Data-driven Site Supervision on Micro Tunnel Boring Machine (MTBM) on Hard Rock Performance - Objective, Analysis and a Case of Effluent Pipeline in a Caverns Project

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ABSTRACT

The Relocation of Shatin Sewage Treatment Works (STSTW) to Caverns involves the construction of twin effluent pipelines for conveying treated effluent to the existing inlet chamber via the Tolo Harbour Effluent Export Scheme (THEES) Tunnel. The paper emphasizes lessons learned from past projects with MTBM jamming underground, leading to project delays, increased costs, safety concerns, and social impacts. This specific case study focuses on a twin pipe driving through a rock mountain. The catastrophic nature of such jamming problem embarks meticulous site supervision, with a 100% successful breakthrough of the MTBM as a paramount objective. Traditional rescue methods, such as vertical shafts, may be impractical and infeasible in our case, further highlighting the importance of comprehensive site supervision by Resident Site Supervisor (RSS). The first part of the paper delves into a detailed case study of one of the twin pipes, and its performance with insights. The second part explores the fundamental aspects of profound site supervision, discussing the rationale for employing site data to achieve project objectives with aims to mitigating the escalating risks associated with MTBM failures. Moreover, it lays the groundwork for further analysis and utilization of operational data for the second effluent pipeline and tunneling industry.

Keywords: Micro Tunnel Boring Machine, Hard Rock, Cutterhead, Profound Site Supervision, Operational Data

1. INTRODUCTION

Throughout the history of MTBM projects, there has never used to be a standard practice for RSS to place emphasis on reviewing the Geotechnical Investigation and cutter head evaluation in terms of cutter disc configuration and opening ratio etc. when approving the Contractor's proposal. However, it has become increasingly clear that thorough scrutiny of these aspects is essential for ensuring the success of MTBM projects. RSS, as the overseeing authority, plays a pivotal role in diligently supervising the entire process – from verifying contractor submissions to on-site supervision. To effectively carry out these responsibilities, RSS must possess a deep understanding of MTBM technology. By actively engaging in the determination of appropriate MTBM cutter head evaluation, RSS can contribute significantly to the overall success of the project. This proactive approach not only enhances the quality and efficiency of MTBM operations but also minimizes the risks associated with tunneling activities.

1.1 Case Study – The Relocation of Shatin Sewage Treatment Works to Caverns

In Relocation of STSTW, a twin effluent pipe, approximately 330m long with a slight gradient and 2.2m internal dimeter, were installed using MTBM, which was manufactured by China Railway Construction Heavy Industry Corporation Limited. The pipes are located underneath Niu Po Shan with depth ranging between 10m and 140m. Figure 1 show the general view of the project and the twin effluent pipes.

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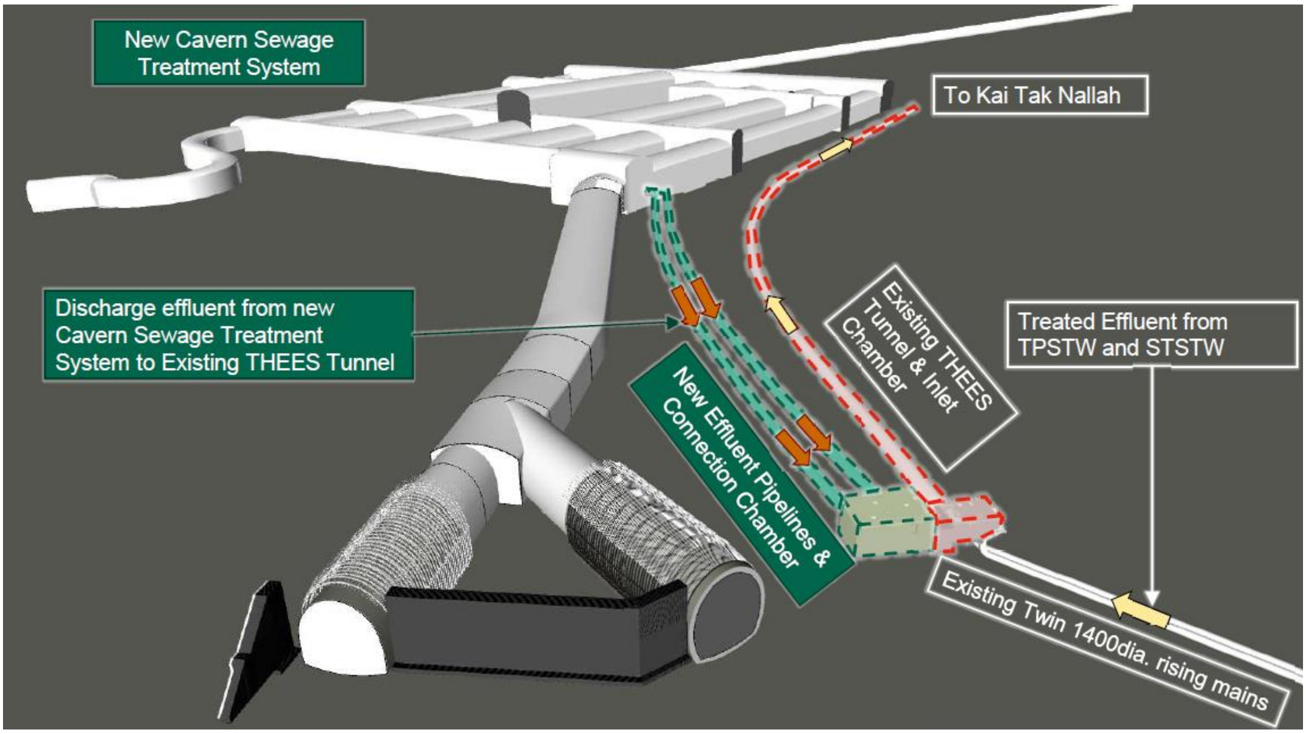


Figure 1 – General view of project and the twin effluent pipes

We are faced with the challenge of beginning the jacking process at a mountain. This unique starting point necessitates the construction of a specific up-stand thrust wall, along with a piling system, to facilitate the jacking process, as shown in Photo 1. This deviation from the norm presents a first-time challenge for our project since, under normal circumstances, an underground jacking pit could be constructed for this purpose. STSTW is Hong Kong's largest secondary sewage treatment works, serving approximately 630,000 residents in Shatin and Ma On Shan. These districts generate a daily sewage volume of 250,000m³. The existing STSTW pumps effluent to the adjacent THEES tunnel, which then flows through a dedicated tunnel to Diamond Hill and discharges into Kai Tak Nullah. The proposed twin effluent tunnels will connect the relocated STSTW with the THEES tunnel, ensuring a continuous discharge route in the future.

