic tunnels. Cross passages can also play a role where sewage collectors have to be connected to extend existing schemes or to connect new interceptors to the existing system.

The general approach to connect two underground structures by a cross passage is not new. The technical approach is very similar to standard pipe jacking, where two shafts serve as launch and reception structures for the tunnelling equipment. Figure 1 gives an overview about different cross passage scenarios in tunnelling projects using the pipe jacking approach.

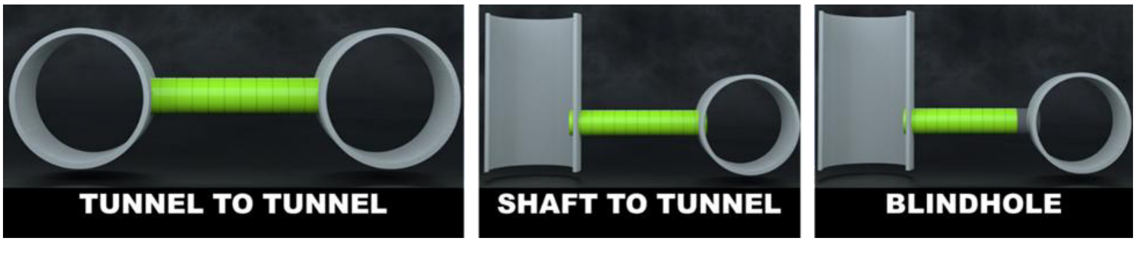


Figure 1. Different cross passage concepts

The major benefit of a completely mechanized approach for cross passage construction is the integrated concept for excavation and final lining at the same time. In the past, mechanized methods have sometimes been used for the excavation of cross passages, however the lining has been done with conventional methods.

2 TUNNELLING MACHINE CONCEPTS

In general, pipe jacking in combination with a Slurry Tunnel Boring Machine (TBM) is the most versatile solution for mechanized cross passage construction, as it is suitable for a large variety of ground conditions and can best handle high groundwater pressures. The so-called AVN machines are closed, full-face microtunnel boring machines (MTBMs) with a hydraulic slurry circuit for face support and soil disposal, which requires a separation plant on the surface. A cone-shaped crusher inside the excavation chamber can crush cobbles, boulders and other obstructions to a conveyable grain size while tunnelling and advancing. For working under water pressure, a launch seal and a pipe brake are important and need to be considered according to the available working space in the launch tunnel. A very compact equipment design for the launch and reception setup in tunnels is required. For main tunnels, which are simultaneously under construction, a minimum inner diameter of 10 m is needed to integrate the pipe jacking setup and logistics for cross passage construction additionally, as it can be seen in Figure 2.

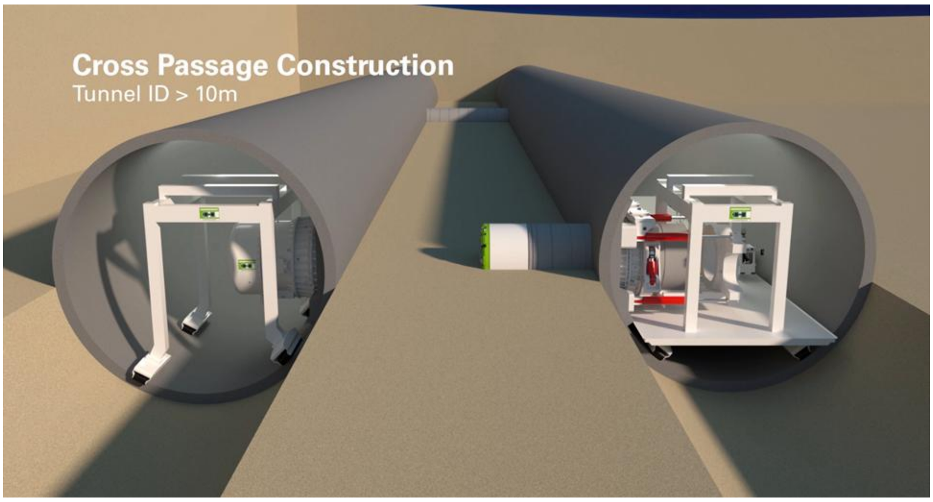


Figure 2. Exemplary equipment setup for AVN3000 MTBM cross passage construction

Nevertheless, other TBM concepts can be considered, according to the investigated ground conditions, project-specific requirements and economic considerations, as shown in Figure 3. As an example, the partial-face machine type allows the implementation of circular and non-circular cross sections. For the excavation of specific rectangular cross passages for pedestrian crossings, an adaptation of an open-face machine was designed, the so-called MH Box.

