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EPB TBM design for deep-overburden and long-distance tunnelling construction

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Abstract: This paper takes the earth pressure balance tunnel boring machine (EPB TBM) used in the Palermo-Catania (PA-CT) high-speed rail tunnel project in Sicily, Italy, as an example to analyze the numerous challenges encountered during deep-overburden and long-distance tunnelling. It conducts an in-depth analysis of key aspects such as cutter head overcutting, main drive lifting, shield structure and high thrust designs, as well as synchronous invert casting. Various innovative designs are proposed to address issues such as high ground pressure, TBM jamming due to ground convergence, wear during long-distance tunnelling, and construction efficiency. It is aimed to enhance the reliability and efficiency of EPB TBMs in deep-overburden and long-distance tunnelling, offering valuable insights for the design selection and construction of future projects.

Keywords: EPB TBM; deep-overburden and long-distance tunnel; overcutting; main drive lifting; synchronous invert casting

1. Introduction

With the growing demand for intercity transportation, regional economic development and resource exploitation in mountainous areas, the tunnel construction has gradually expanded from urban metros to intercity high-speed railways and mountain tunnels, bringing an increasing number of deep-overburden and long-distance tunnelling projects. As a commonly used underground tunnelling equipment, the EPB TBM (earth pressure balance tunnel boring machine) plays a crucial role in such projects. However, deep-overburden and long-distance tunnelling presents numerous challenges, such as high ground pressure, TBM (tunnel boring machine) jamming due to ground convergence and cutter head wear. Therefore, this raises the design requirements for the EPB TBM.

Taking the tunnel projects in Italy as an example, many tunnels have overburdens of over 100m, with some exceeding 400m, and lengths of more than 6km. These conditions require consideration of underground pressure, geological conditions, safety and excavation efficiency to ensure that the TBMs can construct safely and efficiently in deep-overburden tunnel projects (Amadini et al., 2021). This paper takes the Palermo-Catania high-speed rail tunnel project in Sicily, Italy (hereinafter referred to as "PA-CT project") as a case study and provides a detailed discussion on the design of the EPB TBM for deep-overburden and long-distance tunnelling from aspects including cutter head design, main drive lifting technology, shield structure design, thrust system design and synchronous invert casting system.

The PA-CT (Palermo-Catania) project is a twin-tube double-track high-speed rail tunnel located at the northwestern end of Sicily, Italy. In the future, it will connect three major cities, namely, Messina, Catania and Palermo. In this project, the longest section is approximately 15km, the overburden ranges from 10m to 400m, the minimum turning radius is 500m and the segment is 9000 in O.D. (outer

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diameter) and 8000 in I.D. (inner diameter), 1800mm in width and adopts the 7+0 arrangement. The tunnel geology consists of clayey silt, sand layers, sandstone, argillaceous siltstone and quartzitic sandstone. The uniaxial compressive strength reaches up to 80MPa, while the geological strength index (GSI) of the rock is below 60. The maximum static ground and water pressure reaches 15bar, and during construction, the TBM faces risks such as convergence in soft rock strata (Zhu et al., 2016).

2. Targeted Designs

2.1. Special Design of the Cutter Head

2.1.1. Cutter head overcutting

For the deep-overburden and long-distance tunnel excavation, the cutter head overcutting function design is critical to accommodate various geological conditions. The combined method of heightening gauge disc cutters and reserved overcutting cutter housings is adopted to realize the flexible cutter head overcutting function. During normal excavation, the cutter head advances at its originally designed excavation diameter. When the overcutting is required, the installation height of the gauge disc cutters can be adjusted to move them outward. At the same time, additional cutters can be installed in the three reserved empty cutter housings, increasing the excavation diameter. The maximum radial overcutting range can reach up to 150mm. Furthermore, two additional hard rock copy cutters are included in the design to meet short-distance overcutting requirements in specific strata. As shown in Figure 1, the blue areas indicate the positions of the three reserved cutter housings and the pink areas represent the two hard rock copy cutters. For long-distance tunnelling, the overcutting is achieved by heightening the disc cutters and installing additional cutters in the reserved housings. This design not only enhances the adaptability of the cutter head but also ensures efficient excavation performance under varying geological conditions.