Photo 1 – General view of jacking thrust structure and lifting gantry

1.2 Specific Site Constraints

1.2.1 No Turning Back

In the deep bedrock beneath Niu Po Shan, the MTBM faces challenges without the option of a turnaround or rescue shaft. If a cutterhead jam or breakdown occurs, retrieving the machine is unlikely. This limited solution poses a risk of significant disasters, leading to increased costs and delays.

1.2.2 Hard Rock Drilling

Drilling in hard rock presents challenges, especially when continuously drilling over a long distance of 660m in Hong Kong. The extreme hardness of the rock causes rapid wear on the disc cutters, requiring frequent replacements. This process takes place within the confined space of the MTBM, involving the use of hand-held percussion machines and heavy lifting operations, as shown in Photo 2. The frequent disc cutter replacements increase risks, costs, and disruptions to the tunnelling process, raising the likelihood of MTBM failure.

1.2.3 Interference with Nearby Drill-and-Blast Excavation

The receiving pit for the MTBM in the main cavern was excavated using the drill-and-blast method, raising concerns about vibrations causing damage to the surrounding rock. Seismic waves and loads from blasts can harm weak surfaces like joints and fissures, impacting overall stability. Careful planning and monitoring are crucial for the MTBM-blasting interface to minimize risks. Maintaining a safe distance between the MTBM and blasting works is essential to mitigate potential damage.

1.2.4 Sensitive Receiver THEES Tunnels

The proposed effluent pipelines are close to the existing THEES tunnel with minimum separation distance of 7.9m, raising concerns about potential impacts on THEES, such as pressure changes, vibrations, and settlement. To mitigate these impacts, the slurry pressure balance method is used during MTBM operations.

1.3 Tunneling Method and MTBM

The slurry-operated MTBM was adopted. Two intermediate jacks were installed to help pushing the pipeline forward, as shown in Photo 2 and Photo 3 respectively.

Photo 2 – Main jack

Photo 3 – Intermediate jack

1.4 Cutterhead Configuration

In this project, a domed cutterhead was utilized, consisting of various types of cutters, as shown in Photo 5.

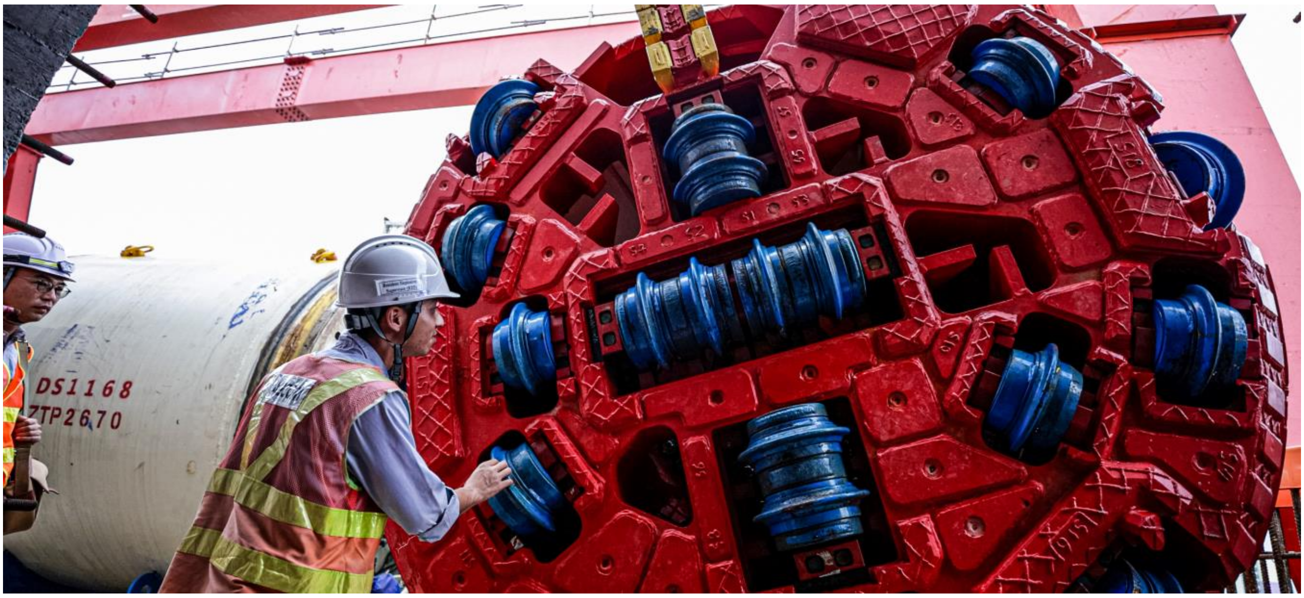


Photo 4 – Adopted cutter head for hard rock MTBM

The center area of the cutterhead featured 4 double-disc cutters with a diameter of 305 mm. The face area had 6 single-disc cutters of the same diameter, while the gauge area also had 6 single-disc cutters. Additionally, a scrapper was incorporated to transport rock fragments out of the excavation face. The spacing between the cutters was set at 80 mm. The single-disc cutters, which played a crucial role in rock breaking, were replaced by double-disc cutters at the center due to space limitations. All the cutters were made of wear-resistant tungsten carbide inserts. The opening ratio of the cutterhead, representing the ratio of the total area of the cutter openings to the total area of the cutterhead, was measured at 16%. Photo 4 show the details of the cutterhead.

1.5 Key Performance Data of MTBM Recorded

Key Performance Indicators during tunnelling were recorded and monitored closely by our RSS to gain an insight into the performance, efficiency and potential issues of MTBM. The indicators include MTBM utilization, jacking force and friction resistance, penetration rate, advancement rate, disc cutter replacement analysis, tolerance of alignment and induced ground settlement. The information helps in making informed decisions and optimizing the tunnelling process.

1.5.1 MTBM Utilization (U)

U refers to the percentage of available shift time during which excavation activities are performed using the MTBM (Gong Qiuming, 2006). It is a comprehensive factor influenced by various operating procedures. The overall U of the MTBM used for the installation of the 1st effluent pipes achieved 39%, as indicated in allocation time chart shown in Figure 2. The U is the result of enhanced site supervision and could be serve as a bench mark for the second effluent pipeline operation in hard rocks. Throughout the tunnelling process, our RSS continuously reviewed U at fixed driving distance of 10m equivalent to the length of 4 nos. concrete pipes, as shown in Figure 3. If exceptionally low U is recorded, a detailed review of the root cause and corresponding corrective measure could be implemented.

