

## APPLICATION OF GROUND IMPROVEMENT FOR LAUNCHING AND RECEIVING OF TBM SHIELD MACHINES ON MRT ORANGE LINE (EAST SECTION) PROJECT

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### ABSTRACT

Ground stabilization and improvement techniques play a significant role in successful implementation of soft ground tunnelling in urban areas. Many methods have been recently utilized to solve geotechnical problems. However, jet grouting is the most typical one which commonly adopted in various manners in tunnelling works, particularly launching and receiving of tunnel boring machine (TBM) at underground stations, intervention shafts and transition between cut & cover tunnel and bored tunnel. The main purposes of jet grouting at these locations are to enhance strength of soil deposits, to ensure the stability at the face of the TBM, to avoid the inflow of groundwater inside the underground structures, and to limit the potential settlements on the surface. Moreover, a special operation of the TBM for break-in and break-out is required to avoid risk of instability and the excessive loads on diaphragm walls. Therefore, this paper aims to introduce design concepts and criteria of ground improvement techniques by jet grouting for TBM break-in and break-out in Bangkok subsoil conditions on the MRT Orange Line (East Section) project. In addition, verification of the effectiveness of the provided ground improvement, the main procedures in practice used for work operations and the major details for construction are also presented.

**Keywords:** Ground improvement, Jet grouting, TBM, Launching, Receiving

### 1. INTRODUCTION

The Mass Rapid Transit Authority of Thailand is implementing the MRT Orange Line (East Section) Project. The main purposes of this project are to develop a complete mass electric system network, to alleviate traffic congestion and to improve quality of life of people. CKST Joint Venture was awarded Contracts E1 and E2 to carry out the design and construction of both contracts.

The MRT Orange Line Project, Contract E1 starts from Thailand Cultural Centre Station (OR13) passing through MRTA Station (OR14) and Pradit Manutham Station (OR15). The alignment continues until the end of the Contract E1 at Ramkhamhaeng 12 Station (OR16). Tunnel construction is divided into two sections, cut and cover tunnel between OR13 and OR14, and twin bored tunnels between OR14 and OR15, and from OR15 to OR16. The total length of Contract E1 is about 5.3 km. The Contract E2 starts from Ramkhamhaeng 12 station (OR16) to Hua Mak station (OR19). The total length of the Contract E2 is approximately 2.7 km. The location and of MRT Orange Line Project, is presented in Fig 1.

For underground construction and tunnelling works, ground improvement by jet grouting technique is commonly implemented in various aspects to solve geotechnical problems e.g. base grouting for deep excavations, protection of the existing structures adjacent to a new tunnel construction and grouting block for launching and receiving of shield machines. Basically, the jet grouting procedure consists of the disaggregation of the soil and partial replacement by a cement agent [1]. It is mainly used to improve the mechanical properties and water tightness of soil and also minimize disturbance to the neighboring structures near the construction site such as piled foundation of infrastructures, drainage culvert and underground utilities [2].

Along the project alignment, a precast segmental tunnel of each tunnel consisting of five segments and a key segment with 6.3 m outer diameter, 5.7 m inner diameter, 0.3 m thickness, and 1.4 m width, is excavated using three Earth Pressure Balance (EPB) shield machines. These EPB-TBMs manufactured by Kawasaki Heavy Industry have 6.58 m diameter and 9.615 m length.