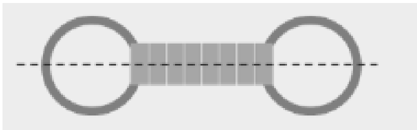
	Excavation (Excavation tools)	**Face Support**	**Soil conveyance**	
Slurry Shields AVN | AVND | Mixshields	**Full-face** (Cutting wheel design according to soil conditions)	**Cutting wheel / Slurry support** (optional air pressure)	**Slurry circuit**	
Earth Pressure Balance Shields (EPB)	**Full-face** (Cutting wheel design according to soil conditions)	**Cutting wheel / Earth pressure**	**Screw conveyor** Muck skip / tunnel belt conveyor	
Partial-face machines (MH/MHSM)	**Partial-face** (Excavator/Roadheader)	**Mechanical**	**Belt conveyor** Muck skip / tunnel belt conveyor	
Shielded Rock TBMs	**Full-face** (Hard rock cutting wheel)	**Cutting wheel / Mechanical**	**Belt conveyor** Muck skip / tunnel belt conveyor	

Figure 3. Overview of TBM types with their characteristics

3 CROSS PASSAGE DESIGN CRITERIA FOR TBM SELECTION

In order to select the most efficient TBM (Tunnel Boring Machine) concept for a mechanized approach, several key criteria must be analyzed, see overview in Table 1. A circular tunnel geometry is typically preferred for its ease of sealing and space optimization, particularly in water-bearing ground. The cross-passage equipment must be carefully positioned to avoid reducing the working space in the main tunnel. The construction process should minimize disruption to main tunnel operations, with blind or dead-end solutions with retractable TBM as the extreme case to ensure continuity. Geological and hydrogeological conditions dictate the technology and TBM concept respectively. Structural adaptations, such as reinforcement modifications and seals, are necessary to accommodate cross passage construction. Space constraints require cross passages to be as large as necessary but as small as possible, typically 2.5-4 meters in diameter. Early clarification of project-specific conditions is critical to defining the technical approach and planning for a mechanized solution.

Table 1. Cross passage design criteria for TBM selection

Geometry	• Shape (circular – rectangular) • Dimensions, cross section • Length • Position to tunnel axis	
Construction Process	Cross passage construction • During tunnel excavation • During tunnel operation • As blind hole (machine retraction)	
Geology Hydrology	• Ground stability • Ground water level	

4 REFERENCE PROJECT: TUEN MUN – CHEK LAP KOK LINK, HONG KONG

The major Tuen Mun – Chek Lap Kok Link project in Hong Kong links the airport with the Tuen Mun city district via a gigantic twin-tube road tunnel under the sea. The high safety requirements for vehicle traffic demand cross passages at regular intervals as escape and rescue tunnels between the tunnel tubes. Figure 4 shows the layout of the overall project. Building such cross passages under water pressure is very complex and expensive to realize, for example, using freezing technologies. This is why tried-and-tested AVN technology (AVN3000, OD 3605mm) was further developed for mechanized cross passage construction during the ongoing works on the main tunnels. The world´s largest TBM, a Herrenknecht Mixshield (Ø 17.6m) and two Mixshields (Ø 13.95m) have constructed the gigantic twin-tube road tunnel. With a length of around 5 kilometers each, the Tuen Mun – Chek Lap Kok Link connects the international airport and the Hong Kong-Zhuhai-Macau with the mainland to the north, crossing under a branch of the Pearl River Delta at depths of up to 50 meters. From the northern launch shaft the world record Mixshield giant first drove a 650meter long section with the larger diameter. The TBM was then scaled down to a diameter of 14 meters for the rest of the tunnelling distance towards the airport.