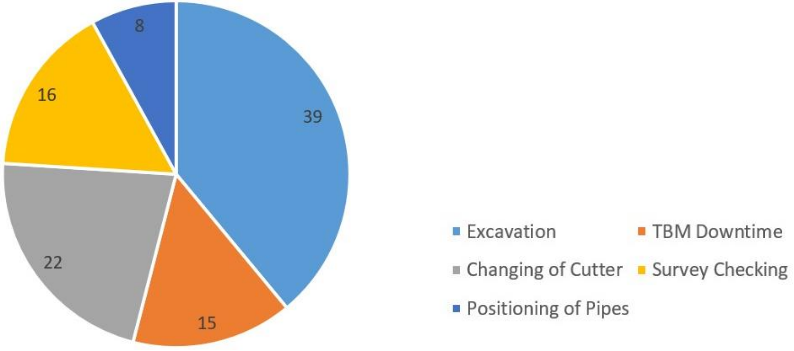


Figure 2 – Allocation time chart for MTBM during installation of 1st effluent pipe

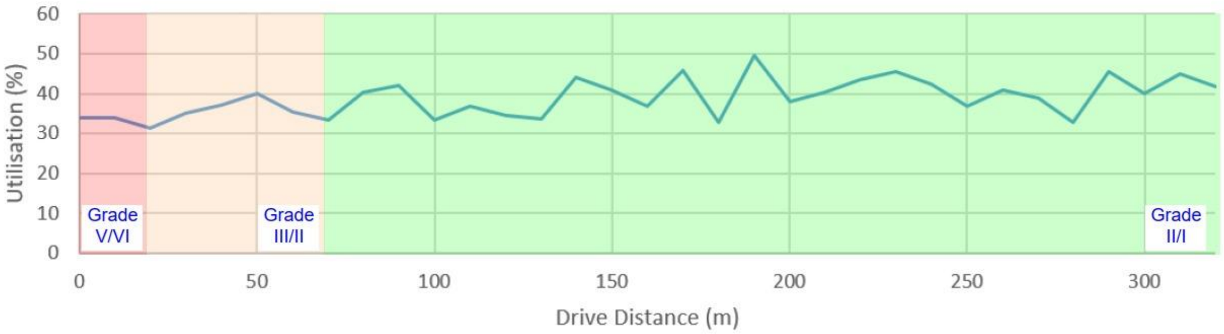


Figure 3 – Utilization along the driving distance of MTBM

1.5.2 Jacking Force and Friction Resistance

In MTBM, the jacking force is necessary to estimate and facilitate the sliding of the pipe through the ground. It involves several factors that complicate the assessment and necessitate close monitoring of the jack force recorded in the field. Figure 4 illustrates the various components contributing to the overall thrust required for an MTBM project. The face pressure component is needed to support the face, balance groundwater pressure, and facilitate excavation by exerting force on cutters. This remains relatively constant along the alignment unless there are significant geological changes. While it becomes a smaller percentage of the total jacking force as the drive progresses, it is generally not a critical factor in estimating the jacking force for long drives. The frictional component increases as the drive length increase and is dominated in long drive. Figure 5 shows the comparison of actual jacking force, design jacking force and the jacking force capacity provided by the main jacks and intermediate jacks along the drive length.

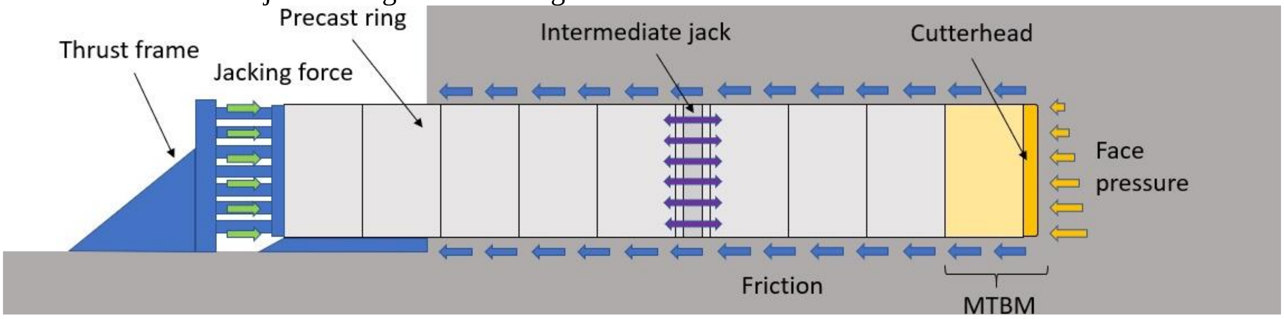


Figure 4 – Contributing components of required thrust force

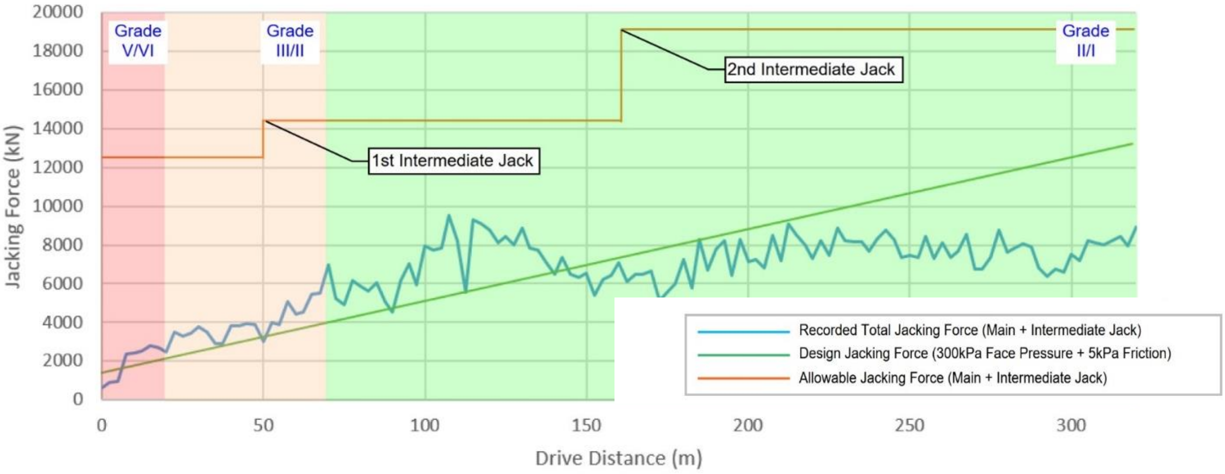


Figure 5 – Comparison between design jack force and actual jacking force

1.5.3 Penetration Rate (PR)

Average PR refers to the excavation distance covered by a TBM per unit of time, usually expressed as meters per hour (Gong Qiuming, 2006). PR is affected by both objective factors, which are geology and MTBM capacity, and subjective factor, which is human operating factor. The Penetration per Revolution (PRev) is a key indicator of excavation efficiency, representing the distance excavated per revolution of the TBM's cutterhead. The average PR ranges from 0.5 to 7 m/h, (Grandori et al., 1990). In the first effluent pipe, the average PR was 1.9 m/h. Figure 6 illustrates the variation of PR along the MTBM drive.