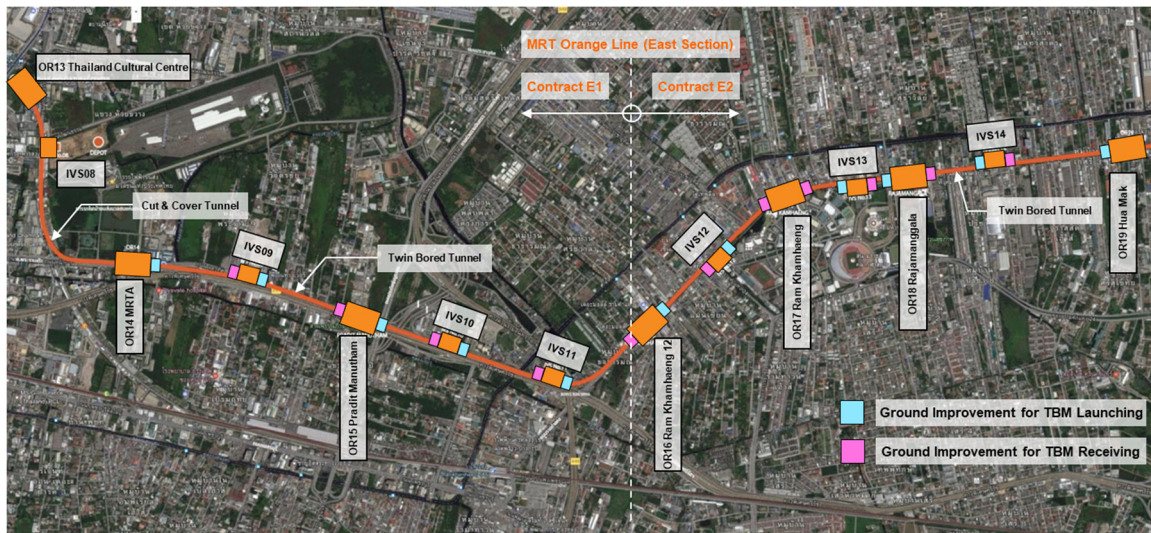


Figure 1 General overview and ground improvement zone for launching and receiving of shield machine

In general, the EPB shield machine uses excavated soils to provide a support (face pressure) to stabilize the ground and control the excessive ground movements. However, when the TBM is approaching to the stations or the intervention shafts (arrival of TBM or TBM Break-in), the TBM face pressure has to be gradually decreased in order to mitigate the impact on diaphragm wall. In this case, the TBM is not able to maintain earth and water pressures and this may lead to potential risks of soil collapse and massive water inflow inside the TBM and the station box. In case of TBM launching (TBM Break-out), the excavation chamber can only be partially filled and the operation of TBM face pressure cannot be fully applied. [3]

As aforementioned, the zone of launching and receiving of the TBMs at stations and intervention shafts, the soil is certainly required to be improved to ensure the safe construction, to reduce the potential of soil instability and to avoid any water ingress.

Therefore, this paper aims to present a design criteria of ground improvement and some practical details which involves the launching and receiving of shield machines for MRT stations.

## 2. GEOLOGICAL AND HYDROLOGICAL CONDITIONS

The geology of Bangkok is relatively uniform throughout the entire area. The uppermost first layer is fill material. The second layer is very soft clay layer

overlying on the medium stiff clay. The 1<sup>st</sup> stiff clay layer is presented as the fourth layer. The 1<sup>st</sup> sand layer is then found below the 1<sup>st</sup> stiff clay which the SPT N-value is in the range of 30 to 50. Geotechnical parameters are taken based on Geotechnical Interpretative Report (GIR) are represented in Table 1.

Table 1 Geotechnical parameters

Soil description	$\gamma_t$ (kN/m <sup>3</sup> )	$S_u$ (kPa)	$c'$ (kPa)	$\phi'$ (°)
Fill material	18.5	25	0	25
Soft clay	15.5	15-25	0	22
Medium stiff clay	17.0	30-35	5	23
1 <sup>st</sup> Stiff clay	19.0	55-120	5	24
1 <sup>st</sup> Sand	21.0	-	0	35

where  $\gamma_t$  is unit weight,  $S_u$  is undrained shear strength,  $c'$  is effective cohesion, and  $\phi'$  is effective friction angle.

A typical groundwater pressure profile in Bangkok is a piezometric drawdown due to the effect of pumping in the past. The current piezometric pressure head is observed at about 13 m below the ground surface [4].

For the tunnel route, the ground overburden above the tunnels varies from 8 to 30 m and the almost tunnel alignment is running beneath the water table. A typical soil profile and piezometric pressure is shown in Fig 2.

