



Original Article

Selection of a Tunnel Boring Machine (TBM): A Case Study of Hanoi Metro Line 2 (Nam Thang Long–Tran Hung Dao)

Bui Huy Quang*, Nguyen Dinh Duc

VNU University of Engineering and Technology, 144 Xuan Thuy, Cau Giay, Hanoi, Vietnam

Received 17th June 2026

Revised 4th July 2026; Accepted 8th October 2026

Abstract: This paper presents the theoretical basis and computational analysis for selecting a Tunnel Boring Machine (TBM) suitable for the underground section of Hanoi Urban Railway Line 2 (Nam Thang Long–Tran Hung Dao). Based on the geological and hydrogeological assessment together with particle size distribution (PSD) analysis of Metro Line 2, the study identifies the Earth Pressure Balance Shield TBM (EPB) as the most suitable tunnelling solution for the prevailing geological conditions, comprising water-saturated soft soils, mixed-face ground conditions, and a high groundwater table. Subsequently, operational data obtained from the geologically comparable Hanoi Metro Line 3 (Nhon–Hanoi Station) were used to constrain the feasible range of the empirical torque coefficient (α) within the range recommended by JSCE (10–25) for preliminary cutterhead torque estimation. The selected design parameters include a shield diameter of approximately 6.73 m, a shield length of approximately 9.8 m, determined in accordance with JSCE recommendations and practical engineering experience, together with a design cutterhead torque of approximately 5,500 kN·m. Accordingly, the torque coefficient ($\alpha = 18$) was selected from operational monitoring data obtained from the S9–S10 section of Hanoi Metro Line 3 under geological conditions comparable to those of Metro Line 2, providing a basis for preliminary TBM design. The proposed procedure provides a practical and quantitative framework for preliminary EPB TBM selection and cutterhead torque estimation for metro projects developed under geological conditions comparable to those of Hanoi Metro Line 2.

Keywords: Urban underground structure; Tunnel Boring Machine (TBM); Earth Pressure Balance Shield (EPB); Metro Line; Cutterhead Torque; Torque coefficient α ; Hanoi.

1. Introduction

In the context of rapid urbanization in major cities, the development of urban rail transit (metro) systems is widely recognized as a strategic solution to alleviate traffic congestion and enhance public

* Corresponding author.

E-mail address: huyquangutc@gmail.com

<https://doi.org/10.25073/2588-1124/vnumap.5164>

transportation capacity. In Hanoi, Metro Line 2 (Nam Thang Long – Tran Hung Dao) is one of the key urban railway projects, connecting the northern area of the city with the central urban district. The line has a total length of approximately 11.5 km, most of which will be constructed underground beneath densely populated urban districts [1, 2].

The geological conditions in central Hanoi are characterized by Red River Delta alluvial deposits, consisting predominantly of water-saturated soft soils, a high groundwater table, and the potential occurrence of mixed-face ground conditions. In such a densely built urban environment, tunnel excavation using Tunnel Boring Machines (TBMs) is considered a superior solution due to its ability to maintain excavation face stability, minimize ground settlement, and reduce impacts on adjacent structures and underground utilities [3-5].

The selection of an appropriate TBM type plays a critical role in ensuring construction safety, project schedule compliance, and overall economic efficiency. This paper presents the theoretical basis for TBM selection, analyzes the geological conditions along Metro Line 2 through geological comparison and particle size distribution (PSD) analysis, and proposes a suitable TBM type for the project. Furthermore, key technical design parameters are estimated based on practical operational data obtained from the Hanoi Metro Line 3 (Nhon–Hanoi Station) tunnelling project under comparable geological conditions [6]. The principal contribution of this study is the development of a practical procedure for preliminary EPB TBM design in Metro Line 2. The procedure first identifies the appropriate TBM type based on project-specific geological conditions and PSD analysis, and subsequently constrains the feasible range of the empirical torque coefficient (α) through comparison with operational data from the geologically comparable Metro Line 3, enabling preliminary cutterhead torque estimation. Rather than directly transferring operational parameters, the Metro Line 3 data are employed to reduce uncertainty in the selection of the empirical torque coefficient under comparable geological conditions.

2. Theoretical Basis for TBM Selection

2.1. Classification and Operating Principles of TBMs

A Tunnel Boring Machine (TBM) is an integrated mechanized system that simultaneously performs excavation, spoil removal, tunnel face support, and installation of precast concrete segmental linings. In urban tunnelling projects constructed in soft ground conditions, the two most commonly adopted closed-face TBM types are [5, 7]:

- Earth Pressure Balance (EPB) TBM: utilizes the excavated soil within the pressure chamber to balance the earth and groundwater pressures acting at the tunnel face. Excavated material is discharged through a screw conveyor.