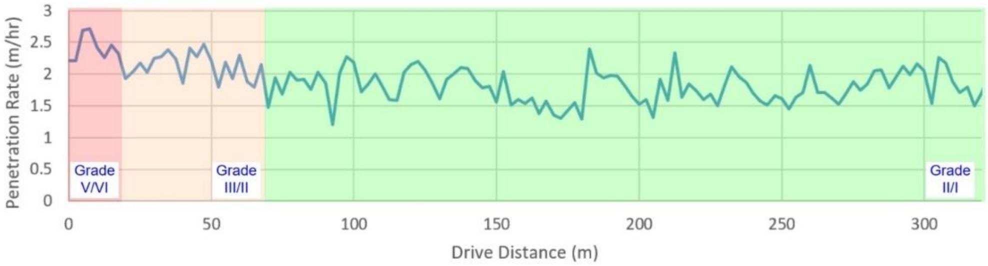


Figure 6 – Variation of PR along MTBM drive

1.5.4 Advance Rate (AR)

Advance rate (AR) is the actual distance mined or supported divided by the total time of the operations and includes downtimes for TBM maintenance (Gong Qiuming, 2006). It equals to the product of U and PR. Based on statistical data suggested by Laughton, 1998, AR ranges from 0.3 to 3.3m/h (Grandori et al., 1990). AR 0.8m/h was achieved in the first effluent pipe as shown in Figure 7.

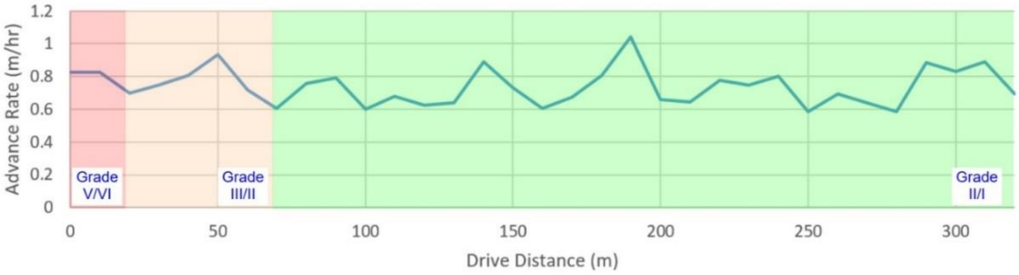


Figure 7 – Variation of AR along MTBM drive

1.5.5 Cutter Wear

Cutter wear is recorded based on the rolling distance of each cutter (Gong Qiuming, 2006), as shown in Figure 8. Due to the outer disc cutter traveling a longer distance than the inner disc cutter for one rotation of the cutterhead, the outer disc cutter should experience more frequent wear compared to the inner disc cutter. Theoretically, a cutter is replaced when its radius loss reaches around 20 mm due to abrasion (Grandori et al., 1990). During MTBM for the first effluent pipe, no centre cutters (S1-S8) were required to be replaced. The average service time were 146m and 114m for face cutters (S9-S14) and gauge cutters (S15-S20) respectively.

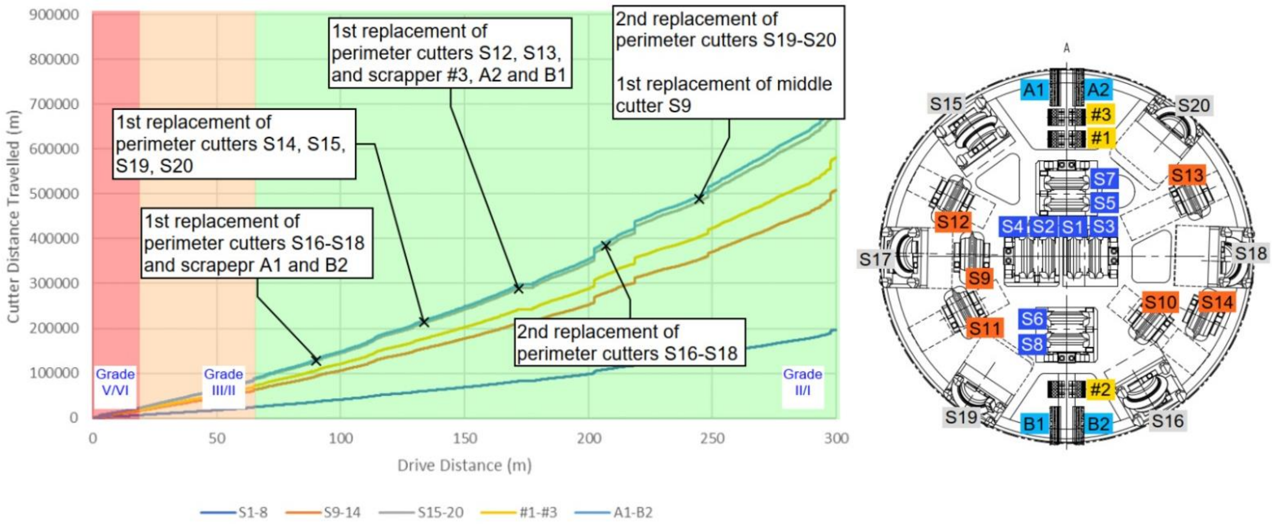


Figure 8 – Records of disc cutter travelling distance

2. ENHANCED SITE SUPERVISION

2.1 Emphasis on reviewing the Geotechnical Investigation for cutter head evaluation

The unique geological conditions at the site, with over 96% of Grade III or above hard rock, present significant challenges for the MTBM. Issues such as penetration rate, cutterhead maintenance, and cutter disc replacement, as shown in Photo 5, are directly impacted by the properties of the rock mass. It is essential to carefully select a MTBM that is specifically designed to handle hard rock conditions, ensuring efficient excavation and minimizing risks and delays.