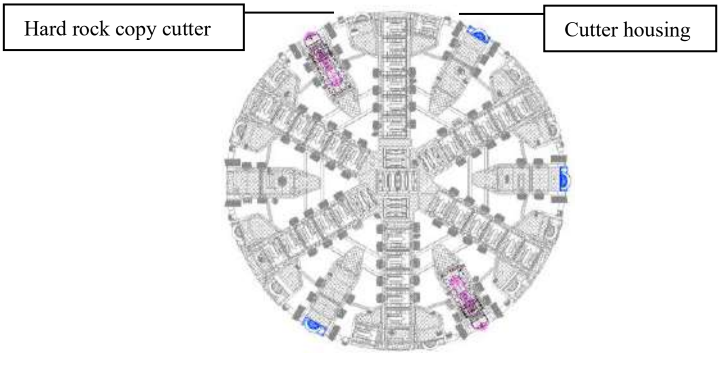


Fig. 1. Cutters for overcutting.

2.1.2. Cutter configuration and wear resistance

Based on the geological conditions, appropriate cutter types and arrangements are selected. This project involves hard rock and composite strata with upper-soft and lower-hard layers. Therefore, wear-resistant disc cutters are used and the cutter arrangement and spacing are optimized to improve rock-breaking efficiency and cutter lifespan. The dual-layer cutting structure is formed by adopting disc cutters with the cutter space of 90mm and cutter height of 185mm, and replaceable rippers with the same track and 25mm height lower than the disc cutter height. When the disc cutters are worn to a certain extent, the rippers can continue to bore, thus extending the overall cutter change interval, reducing the frequency of cutter changes, and improving construction efficiency and cost-effectiveness. In soft soil strata, the disc cutters at the front can be replaced with rippers and the number of replaceable ripper bits at the front can be adjusted according to the geological conditions of the project.

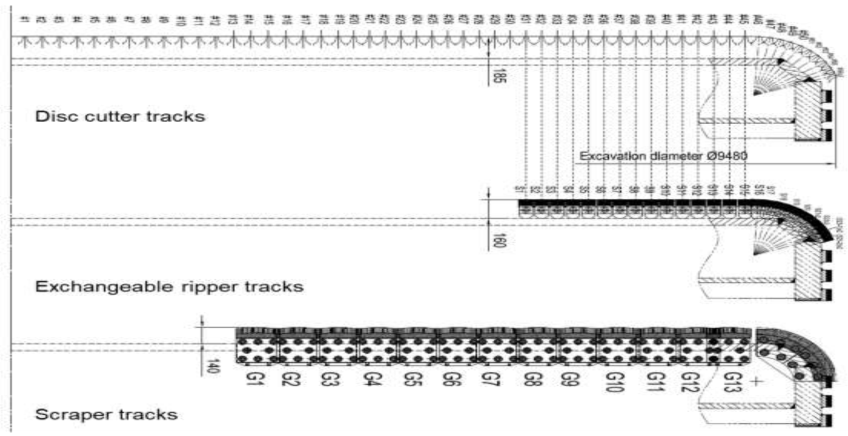


Fig. 2. Cutter track.

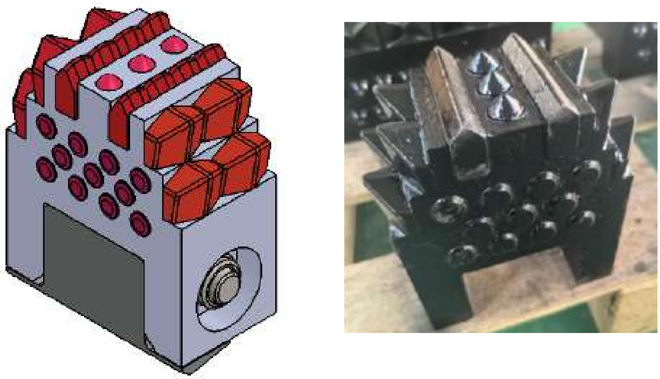


Fig. 3. Replaceable ripper bit.