- Slurry Shield TBM: employs pressurized bentonite slurry to transmit and maintain support pressure at the excavation face. This type is particularly suitable for coarse-grained soils with high permeability.

According to the shield tunnelling design guidelines issued by the Japan Society of Civil Engineers (JSCE, 2016) [7], the TBM selection process consists of four fundamental steps: (1) assessment of geological and hydrogeological conditions; (2) evaluation of tunnel alignment geometry; (3) consideration of environmental constraints and adjacent structures; and (4) selection of the most appropriate shield TBM type.

2.2. Principal Technical Parameters

According to JSCE [7], the principal technical parameters of a TBM include:

- i) Shield Diameter (**D**): The shield diameter is determined using: $D = D_0 + 2(x + t)$, where D_0 is the external diameter of the segmental lining, x is the tail skin clearance and t is the thickness of the tail

shield skin. For TBMs with diameters ranging from 6 to 7 m, the tail clearance is typically 30–50 mm, while the shield tail thickness is generally between 60 and 80 mm [5, 7];

ii) Shield Length (L): The total shield length consists of the cutterhead section length (L_c) and the shield body length (L_m). The tail section must provide sufficient space for the tail seal system, thrust jack stroke, and segment erection overlap. The ratio $\xi = L/D$ typically ranges from 1.1 to 1.6 for articulated TBMs with diameters of approximately 6–7 m [7];

iii) Cutterhead Torque (T): The required cutterhead torque can be estimated by: $T = \alpha \cdot D^3$ (kN·m), where D is the TBM diameter (m) and α is the torque coefficient reflecting geological conditions and operational performance. According to JSCE [7], α generally ranges from 10–25 for EPB TBMs and from 8–20 for Slurry Shield TBMs. Among the technical parameters, cutterhead torque is one of the most critical indicators governing TBM performance and machine selection. The torque coefficient (α) represents the combined influence of geological conditions, face stability requirements, and machine operating characteristics. For project-specific preliminary TBM design, an appropriate α value should first be selected within the range recommended by JSCE according to the project geological conditions and may subsequently be refined using operational data obtained from the geologically comparable Hanoi Metro Line 3 project. Consequently, reliable estimation of α is essential for determining the required cutterhead torque and evaluating TBM suitability for a given project.

Table 1. Applicability of Closed-Face Shield TBMs under Different Ground Conditions [7, 8]

Ground Condition	EPB Shield TBM	Slurry Shield TBM
Fine-grained soils (CL, CH, ML)	Suitable (with soil conditioning)	Suitable
Silty sand and sand mixtures (SM, SC)	Suitable (with soil conditioning)	Suitable
Coarse sand and gravel (GP, GM)	Suitable (with intensive soil conditioning)	Suitable
Mixed-face conditions	Suitable (high operational flexibility)	Moderately suitable
High groundwater table	Suitable	Suitable
Construction site space	Small	Very large
Previous experience in Hanoi	Successfully applied in Metro Line 3	Limited practical application

Table 1 summarizes the principal technical criteria recommended by JSCE for selecting closed-face shield TBMs under different ground conditions. These criteria constitute the theoretical basis for the project-specific TBM selection procedure adopted in this study. Their application to the geological conditions of Hanoi Metro Line 2 is presented in the following section.

3. Overview of Hanoi Metro Line 2

3.1. Project Overview

Hanoi Metro Line 2, Nam Thang Long–Tran Hung Dao section, has a total route length of approximately 11.5 km and comprises 10 stations, including 3 elevated stations and 7 underground stations (C4–C10). The project is being implemented by the Hanoi Metropolitan Railway Management Board (MRB) and is financed through a combination of Official Development Assistance (ODA) from the Japan International Cooperation Agency (JICA) and counterpart funding from the Vietnamese Government [3].

The tunnel alignment passes through densely developed urban areas characterized by numerous historical buildings, the Old Quarter district, and existing underground utility networks. The tunnel crown elevation varies from approximately -2.5 m to -20.48 m, while the tunnel invert elevation ranges from -9.0 m to -26.98 m. The overburden thickness above the tunnel generally ranges from approximately 13.8 m to 31.3 m. The designed excavation diameter is approximately 6.6–6.8 m, with a segmental lining thickness of 300 mm and a segment ring width of 1.4 m [3].