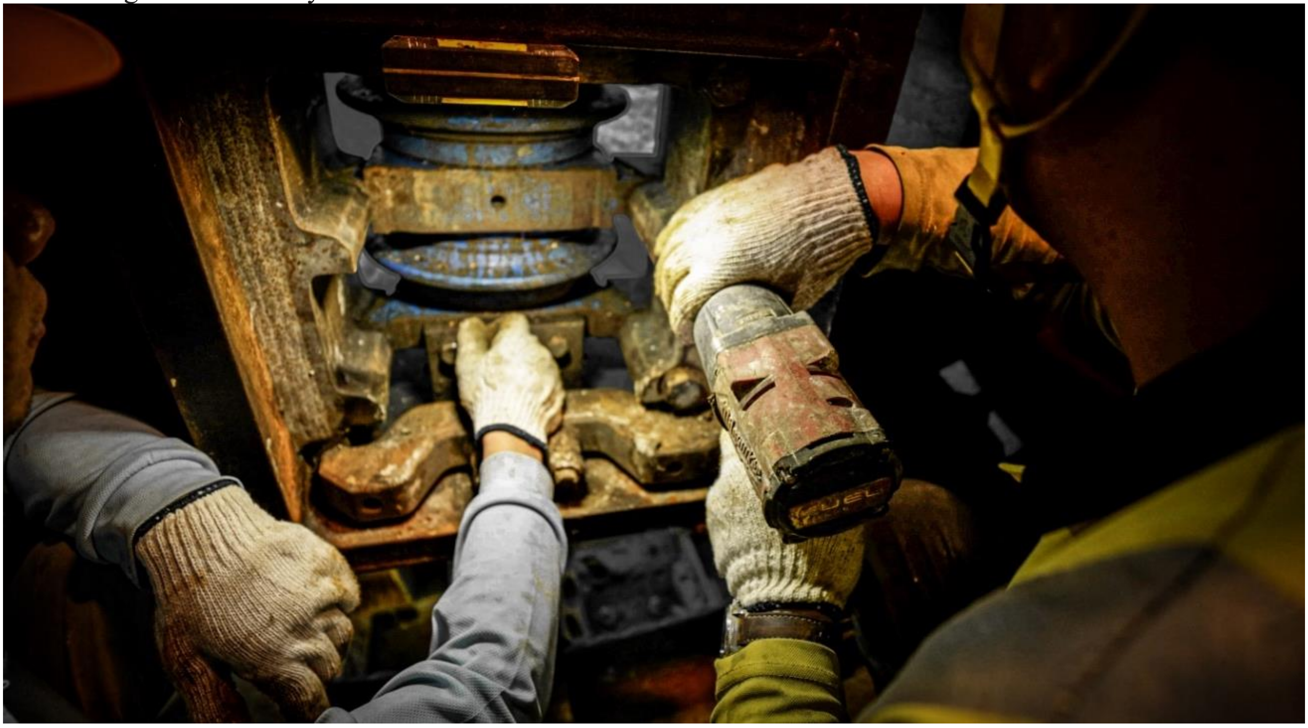


Photo 5 – Replacement of cutter disc

2.1.1 Key Geotechnical Parameters for MTBM in Hard Rock

Considering over 96% of total MTBM drive length was in hard rock under this project, RSS critically reviewed all the governing rock parameters in evaluating a suitable MTBM for hard rock excavation, as summarized in Table 1. The density, abrasiveness, cohesion values, permeability, friction angle, unconfined compressive strength, tensile splitting strength, and triaxial strength of rock all impact the cutting power, tools, durability, torque, thrust, waterproofing measures, and cutter design of MTBMs.

Table 1 – Summary of key geological parameters

Parameters	Grade I	Grade II	Grade III	Grade IV/V
Density (kg/m3)	2540 to 2610	2420 to 2690	2540 to 2560	1550 to 2400
Abrasiveness	2.85 to 5.2	4.01 to 5.67	3.92 to 5.38	-
Cohesion (kPa)	-	-	71.83	3
Permeability (m/s)	1E-9 to 1.13E-6	1.58E-06	2.3E-9 to 2.48E-6	1.52E-8 to 9.42E-6
Friction Angle (°)	13.4 to 66.3	11.8 to 53.6	29 to 54	37
Unconfined Compressive Strength (MPa)	72.3 to 245.4	15.4 to 225	16.4 to 82.3	-
Tensile Splitting Strength (MPa)	5.01 to 11.64	3.54 to 12.55	3.87 to 7.59	-
Triaxial Strength (MPa)	120.27	106.48 to 193.08	-	-

2.2 Enhancing Efficiency and Safety through Evaluation of Cutterhead Design

Currently, the design and evaluation of the MTBM cutterhead are primarily led by the contractor and MTBM manufacturer, with limited involvement from the RSS during the supervision of MTBM works. In response to this, our RSS has developed a cutterhead evaluation protocol (CEP) to systematically evaluate the suitability of a cutterhead design for specific ground conditions. The CEP includes a checking flowchart, as illustrated in Figure 9, which outlines the steps to be followed. Through the implementation of CEP, the RSS aims to actively contribute to the decision-making process regarding the evaluation of the MTBM cutterhead design.

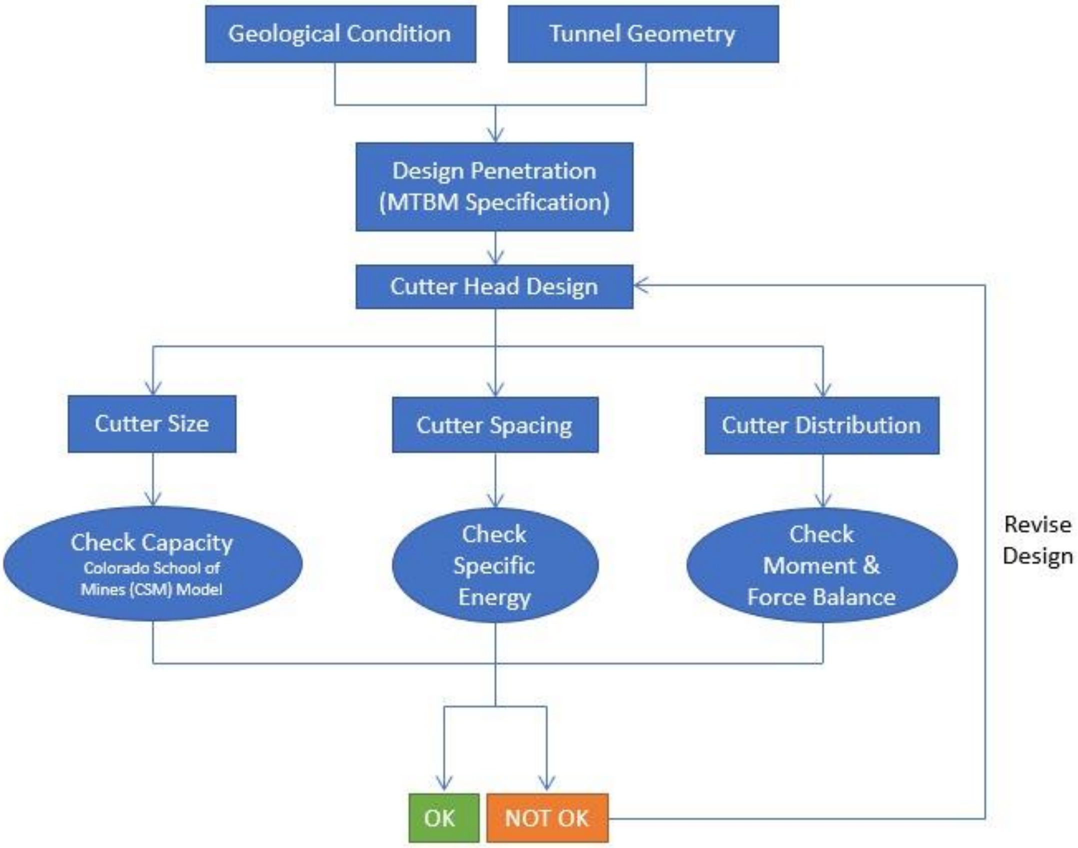


Figure 9 – Flowchart to evaluate the cutterhead in CEP

2.2.1 Basics of Cutterhead Design for Different Geology

MTBMs are adaptable machines that can operate in various ground conditions. Different cutterheads, such as spoke or fan for soft ground and domed with disc cutters for hard rock, are tailored to the specific needs of the project.