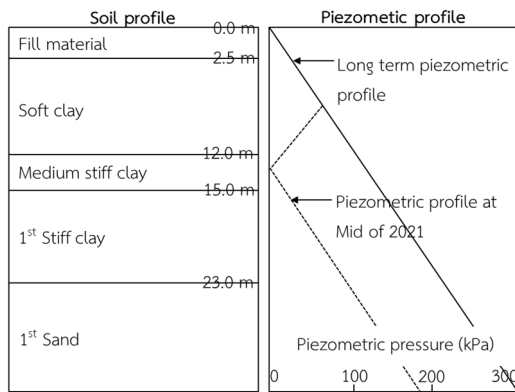


Figure 2 Typical soil profile and piezometric profile

### 3. DESIGN CRITERIA OF GROUND IMPROVEMENT

The calculation of ground improvement for launching and receiving of TBM is based on the recommendations of the Japanese Jet Grouting Association (JJGA) [5]. This guideline gives information about the activity lists in design and construction for jet grouting such as site investigation, design purposes, jet grouting execution, monitoring, and acceptance criteria. Two conditions to be calculated consisting of improved length and improved section. Designed parameters for ground improvement is presented in Table 2. It should be noted that the unit weight of ground improvement is considered to be the same as the original soils. Furthermore, a safety factor ( $F_s$ ) of 1.5 is suggested involving a temporary work condition.

Table 2 Ground improvement parameters

Soil condition	Sandy soil	Cohesive soil
Unconfined compressive strength, $q_u$ (MPa)	3	1
Cohesion, $c$ (MPa)	0.5	0.3
Adhesive force, $f$ (MPa)	1/3c	
Bending tensile strength, $\sigma_t$ (MPa)	2/3c	
Modulus of deformation, $E$ (MPa)	300	100

#### 3.1. IMPROVED LENGTH

The length of ground improvement section is mainly dependent of natural ground conditions, depth of tunnel and groundwater condition. Three criteria need to be

calculated and the maximum value will be used to provide the length of jet grouting zone.

##### 3.1.1. BENDING STRESS

The improved length is considered to resist bending stress induced by soil and water pressures acting in front of the excavation face (Fig 3).

$$t_1 = F_s \sqrt{\frac{1.2 \cdot W \cdot R^2}{\sigma_t}} \quad (1)$$

$$W = P_a + P_w \quad (2)$$

where  $W$  is pressures acting on ground improvement,  $P_a$  is active earth pressure,  $P_w$  is water pressure, and  $R$  is excavation radius.

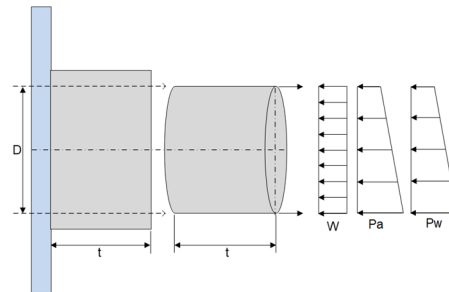


Figure 3 Improved length – bending stress

##### 3.1.2. PUNCHING SHEAR

The improved length is considered to resist punching shear induced by soil and water pressures acting in front of the excavation face (Figure 4).

$$t_2 = \frac{F_s \cdot W \cdot S}{L \cdot c} \quad (3)$$

where  $W$  is pressures acting on ground improvement,  $S$  is section area,  $L$  is perimeter of section, and  $c$  = cohesion of improved soil.

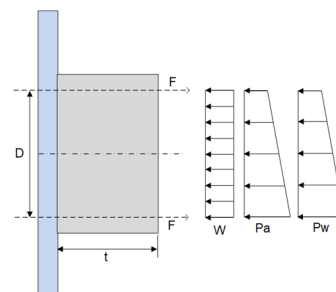


Figure 4 Improved length – punching shear

### 3.1.3 ARCH SLIDING

The calculation of this case is based on an arc sliding along the radius of the opening, the sliding moment is to be resisted by adhesive force of the improved body. The improved length can be calculated from the balance moments around point *O* (Fig 5).

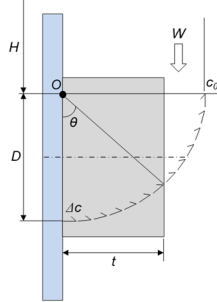


Figure 5 Improved length – arch sliding

- Driving moment,  $M_d$

$$M_d = M_{d1} + M_{d2} \quad (4)$$

$$M_{d1} = \left( \sum_{i=1}^n (\gamma_{ti} \cdot h_i) + q \right) \cdot D \cdot \frac{D}{2} \quad (5)$$