3.2. Geological and Hydrogeological Conditions

The Hanoi metropolitan area is located within the Quaternary sedimentary deposits of the Red River Delta. According to the geotechnical investigation report for the project [3], the ground profile along the tunnel alignment consists of the following principal strata:

- TB1 Layer (CL, CH, ML – Clay and Silt): N-SPT values ranging from 2 to 38, with a thickness of approximately 15–30 m.
- TB2 Layer (SM – Silty Sand and Fine Sand): water-saturated sandy deposits with N-SPT values ranging from 6 to 32, constituting the dominant ground formation within the tunnel excavation zone.
- HH Layer (Organic Soft Soil): N-SPT values ranging from 1 to 6, occurring locally in the vicinity of West Lake.
- VP1 Layer (SM-GM – Coarse Sand with Gravel): N-SPT values ranging from 9 to 50, generally encountered at greater depths.
- HN Layer (GP-GM – Gravel and Cobbles): N-SPT values exceeding 50, located below the planned TBM excavation level.

The SM layer (silty sand) accounts for approximately 57.11% of the tunnel alignment length, while the SM-GM layer represents approximately 20.94%. The remaining portion consists primarily of fine-grained soils classified as CL, CH, and ML, accounting for approximately 19.76% of the alignment. Groundwater levels along the route vary from approximately -7 m to -19 m relative to the existing ground surface and are significantly influenced by the urban river and lake system in Hanoi [3].

Table 2. Principal Geotechnical Parameters of Hanoi Metro Line 2 [3]

Geological Unit	Soil Type (USCS)	N-SPT (Average)	γ (kN/m ³)	ϕ (°)	E (MPa)
TB1	CL, CH, ML	10	19	5	28
HH	CL, ML	3	17.5	5	3
TB2	SM	7	18.5	28	19.6
VP1a	SM (Medium Sand)	16	19	33	44.8
VP1b	SM-GM (Coarse Sand)	28	20	37	78.4
VP2	CL, ML	21	19	10	58.8
HN	GP-GM (Gravel and Cobbles)	>50	20.5	40	140

Note: N-SPT = Standard Penetration Test blow count; γ = unit weight; ϕ = effective friction angle; E = deformation modulus.

The predominance of water-bearing silty sand (SM) and sandy gravelly soils (SM-GM), together with a relatively high groundwater table, indicates that face stability and groundwater control are critical considerations in tunnel construction. These geological characteristics strongly influence the selection of an appropriate TBM type and the estimation of key operational parameters, particularly cutterhead torque.

Although the geological classifications of the two metro projects are not identical, both alignments are characterized by saturated soft soils, silty sands, localized gravelly deposits, and high groundwater

conditions. These similarities indicate comparable tunnelling environments with respect to face stability, groundwater control, and excavation resistance. Therefore, the geological comparison provides a technical basis for using operational data from Hanoi Metro Line 3 to support the selection of the EPB TBM and the refinement of the empirical torque coefficient (α) for the preliminary design of Metro Line 2.

Table 3. Comparison of Geological Characteristics between Metro Line 2 and Metro Line 3 [3, 6]

Parameter	Metro Line 2	Metro Line 3	Engineering implication
Dominant fine-grained soils	CL, CH, ML	CL, CH-MH	Similar cohesive soils facilitate stable face support using EPB.
Dominant granular soils	SM, SM-GM	SC-SM-SP	Similar sand composition is suitable for EPB with soil conditioning.
Gravel/cobbles	GP-GM	GM-GP-GC	Localized coarse layers may increase cutterhead torque.
N-SPT	3–50	Loose–Very Dense	Comparable ground density.
Friction angle (°)	5–40	20–40	Similar shear strength of granular soils.
Groundwater	EL = –13.84 to +2.98 m	EL = –3.58 to +5.79 m	Both tunnel alignments are excavated below the groundwater table, requiring closed-face excavation and effective groundwater pressure control.
Mixed-face condition	Expected	Observed	Similar excavation challenges affecting TBM performance.
Dominant tunnelling environment	Urban soft ground	Urban soft ground	Comparable construction constraints.

4. Selection of the Recommended TBM Type

4.1. Necessity of Using a Closed-Face Shield TBM

Considering the presence of water-saturated soft ground, a high groundwater table, and densely developed urban surroundings, the use of a closed-face Shield TBM is essential to ensure excavation face stability, control ground deformation, and protect existing surface and underground structures. Under these conditions, two tunnelling technologies are generally considered: the Earth Pressure Balance (EPB) Shield TBM and the Slurry Shield TBM [5, 7].

4.2. Particle Size Distribution Analysis and Applicability of EPB Technology

The particle size distribution (PSD) analysis indicates that the ground conditions along Metro Line 2 are dominated by silty sand (SM) and gravelly silty sand (SM-GM), characterized by a wide grain-size distribution and a significant proportion of fine particles. According to the EPB applicability chart proposed by Thewes (2007) [8], both SM and SM-GM soils fall within the range where EPB technology can be effectively applied when appropriate soil conditioning measures are adopted.