Figure 4. Twin-tube road tunnels and cross passage location along the tunnel route

Due to the necessity to construct 46 cross passages under extremely difficult conditions with a very tight schedule, Herrenknecht and Dragages-Bouygues Joint Venture, jointly developed a concept for the two AVN3000 specially designed cross passage TBMs. In addition, special launch and reception structures were designed. These allow for pipe jacking directly from one of the large tunnel tubes while all logistic processes for the large diameter TBMs can continue simultaneously. For the completion of the cross passages of up to 13 meters length each, two complete sets of equipment have been used to meet the tight time schedule. As logistics in both large diameter tunnels had to be considered to assure excavation of the tunnels could continue simultaneously with cross passage construction the available space for the cross-passage equipment is very restricted. Therefore, a very compact design of machine and launch structure was required. The setup of the MTBM breakthrough and recovery on target side is shown in Figure 5.

Figure 5. AVN 3000 recovery in the tunnel, after breakthrough into reception bell

On the launch side, a jacking trailer with a mobile gantry crane was used to allow quick repositioning of the equipment for the construction of the next cross passage. Due to the surrounding groundwater pressure of 5.5 bar a safe launch and breakthrough procedure was designed. While a special launch seal with emergency seal is installed on the launch side, safe breakthrough into the “target tunnel” was assured by using a reception capsule construction, which can be seen in Figure 6.

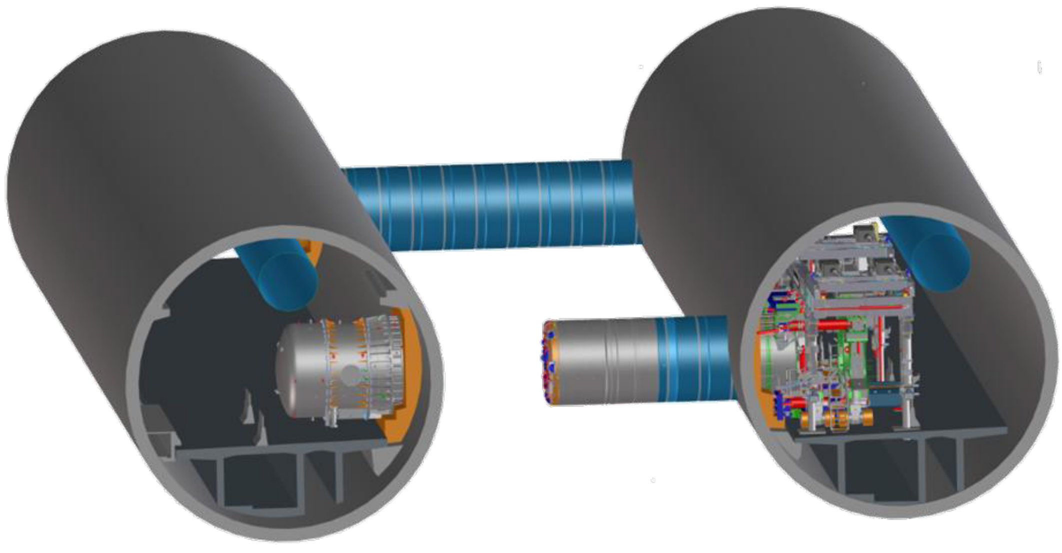


Figure 6. Cross passage installation between the two main tunnels under construction

The average performance for the construction of one cross passages on TMCLK project was 20 days, encompassing the entire advance cycle, including assembly, advancement, disassembly, and transport of the equipment within the tunnel. On a further similar cross passage project, this performance has even been significantly improved.

5 CONCLUSION

The current and worldwide trend in inner-city environment is to construct more and more infrastructure underground, which causes a growing demand for the construction of ever deeper tunnels. In challenging ground with high groundwater levels and increasing depths, conventional methods for cross passage construction reach their technical and economical limits.

The mechanized approach for cross passages is a proven technology, successfully implemented in several projects, including challenging conditions like Hong Kong's tight tunnel spaces and high groundwater pressures of up to 5.5 bar. While conventional methods like ground freezing are more complex and costly in such settings, mechanized techniques offer significant advantages in terms of safety, efficiency, and adaptability to various geological conditions. With existing expertise and practical experience, the mechanized approach ensures reduced risks, faster execution, and better cost control for future projects.