2.2.2 Opening Ratio

The opening ratio is the ratio between the open area on the cutterhead and the total face area. The main considerations are (1) the required cutterhead stiffness to support the cutting tools during excavation; (2) the required support to the excavation face; and (3) the efficiency of the mucking process. According to our CEP, the suitable opening ratio is >35% for soft ground, 20%-35% for mixed ground and <20% for rock. The cutter head in hard rock needs to be stronger and more robust to handle the higher cutter forces required and the chips generated are smaller due to slower advancement.

2.2.3 Cutter Disc Size

The main design considerations when selecting the suitable disc cutter sizes are (1) the required cutter load bearing capacity; (2) the cutter velocity; and (3) the space constraint on the cutterhead. In general, the larger the cutter the higher is its load bearing capacity. Larger cutters have higher load capacity, deeper penetration and higher velocity limit. For 2-3m diameter MTBMs, the recommended cutter ring size is typically 305mm in diameter. For 3-5m diameter MTBMs, the recommended cutter ring size is generally 394mm in diameter. In our CEP, the maximum cutter force was estimated using the Colorado School of Mines (CSM) prediction model based on the expected geology, cutter spacing, and design penetration (Guo et. al. 2016). The CEP is designed to facilitate the evaluation of the proposed cutter head design, ensuring that the cutter force remains within acceptable operational limits and effectively prevents cutter overloading.

2.2.4 Cutter Spacing

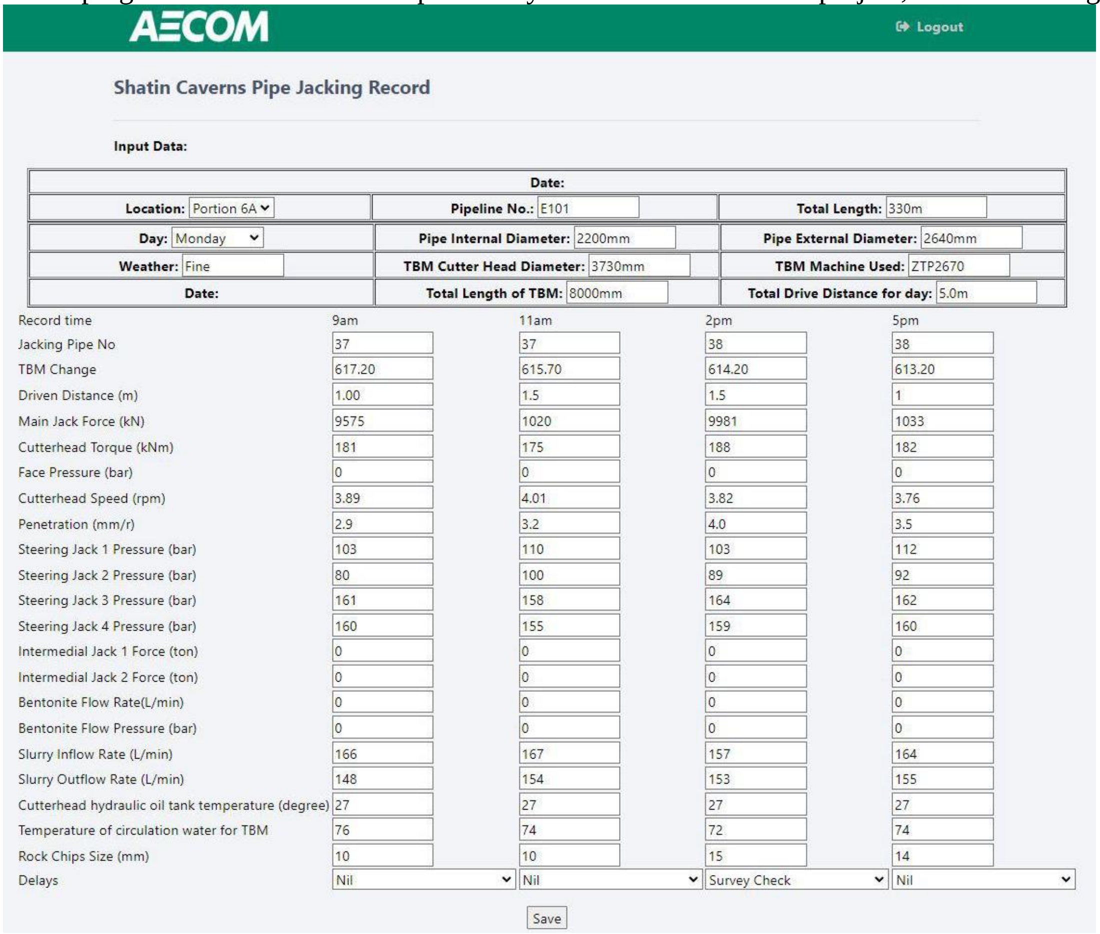
The spacing between cutters is an important factor on the rock breaking efficiency of the cutterhead. Too large of a spacing impedes the formation of cracks between subsequent cuts while too small of a spacing would lead to excessive crushing and overbreak. A general guideline is that the optimum cutter spacing/penetration ratio shall be between 10 and 20 (Jamal et. al. 2017). The individual spacings between subsequent cutters could potentially be optimized using the principle of minimizing the specific energy of the cutterhead. The specific energy is the amount of energy required for the MTBM cutterhead to break a unit volume of rock and it is calculated based on the cutting force and torque contribution from individual cutters (Guo et. al. 2016). In the CEP, the specific energy of the proposed cutterhead was evaluated with the spacing of the cutters such that we could make a more informed judgement on whether there is room for optimization given the other cutterhead design constraints.

2.2.5 Cutter Distribution

The spatial distribution of disc cutters on the cutterhead is directly related to the balance of the cutterhead in terms of force and moment (Jamal et. al. 2017). A well-balanced cutterhead would reduce its distortion during excavation, reduce the burden of the MTBM bearing and improve the steering efficiency . However, in reality the cutters are often not distributed perfectly in terms of balance due to the other design constraints such as the need to maintain optimum spacing between cutters and the need to provide openings for efficient mucking. The CEP allows us to evaluate the balance of the proposed cutterhead.

2.3 RSS's Commitment to Innovation

In the ever-evolving construction industry, the use of Common Data Environments (CDE) has become increasingly prevalent for streamlining project management and enhancing collaboration among stakeholders. While there are numerous CDE platforms available in the market, RSS has taken a proactive approach by developing a tailor-made solution specifically for the Shatin Caverns project, as shown in Figure 10.