The representative PSD curves shown in Figure 2 indicate that the dominant SM and SM-GM soils of Metro Line 2 fall within the applicability range of EPB technology presented in Figure 1 when appropriate soil conditioning measures are adopted. Practical tunnelling experience from the Hanoi Metro Line 3 (Nhon–Hanoi Railway Station) project [6] further supports the applicability of EPB technology. Similar geological units, including GU5a (SC-SM-SP) and GU5b (SC-SM-SW), were

successfully excavated using an EPB TBM combined with foam and polymer conditioning agents. This successful implementation provides valuable empirical evidence supporting the use of EPB technology for Metro Line 2.

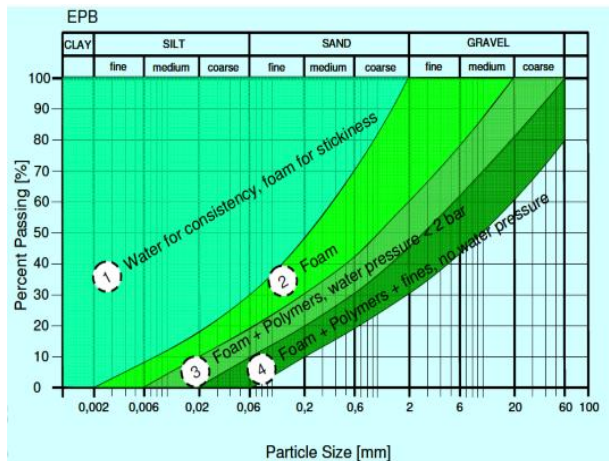


Figure 1. Applicability range of EPB technology with soil conditioning (adapted from Thewes, 2007) [8].

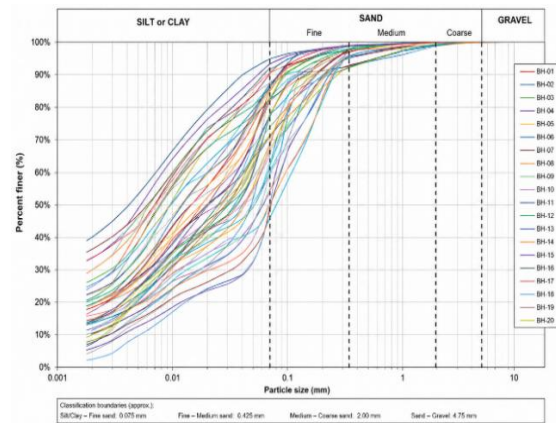


Figure 2. Particle size distribution curves of representative soil samples along Metro Line 2.

4.3. Soil Conditioning Requirements

For the SM and SM-GM soil layers that predominate along the tunnel alignment, foam and polymer additives play a crucial role in improving pressure retention capacity, reducing permeability, and enhancing the formation of a stable excavated soil paste within the pressure chamber.

For fine-grained soils classified as CL, CH, and ML, bentonite slurry or anti-clogging additives may be applied to mitigate clogging phenomena and improve workability. Where adjustment of the grain-size distribution is required, filler materials such as calcium carbonate (CaCO_3) can be incorporated into the conditioning process [8, 9].

4.4. Selection Matrix Evaluation and Recommended TBM Type

A decision matrix was established to compare the applicability of the EPB Shield TBM and the Slurry Shield TBM for Hanoi Metro Line 2 based on the geological conditions, hydrogeological characteristics, construction constraints, and practical operational experience discussed in the preceding sections.

The decision matrix presented in Table 4 indicates that the EPB Shield TBM equipped with appropriate soil conditioning measures provides the most suitable solution for the geological, hydrogeological, and construction conditions of Metro Line 2. Compared with the Slurry Shield TBM, the EPB TBM offers superior adaptability to mixed-face ground conditions, lower site-space requirements, simpler material handling, and demonstrated operational feasibility under comparable geological conditions in Hanoi.

Based on the geological characteristics, hydrogeological conditions, urban construction constraints, and practical experience gained from the Hanoi Metro Line 3 project, an Earth Pressure Balance (EPB) Shield TBM is recommended as the most appropriate tunnelling solution for the underground section of Hanoi Metro Line 2.