2.2. Main Drive Lifting Design

To prevent TBM jamming caused by ground convergence at the tunnel crown during excavation, it is common to adopt the main drive lifting technology to achieve overcutting at the top of the cutter head. This also helps to avoid overcutting at the bottom of the cutter head, which can lead to the TBM "nosing down". While this main drive lifting technology is relatively mature in hard rock TBMs, its application in deep-overburden EPB TBMs remains undeveloped.

Unlike hard rock TBMs, the EPB TBMs advances with the excavation chamber under pressure, making the sealing between the lifting structure and the shield structure critically important. Inadequate sealing may allow the muck and slurry to flow from the excavation chamber into the inside of the shield structure, potentially leading to equipment failure and increased construction risks. Therefore, based on complying with the main drive lifting's basic functions, this project has also incorporated special sealing designs for the main drive lifting structure. Additionally, pre-reinforcement of the tunnel face is mandatory before lifting operations to create a relatively safe working environment and prevent large volumes of groundwater from entering the TBM through gaps during lifting, thereby mitigating unforeseen consequences.

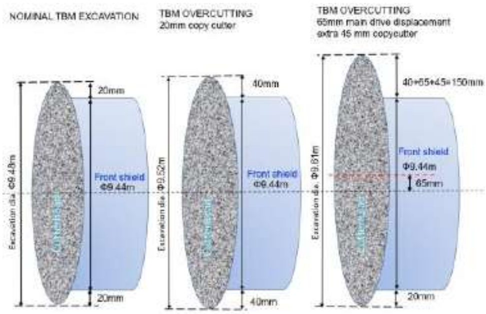


Fig. 4. Main drive lifting during overcutting.

2.3. Special Design of the Shield Structure

2.3.1. Step design of the shield structure

In deep-overburden strata, increasing the step between various parts of the shield structure (front shield, middle shield and tail shield) can help to alleviate TBM jamming caused by ground convergence. In the design of these steps, those factors such as strata characteristics, TBM dimensions and tunnelling parameters must be comprehensively considered to ensure their rationality and effectiveness. For conventional TBMs of similar diameter, the shield structure step is normally designed to be 30–35mm. After enlargement, the shield structure step can reach up to 100mm. In deep-buried strata, prolonged stoppage is not recommended, and the thrust speed should be maintained at no less than 10mm/min. For the specific construction process, the convergence rate of the strata and the minimum TBM thrust speed need to be determined based on calculations by geotechnical engineers to prevent the shield structure from jamming. In summary, a well-designed stepped configuration can significantly reduce friction between the shield structure and the strata, thus lowering the risk of TBM jamming and ensuring smooth advancement of the TBM. Additionally, the step design must be determined after considering factors such as support from the strata at the bottom of the TBM, prevention measures of backflow during tail shield grouting and TBM attitude control.

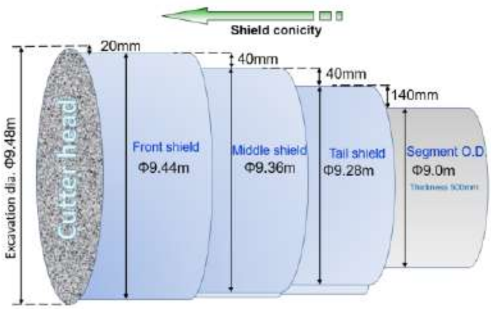


Fig. 5. Step arrangement of the shield structure.