Shatin Caverns Pipe Jacking Record

Input Data:

Date:
Location: Portion 6A | **Pipeline No.:** E101 | **Total Length:** 330m
Day: Monday | **Pipe Internal Diameter:** 2200mm | **Pipe External Diameter:** 2640mm
Weather: Fine | **TBM Cutter Head Diameter:** 3730mm | **TBM Machine Used:** ZTP2670
Date: | **Total Length of TBM:** 8000mm | **Total Drive Distance for day:** 5.0m

Record time	9am	11am	2pm	5pm
Jacking Pipe No	37	37	38	38
TBM Change	617.20	615.70	614.20	613.20
Driven Distance (m)	1.00	1.5	1.5	1
Main Jack Force (kN)	9575	1020	9981	1033
Cutterhead Torque (kNm)	181	175	188	182
Face Pressure (bar)	0	0	0	0
Cutterhead Speed (rpm)	3.89	4.01	3.82	3.76
Penetration (mm/r)	2.9	3.2	4.0	3.5
Steering Jack 1 Pressure (bar)	103	110	103	112
Steering Jack 2 Pressure (bar)	80	100	89	92
Steering Jack 3 Pressure (bar)	161	158	164	162
Steering Jack 4 Pressure (bar)	160	155	159	160
Intermedial Jack 1 Force (ton)	0	0	0	0
Intermedial Jack 2 Force (ton)	0	0	0	0
Bentonite Flow Rate(L/min)	0	0	0	0
Bentonite Flow Pressure (bar)	0	0	0	0
Slurry Inflow Rate (L/min)	166	167	157	164
Slurry Outflow Rate (L/min)	148	154	153	155
Cutterhead hydraulic oil tank temperature (degree)	27	27	27	27
Temperature of circulation water for TBM	76	74	72	74
Rock Chips Size (mm)	10	10	15	14
Delays	Nil	Nil	Survey Check	Nil

Figure 10 – Tailor-made platform for pipe jacking supervision

This bespoke CDE not only caters to the unique requirements of the project, such as blasting cycle monitoring and pipe jacking supervision, but also allows RSS and the contractor to actively contribute ideas for improving the supervision regime. This collaborative effort enables real-time adjustments and enhancements to be made to the program, ensuring that it remains relevant and effective throughout the project lifecycle. Under the Construction 2.0 framework, RSS has utilized PHP and MySQL for data input and database management, setting the groundwork for future integration of Python for data analysis and prediction. This forward-thinking approach not only enhances the efficiency and effectiveness of the CDE but also demonstrates RSS's commitment to innovation and continuous improvement in construction project management.

2.4 Verification of Jacking Force by BIM

The use of BIM and Robot Structural Analysis (RSA) by RSS, as shown in Figure 11, has transformed their design review process for pipe jacking systems. Previously, RSS had to rely on contractor designs for determining jacking force, but now they use BIM to create analytical models in Revit and import them into RSA for detailed analysis. This allows for accurate determination of thrust force, face pressure, and structural behavior, ensuring project requirements are met. The adoption of BIM and RSA has increased efficiency, accuracy, and confidence in project planning and execution, ultimately delivering projects with greater precision and quality. This technological advancement benefits this project and the construction industry as a whole.

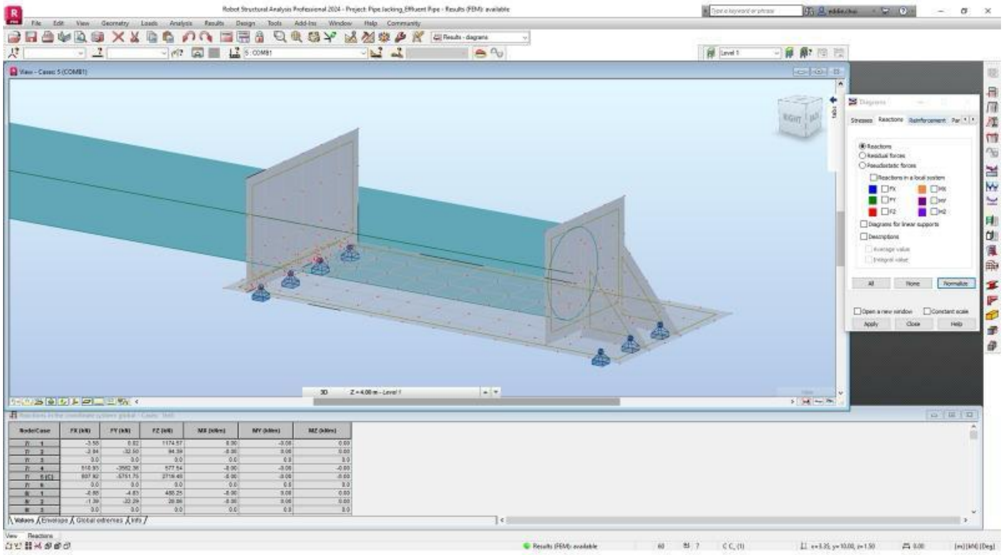


Figure 11 – Robot Structure Analysis to review the pipe jacking system

2.5 RSS Supervision Insights

In practice, MTBM operators rely on experience to operate the machine, but dynamic operating conditions present challenges. Maximizing penetration rate and prolonging worn cutter discs are common practices to reduce costs and replacement time. However, this can lead to decreased cutting efficiency, increased wear, and potential damage to the cutterhead.

2.5.1 Slurry inflow/outflow rate and slurry pressure

The inflow and outflow rate and pressure of the slurry should be balanced under normal working conditions. RSS should pay attention if the situation of "Small-In-Large-Out" occurs, where the inflow rate and pressure are lower than the outflow rate and pressure. This observation suggests the possibility of cutter disk damage and the formation of larger-than-optimum-size chips, which can lead to blockages in the slurry pipe.