Table 4. Decision matrix for selecting the appropriate Shield TBM for Hanoi Metro Line 2

Evaluation criterion	EPB Shield TBM	Slurry Shield TBM	Basis
Fine-grained soils (CL–CH–ML)	Suitable	Suitable	JSCE [7], Thewes [8]
Silty sand (SM, 57.11%)	Suitable	Suitable	PSD analysis, Table 3, Thewes [8]
Sandy gravel (SM-GM, 20.94%)	Suitable	Suitable	JSCE [7], Thewes [8]
Mixed-face conditions	Suitable	Suitable	Geological comparison with Metro Line 3
Settlement control	Good	Good	JSCE [7]
Construction in confined urban areas	Suitable	Limited	Metro Line 2 project conditions
Construction site requirement	Small	Very large	TBM operating principle
Excavated material handling	Simple	Complex	TBM operating principle
Slurry treatment	Minimal	Extensive	Shield TBM operating principle
Adaptability to geological changes	Good	Moderate	Geological comparison with Metro Line 3
Clogging risk	Controllable by conditioning	Low	Soil conditioning [8, 9]
Construction complexity	Lower	Higher	TBM operating principle
Experience in Hanoi	Successfully applied	Limited	Metro Line 3 operational experience [6]

Source: Compiled by the authors from [3, 6-9].

5. Preliminary Design of the Proposed EPB TBM

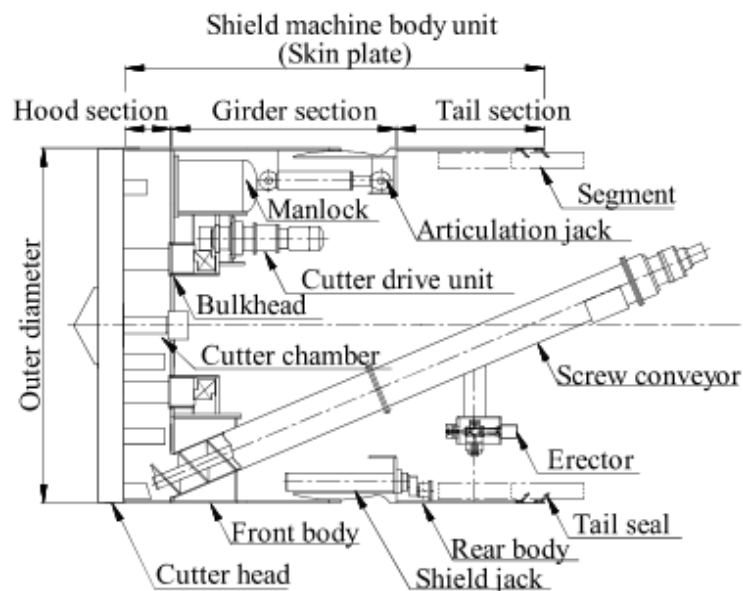


Figure 3. Typical configuration of an EPB Shield TBM.

The shield body is the main structural component of a TBM, serving to protect the excavation area, prevent ground collapse, and provide sufficient space for segmental lining installation. According to JSCE [7], the two principal design parameters of the shield body are the shield diameter and the shield length as shown in Figure 3.

5.1. Shield Diameter

According to the JSCE design guidelines [7], the external diameter of the TBM shield is determined as:

$$D = D_0 + 2(x + t) \quad (1)$$

where: $D_0 = 6.50$ m (external diameter of the segmental lining) [3]; $x = 40$ mm (shield tail clearance) [5]; $t = 75$ mm (thickness of the tail shield skin) [5] as shown in Figure 4:

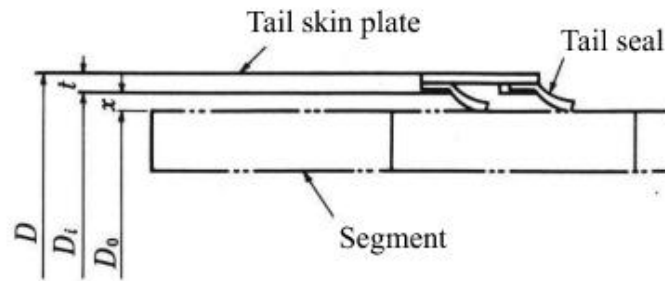


Figure 4. Details of tail section and shield diameter.

Substituting the design parameters into the above equation yields:

$$D = 6.50 + 2 \times (0.040 + 0.075) = 6.73 \text{ m}$$

Accordingly, a shield diameter of approximately 6.73 m is proposed for Metro Line 2. The calculated value is compatible with the adopted segmental lining configuration and satisfies the dimensional requirements for shield tail clearance and structural thickness in accordance with JSCE recommendations [7]. Therefore, the proposed diameter is considered appropriate for the planned tunnel cross-section and construction requirements of the project.

The implications of the proposed diameter on TBM manoeuvrability and steering performance are further evaluated through the shield length-to-diameter ratio presented in Section 5.2.