2.3.2. Anti-roll design of the shield structure

When the shield structure has a large step and the cutter head needs to overcut, the contact area between the shield structure and the strata is reduced, which lowers the confining force exerted by the strata on the shield structure. This increases the risk of shield structure rolling. In addition to the conventional method of cutter head CW (clockwise) and CCW (anticlockwise) rotation, the fin stabilizer is also equipped to correct the rolling. This stabilizer consists of a driving component and a stabilizing component located inside the shield structure. One end of the stabilizing component is hinged to the shield structure, and the other end is hinged to the driving component. The driving component uses a direct-drive mechanism to rotate and extend the stabilizer outward from the shield structure. The stabilizing component that contacts the strata is capable of penetrating into the earth, anchoring itself to stabilize the shield structure and thereby preventing rolling.

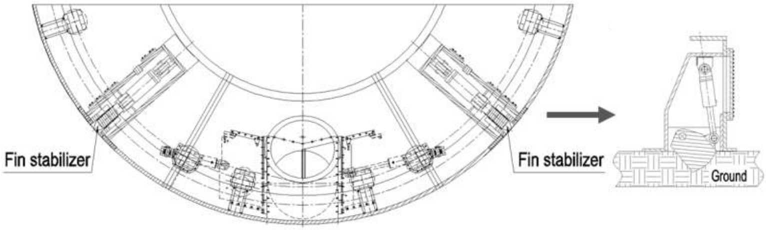
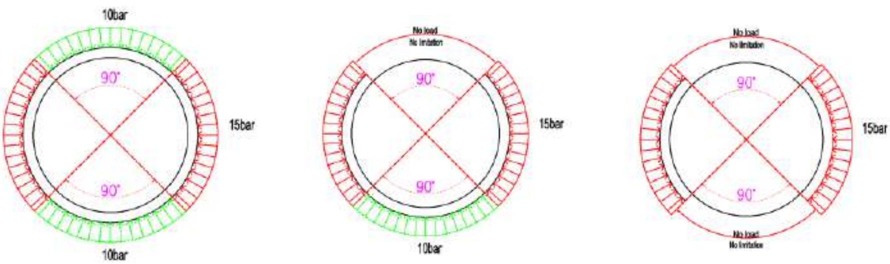


Fig. 6. Fin stabilizer.

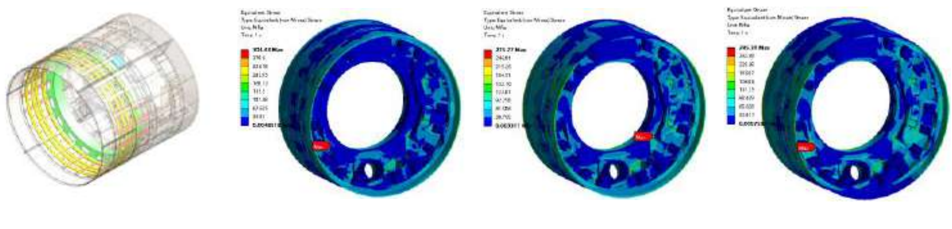
2.3.3. Shield structure strength design

For deep-overburden tunnels, the shield structure must withstand significant strata pressure, water pressure and various loads during excavation. Therefore, it must have sufficient strength and rigidity to ensure operational stability and safety. Given that the front shield has abundant stiffeners and support structures inside it, while the tail shield is typically a circular structure without internal supports to accommodate segment erection, high-strength steel and rational structural configurations, such as sandwich structures or additional reinforcement plates, can be adopted to enhance its load-bearing capacity (DAUB, 2005). Considering that the maximum strata pressure encountered in this project may reach 15bar, a stress analysis of the tail shield under different scenarios is carried out based on the geotechnical parameters of the project. It is concluded that reinforcement steel bars are to be added inside the tail shield to meet the potential maximum earth and water pressure as well as any abnormal squeezing conditions.



Case 1 Case 2 Case 3

Fig. 7. Stress conditions of the shield structure in the strata.



(**a**) (**b**) Case 1 (**c**) Case 2 (**d**) Case 3

Fig. 8. Stress analysis of tail shield with reinforcement plates. (a) Reinforcement schematic of the tail shield; (b) Tail shield stress analysis; (c) Tail shield stress analysis; (d) Tail shield stress analysis.