2.5.2 Cutterhead pressure and hydraulic oil tank temperature

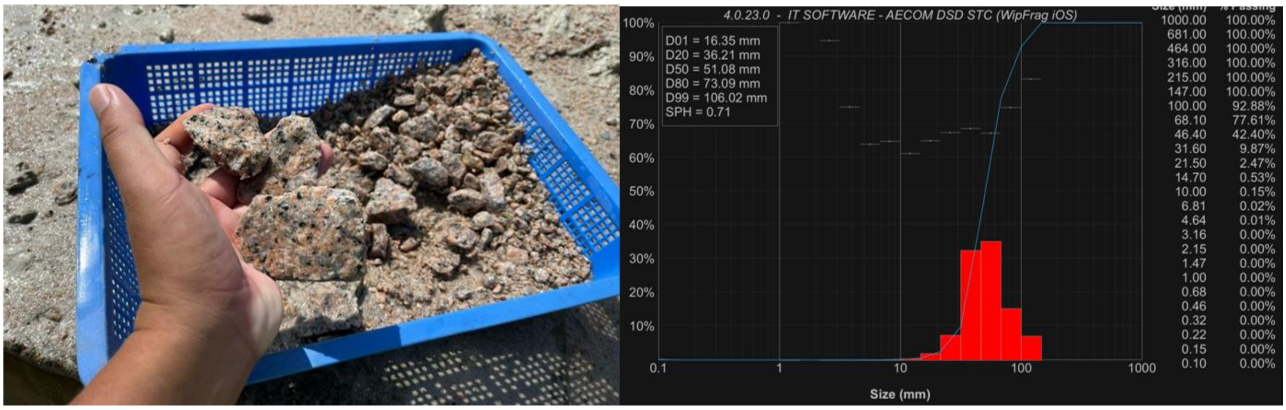
The cutterhead pressure and the hydraulic oil tank temperature should be within a specified range, depend on the MTBM specification. If the pressure exceeds or falls outside these ranges, it indicates that the cutterhead is experiencing an additional load. In such cases, it is possible that the encountered rock has become harder or that the cutter disks have worn down significantly, leading to the inability to maintain normal values. Under such condition, our RSS would request an inspection of the cooling system, cutter disks, and oil tank to gradually identify the underlying causes of the problem, thereby avoiding a situation where the MTBM becomes inoperable and cannot be repaired.

2.5.3 Total thrust and cutterhead torque

RSS should monitor the total thrust and cutterhead torque to ensure they stay within the design value and optimum range. In one instance, an abnormal thrust and torque were recorded, accompanied by unusual sounds from the MTBM. The operator considered it a normal situation resulting from encountering large boulders and insisted on continuing the excavation. However, our RSS suggested a thorough inspection of MTBM should be taken. It turned out to be found that one of the fastening screws for the cutter disk was damaged. If the damaged cutter disk had not been detected early, it could have fallen between the MTBM and the rock face, making it challenging to address the situation effectively.

2.5.4 Rock fragment inspection

RSS should carry out regular inspections and records the stone fragments brought out by the slurry pipe on a regular basis. Image analysis, as shown in figure 12, was carried out to determine the size distribution curve of the rock fragments. In case that abnormal large size of rock fragment is observed, RSS would stop the MTBM operation and would request a detailed inspection of the cutter disk. It is important to promptly replace excessively worn cutter discs in order to prevent unnecessary adverse impacts on other components of the MTBM.



Size (mm)	% Passing
1000.00	100.00%
681.00	100.00%
464.00	100.00%
316.00	100.00%
215.00	100.00%
147.00	100.00%
100.00	92.88%
68.10	77.61%
46.40	42.40%
31.60	9.87%
21.50	2.47%
14.70	0.53%
10.00	0.15%
6.81	0.02%
4.64	0.01%
3.16	0.00%
2.15	0.00%
1.47	0.00%
1.00	0.00%
0.68	0.00%
0.46	0.00%
0.32	0.00%
0.22	0.00%
0.15	0.00%
0.10	0.00%

Figure 12 – Periodic inspection of rock fragment by RSS

2.5.5 MTBM advancement rate

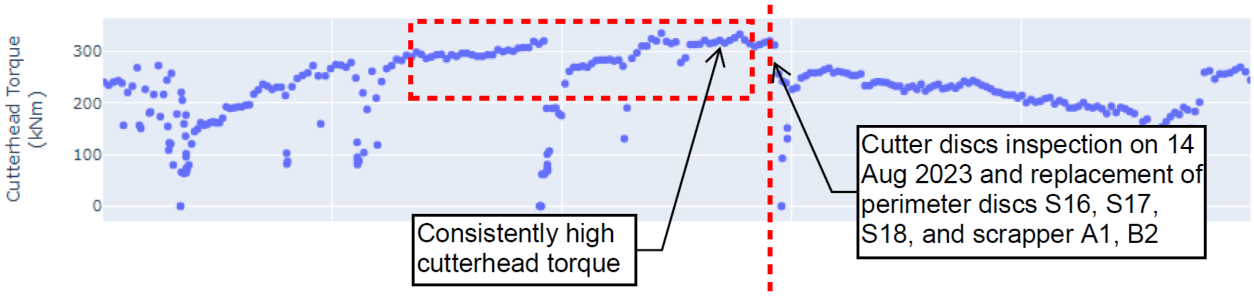
The RSS should closely monitor the advancement rate of the MTBM. It is crucial to take note of prolonged stops of the MTBM at the same location during normal working conditions. Such extended pauses raise concerns about excessive ground settlement in adjacent areas, particularly when encountering materials with varying hardness at the excavation face. The softer portion of the material may undergo excessive drilling, resulting in significant ground loss as the MTBM overcomes the harder section of the material. It is important to address these issues promptly to mitigate potential adverse effects on the surrounding ground.

2.5.6 Usage of slurry and bentonite

The RSS also needs to monitor the usage of slurry and bentonite. Operators typically prioritize progress without considering the excessive use of slurry and bentonite, which indicates potential underground leakage, caused by damaged underground pipes or the presence of sinkholes, etc. RSS should also inspect the surrounding area adjacent to MTBM operations to see if there is any excessive settlement.

2.5.7 Prediction of cutter disc replacement

The detrimental effects of exceeding the critical wear of cutters, which not only reduce the cutting efficiency, but also increase stress and potentially leads to bearing damages and overall failure of MTBM. Our RSS realized the importance of timely replacement of the worn cutters and adopted 3-steps cutter wear supervision. First, the average lift time of the cutters were recorded and used as benchmark for estimation of wear levels. Secondly, we monitor the size of chips collected from desilting tanks, identifying any progressively increase in chip size as a warning sign of increasing cutter wear. Lastly, we closely observe applied torque, specifically abnormal high torque that persists over time, indicating potential wear issues, as shown in Figure 13.



Consistently high cutterhead torque

Cutter discs inspection on 14 Aug 2023 and replacement of perimeter discs S16, S17, S18, and scrapper A1, B2

Figure 13 – Evaluation of drilling parameters for disc cutter replacement

3.0 CONCLUSION

The proper selection of the MTBM cutter head is crucial for the successful and efficient tunneling in hard rock conditions. RSS plays a critical role in ensuring that the right cutter discs and configurations are chosen, as it can have far-reaching impacts on the progress, safety, quality, environmental sustainability, and cost effectiveness of the tunneling project. A thorough review and supervision of the MTBM cutter head selection process is essential to mitigate risks and maximize the success of the project. The successful breakthrough of the MTBM for the 1st effluent pipeline, as shown in Photo 6, stands as a confirmation to importance of meticulous site supervision and the careful evaluation of cutterheads. This achievement highlights the significance of data-driven decision making and utilization of operational data to inform future tunneling project.

Photo 6 – Successful completion of 1st effluent pipe

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