5.2. Shield Length

According to JSCE [7] and the Herrenknecht Technical Manual [10], the total shield length is determined as shown in Figure 5:

$$L = L_c + L_H + L_G + L_T \quad (2)$$

where $L_c = 1.5$ m is the cutterhead section length, $L_H = 1.2$ m is the hood section length, $L_G = 3.3$ m is the girder section length adopted from the Herrenknecht EPB TBM technical [10], and the tail section length is calculated as: $L_T = L_j + C + b + C' + l_p = 1.5 + 0.15 + 1.4 + 0.15 + 0.6 = 3.8$ m.

Substituting the design parameters into the above equation yields:

$$L = 1.5 + 1.2 + 3.3 + 3.8 = 9.8 \text{ m} \rightarrow \xi = L/D = 9.8/6.73 \approx 1.45$$

The ratio $\xi = 1.45$ falls within the recommended range of 1.1–1.6 specified by JSCE [7] for articulated TBMs. This result indicates that the proposed shield geometry is suitable for steering along the planned tunnel alignment while maintaining acceptable shield-soil interaction under mixed-face ground conditions.

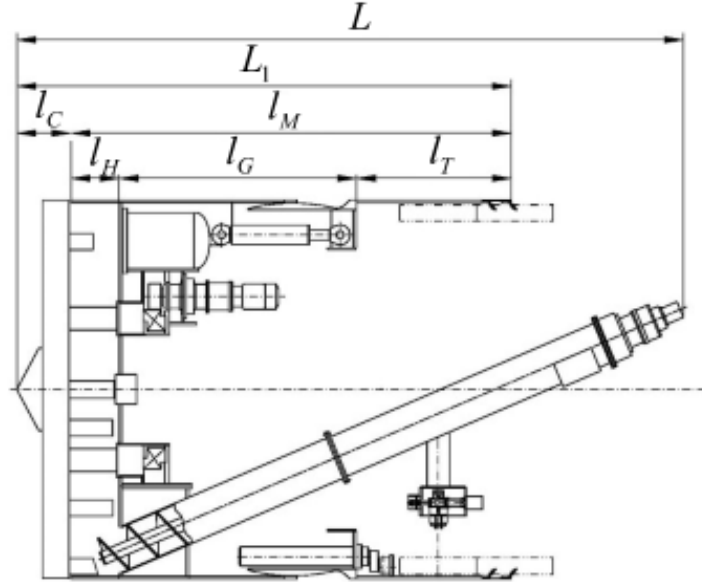


Figure 5. Details of shield length (EPB).

5.3. Cutterhead Torque – Determination of the Torque Coefficient (α) Using Operational Data from Metro Line 3

Cutterhead torque is one of the most important parameters governing excavation performance and operational stability of a Tunnel Boring Machine. According to JSCE [7], the required cutterhead torque can be estimated as:

$$T = \alpha \cdot D^3 \text{ (kN}\cdot\text{m)} \quad (3)$$

where α is the torque coefficient reflecting geological conditions and TBM operating characteristics. The recommended range of $\alpha = 10\text{--}25$ provided by JSCE is based on general empirical experience and may not fully represent the specific geological conditions of the Red River Delta. Therefore, the empirical torque coefficient was estimated using actual operational data obtained from the EPB TBM excavating the S9–S10 section of Hanoi Metro Line 3 [11].

The S9–S10 section traversed a mixed geological profile comprising: GU5a (SC-SM-SP), medium-dense to dense silty sand (approximately 52%); GU7&8 (GM-GP-GC), very dense gravel and cobble deposits (approximately 17%); GU1s and GU3&4, representing fine-grained soils (approximately 27%). These ground conditions represent a typical mixed-face environment and exhibit strong similarities to the geological conditions encountered along Metro Line 2 [11].

Figure 6 illustrates the variation of cutterhead torque and advance rate during excavation. The cutterhead torque increased significantly when the TBM encountered mixed-face conditions containing dense sand, gravel and cobbles. In contrast, the advance rate generally decreased as excavation resistance increased, demonstrating the strong influence of geological conditions on TBM performance.