According to the stress analysis in the Fig. 8, it can be seen that the stress cloud map for case 1 shows a maximum calculated stress of 304MPa; for case 2, the maximum stress is 277MPa; and for case 3, it is 295MPa. In all cases, the maximum stress occurs at the junction between the reinforcement plates and the rear bulkhead. The plate thickness is 70mm, with a corresponding minimum yield strength of 325MPa. Therefore, the structural strength meets the requirements.

2.3.4. High-pressure breakout design of the shield structure

To prevent unexpected TBM jamming, the EPB TBM for this project is equipped with a sufficiently powerful thrust system, which can provide a thrust of 118,692kN. In addition, the machine features a high-pressure breakout capability of 550bar, which can generate a maximum thrust of 163,201kN to assist in breakout. Five rows with a total of 39 DN80 high-pressure water ports are reserved around the shield structure. The rock around the shield structure is continuously flushed by 1,000bar high-pressure water to being broken or loosened, creating an appropriate space for solving TBM jamming. This technique was first successfully applied by Seli Overseas on the Cociv Ramimero Project in Italy and has demonstrated good results.

Table 1. Configuration of the thrust system.

Item	Parameter	Unit
Cylinder specification	Φ300/240	mm
Cylinder quantity	42	pcs
Rated working pressure	400	bar
Rated thrust	118692	kN
Working pressure for breakout	550	bar
Thrust for breakout	163201	kN

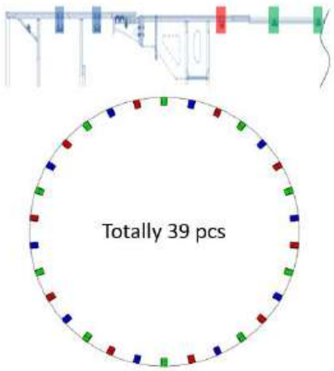


Fig. 9. Distribution of high-pressure water ports on the shield structure.

2.4. Back-up Synchronous Invert Casting System

In the traditional construction method of invert bridge casting, it is necessary to separately set up a track area, a concrete transport passage and a working platform. For tunnels with the inner diameter of being equal or greater than 8m, the height of the bridge structure usually occupies more than one-third of the tunnel's clear space, resulting in interference between material transportation and TBM advance. Moreover, invert casting can only proceed in sections after the tunnel face has been bored forwards a certain distance, leading to a non-continuous "excavation–waiting–casting" workflow. Statistics show that in traditional methods, invert construction typically is behind the tunnel face by 200–300m and requires dedicated mobile steel structures, which adds significantly to overall costs.

For long-distance tunnels with an inner diameter greater than 8m, a synchronous invert casting system based on an integrated back-up design can replace the traditional invert bridge system by using the “structural sharing + process coupling” approach. Due to the configuration of such TBMs, the back-up gantry is usually nearly 100m long, enabling the integration of the invert casting equipment directly onto the TBM back-up platform, which can satisfy the constraints of casting time and construction efficiency.

This system uses intelligent control to achieve precise coordination between excavation and casting, enabling accurate adjustment of concrete placing speed and levelling quality. It synchronously completes invert casting, levelling and curing operations, allowing excavation and casting to proceed at the same time. This reduces worksite interference, ensures timely formation of the invert structure, shortens construction periods, lowers costs and aligns with green construction principles. There are designated zones for casting cleaning, concrete placing, concrete levelling, concrete demoulding and mould transfer, concrete curing and concrete transfer on the back-up system. By optimizing the workflow, the system minimizes construction interruptions and significantly enhances the overall efficiency of both tunnel excavation and invert casting.