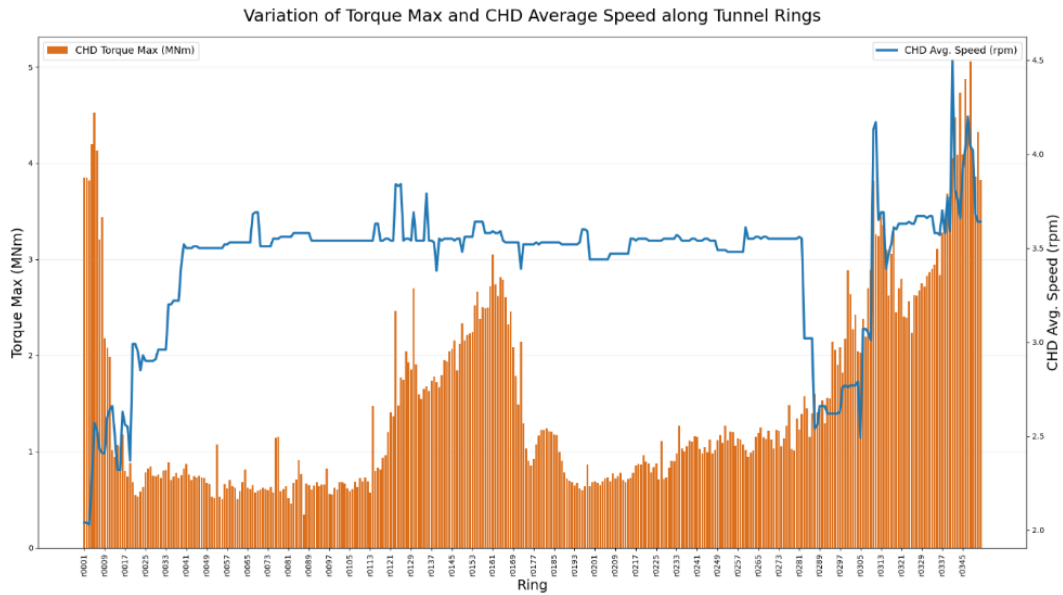


Figure 6. Recorded cutterhead torque and advance rate during excavation of the S9–S10 section of Hanoi Metro Line 3.

Table 5. Cutterhead Torque Analysis of Metro Line 3 (S9–S10 Section) [11]

Ring Section	Predominant Geological Conditions	T _{max} (MN·m)	$\alpha_{\max}$	Remarks
r0001–r0011	GU1s + GU5a	4.53	16.1	Transition between stiff clay and silty sand
r0012–r0113	GU3&4 + GU5a	1.16	4.1	Fine-grained soils and silty sand; favourable conditions
r0114–r0179	GU3&4 + GU5a	3.05	10.9	Water-bearing sand; significant increase in α
r0180–r0250	GU3&4 + GU5a	3.94	14	Heterogeneous ground conditions
r0251–r0308	GU5a + GU1d	2.89	10.3	Dense silty sand and clayey sand
r0309–r0352	GU5a + GU1d + GU7&8	5.06	18	Mixed-face condition with gravel and cobbles; highest recorded load

(Source: Metro Line 3 TBM operational data provided by FECON [11]).

Analysis of the recorded TBM operational data indicates that the maximum cutterhead torque reached $T_{\max} = 5.06 \text{ MN}\cdot\text{m}$ ($5,060 \text{ kN}\cdot\text{m}$) at ring r0348, when the TBM was excavating through a mixed-face zone consisting of GU5a, GU1d, and GU7&8, characterized by dense sand, gravel, and very dense cobbles under high groundwater conditions. The torque coefficient $\alpha_{\max}$ was calculated as:

$$\alpha_{\max} = T / D^3 = 5,060 / 6.55^3 \approx 18$$

The value $\alpha = 18$ corresponds to the most adverse excavation conditions encountered during the Metro Line 3 project. Rather than adopting the full range of α values obtained from Metro Line 3, only the maximum value ($\alpha = 18$) was selected as the design coefficient because preliminary TBM design should be based on the most unfavourable excavation conditions expected along the alignment. Since

Metro Line 2 is expected to encounter comparable mixed-face conditions involving dense sand, gravelly deposits and high groundwater levels, adoption of $\alpha = 18$ provides a conservative basis for preliminary TBM design while remaining within the JSCE recommended range (10–25). Rather than directly transferring operational parameters from Metro Line 3, the operational data were used to constrain the selection of the empirical torque coefficient under comparable geological conditions. The selected value is also consistent with the empirical range recommended by JSCE for EPB TBMs.

Using the selected design coefficient ($\alpha = 18$), the required cutterhead torque for Metro Line 2 is estimated as:

$$T = \alpha \cdot D^3 = 18 \times 6.73^3 = 18 \times 304.8 \approx 5,486 \text{ kN}\cdot\text{m} \rightarrow \text{proposed } T \approx 5,500 \text{ kN}\cdot\text{m}$$

The calculated design torque is comparable to the overload torque (5,045 kN·m) and breakaway torque (5,384 kN·m) specified in the Herrenknecht technical data for the Metro Line 3 EPB TBM [10], indicating that the recorded maximum operational torque is consistent with the machine design capacity. Although the Metro Line 3 TBM has a different shield diameter and overall dimensions from the proposed Metro Line 2 TBM, this comparison confirms that the operational data provide a realistic basis for selecting the empirical torque coefficient used in the preliminary design. The use of operational data from Metro Line 3 provides a practical reference for estimating TBM design parameters under geological conditions similar to those encountered in Hanoi, thereby supporting TBM selection and preliminary machine design for Metro Line 2.

6. Conclusions

This paper presents the theoretical framework and methodology for selecting an appropriate Tunnel Boring Machine (TBM) for Hanoi Metro Line 2 (Nam Thang Long–Tran Hung Dao section). The main findings can be summarized as follows:

i) The geological conditions along the tunnel alignment are characterized by typical Red River Delta deposits, consisting of fine-grained soils, water-bearing silty sands, and localized gravelly layers. These strata occur under high groundwater conditions and may result in mixed-face ground conditions during tunnel excavation;

ii) Based on the assessment of particle size distribution, geological and hydrogeological conditions, urban construction constraints, and operational experience from Hanoi Metro Line 3, the Earth Pressure Balance (EPB) Shield TBM is identified as the most suitable tunnelling solution for Metro Line 2. Operational experience from Hanoi Metro Line 3 further supports this selection under comparable geological conditions;

iii) The principal design parameters of the proposed EPB TBM were determined in accordance with JSCE guidelines [7]: shield diameter $D \approx 6.73$ m; shield length $L \approx 9.8$ m ($\xi = L/D \approx 1.45$); and design cutterhead torque $T \approx 5,500$ kN·m;

iv) The main contribution of this study is the use of operational EPB TBM data from Metro Line 3 to constrain the selection of the empirical torque coefficient ($\alpha = 18$) and to support the preliminary selection and design of a TBM for Metro Line 2.

The findings of this study may serve as a useful reference for TBM selection and preliminary machine design in future urban railway and underground construction projects developed under geological conditions similar to those encountered in Hanoi and the Red River Delta region.

Study limitations: The proposed TBM parameters are intended for preliminary machine selection and conceptual design purposes. Detailed machine specifications and final torque requirements should be verified through additional geotechnical investigations, laboratory testing and numerical analyses during the detailed design stage.

References

- [1] Prime Minister of Vietnam, Decision No. 355/QĐ-TTg Dated 25 February 2013 on the Approval of the Adjustment of the Transport Development Strategy of Vietnam to 2020, with a Vision to 2030, Hanoi, Vietnam, 2013 (in Vietnamese).
- [2] Prime Minister of Vietnam, Decision No. 519/QĐ-TTg Dated 31 March 2016 on the Approval of the Hanoi Capital Transport Development Master Plan to 2030, with a Vision to 2050, Hanoi, Vietnam, 2016 (in Vietnamese).
- [3] Hanoi Metropolitan Railway Management Board (MRB), Feasibility Study and Basic Design Documentation for Hanoi Metro Line 2 (Nam Thang Long–Tran Hung Dao Section), Hanoi, Vietnam, 2019.
- [4] V. Guglielmetti, P. Grasso, A. Mahtab, S. Xu (Eds.), *Mechanized Tunnelling in Urban Areas: Design Methodology and Construction Control*, CRC Press, Boca Raton, FL, USA, 2008.
- [5] S. Wang, J. Fu, C. Zhang, J. Yang, *Shield Tunnel Engineering: From Theory to Practice*, Elsevier, Amsterdam, Netherlands, 2021.
- [6] Hanoi Metropolitan Railway Management Board (MRB), Hanoi Metro Line 3 (Nhon–Hanoi Station Section): Project Documentation, Hanoi, Vietnam, 2021.
- [7] Japan Society of Civil Engineers (JSCE), *Standard Specifications for Tunneling–2016: Shield Tunnels*, Japan Society of Civil Engineers, Tokyo, Japan, 2016.
- [8] M. Thewes, TBM Tunnelling Challenges – Redefining the State of the Art, Keynote Lecture, ITA-AITES World Tunnel Congress 2007, Prague, *Magazine Tunnel*, Vol. 16, 2007, pp. 13–21.
- [9] FECON Corporation, PIC-TEC-TRE-WTO-L10-32001-V-2A, Tunnel – General Description Report, Hanoi Metro Line 3 (Nhon – Hanoi Station Project), Hanoi, Vietnam, 2021.
- [10] Herrenknecht AG, *Tunnel Boring Machines – Technical Manual*, Schwanau, Germany, 2018.
- [11] FECON Corporation, TBM Operational Monitoring Data for the Underground Section of Hanoi Metro Line 3 (Nhon–Hanoi Station), Internal Project Database, Hanoi, Vietnam, 2024.