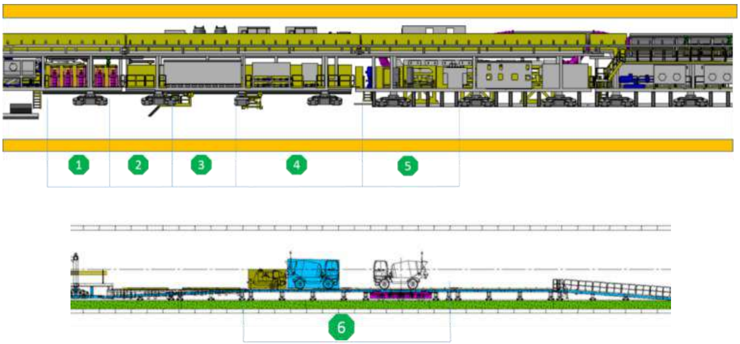


Fig. 10. Schematic diagram of simultaneous invert casting. 1-Cleaning area for concrete placing area; 2-Concrete placing area; 3-Concrete leveling area; 4-Demoulding and mould transfer area; 5-Concrete curing area; 6-Concrete transfer area.

Taking a Φ9.48m EPB TBM as an example, and assuming an average thrust speed of 60mm/min, the construction data for the system can be calculated as the following table.

Table 2. Construction data.

Item	Parameter	Item	Parameter
TBM thrust speed	60mm/min	Invert casting area	24m
Segment length	1800mm	Actual concrete placing section	6m
Segment erection	30min/ring	Embedded pipeline	6m
TBM advance speed per hour	1.8m/h		

It is evident that this synchronous invert casting system can theoretically match the TBM maximum daily advance speed of 36m, which is essentially its optimal performance, indicating that the casting efficiency can fully keep pace with advance speed and it is an efficient and cost-effective construction solution.

3. Conclusion

This paper takes the EPB TBM used in the PA-CT high-speed rail tunnel project in Sicily, Italy, as the research object. It focuses on addressing key challenges encountered during deep-overburden and long-distance tunnelling, such as high ground pressure, TBM jamming, cutter head wear and low construction efficiency, and carries out innovative design and in-depth research in terms of cutter head, main drive, shield structure, back-up system and other aspects, forming a tailored EPB TBM solution suitable for complex deep-overburden and long-distance strata. The cutter head adopts designs such as heightening gauge disc cutters and reserved cutter housings, enabling flexible overcutting. The dual-layer cutter configuration extends the lifespan. The main drive lifting technology, together with sealing and advanced ground reinforcement, fills a technological gap in deep-overburden EPB TBM construction. The shield structure is optimized through stepped configuration, anti-roll design, enhanced structural strength, and high-pressure breakout capabilities to improve adaptability and safety. The back-up synchronous invert casting system enables the excavation and concrete placing can be implemented at the same time, significantly improving construction efficiency and reducing costs. The relevant design concepts and methods provide valuable references for TBM selection and construction in similar projects and offer important engineering application value and theoretical guidance for the advancement of deep-overburden and long-distance tunnel engineering. Future work may further integrate intelligent and information technologies to optimize system monitoring, fault diagnosis, and prediction of the TBM, thereby achieving safer and more efficient tunnel construction.

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References

Amadini, F., et al., 2021. Case studies related to jammed TBM in rock. Gallerie e grandi opera sotterranee, Italy, pp. 15–25.

German Committee for Underground Construction (DAUB) – Shield Statics Working Group. 2005. Statische Berechnungen von Schildvortriebsmaschinen. *Tunnel* 7: 49.

Liu Haibo, 2021. Selection of Shield Machine for Great Depth and Long Distance Water-Carrying Tunnel Project [J]. *Haihe Water Resources*, 2021. (03):108-110+116.

Li Guang, Research and Application of Key Technologies for Small-Diameter Shield Machines in Long-Distance, Deeply Buried Tunnels. Henan Province, China Railway Engineering Equipment Group Co., Ltd., 2019-08-28.

Wang Zhenfei, 2023. Synchronous Construction Technology of Large-diameter Shield Tunnel for Single-track Railway [J]. China Railway, 2023. (03):58-62.

Zhu, Y., Xia, H., Hu, Z., 2016. An uplifting practice of shield tunnel in soft ground. *Rock and Soil Mechanics*, 37(S2), 543–551.