$$M_{d2} = \gamma_t \cdot \frac{\pi D^2}{4} \cdot \frac{4}{3\pi} \quad (6)$$

- Resisting moment,  $M_r$

$$M_r = \frac{c\pi D^2}{2} \quad (7)$$

- Increased Resisting moment,  $\Delta M_r$

$$\Delta M_r = \Delta c \cdot \theta \cdot D^2 \quad (8)$$

$$\Delta M_r = M_d - M_r \quad (9)$$

- Improved length,  $t_3$

$$\theta = \frac{Fs \cdot M_d - M_r}{\Delta c \cdot D^2} \quad (10)$$

$$t_3 = D \sin \theta \quad (11)$$

### 3.2 IMPROVED SECTION

The improved section of the ground improvement including top thickness, side thickness and bottom thickness should be also indicated prior to construction as represented in Figure 6. A minimum value recommended by JJGA is shown in Table 3. However, the value that

commonly adopted in this project which is based on past experience associated with the MRT projects is in ranges of 2.0 to 3.0 m or equivalent to 0.3D - 0.5D depending on geological conditions.

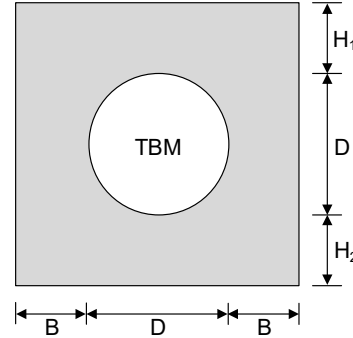


Figure 6 Improved section dimensions

Table 3 Minimum dimensions of ground improvement block [1]

$D$ (m)	$D < 1.0$	$1.0 \leq D < 3.0$	$3.0 \leq D < 5.0$	$5.0 \leq D < 8.0$
	$B$ (m)	1.0	1.0	1.5
$H_1$ (m)	1.0	1.5	2.0	2.5
$H_2$ (m)	1.0	1.0	1.0	1.5

However, the improved section of the ground improvement is necessary to be verified by a method derived from the concept based on the additional stress (plastic region) generated around a tunnel excavation as follows (Fig 7);

- Top thickness,  $H_1$

$$\ln R + \frac{R\gamma_t}{2c} = \frac{H\gamma_t + q}{2c} + \ln r \quad (12)$$

$$H_1 = Fs(R - r) \quad (13)$$

- Side thickness,  $B$

$$\beta = \cos^{-1} \frac{r}{r + H_1} - \left( 45^\circ - \frac{\phi}{2} \right) \quad (14)$$

$$B = (r + H_1) \cos \beta - r \quad (15)$$

- Bottom thickness,  $H_2$

In case of groundwater pressure below the excavation region is not greater than 0.2 MPa, minimum thickness according to table 2 shall be adopted. While the ground water pressure is higher than 0.2 MPa, the bottom thickness should be increased to the side thickness.

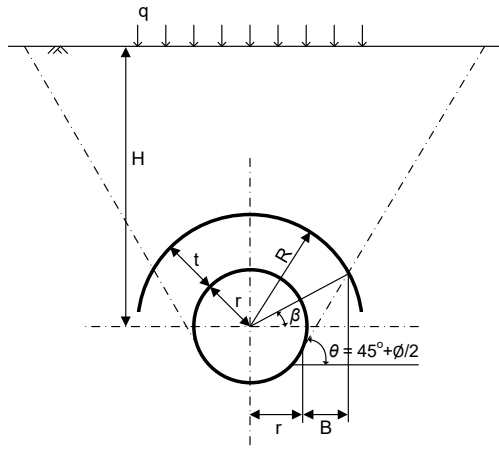


Figure 7 Plastic region around tunnel excavation

#### 4. UTILIZATION OF GROUND IMPROVEMENT

The longitudinal section of grout treatment block for TBM launching and receiving at one of the stations in this project is presented in Fig 8. A tunnel is fully located in the 1<sup>st</sup> sand layer which the depth from ground surface to the tunnel axis is about 29.2 m. Based on the calculation and guideline, design dimensions of ground improvement can be summarized in Table 4.

The dimensions of ground improvement section for launching and receiving of TBMs are represented in Fig 9. Top thickness, side thickness, and bottom thickness of 3.0 m is applied for both portions.

For TBM launching work, the length of 4.5 m for ground treatment block to prevent soil failure and water ingress derived from the calculation regarding to JJGA is employed as shown in Fig 8. In addition, an apparatus “seal ring”, which widely used in tunnelling practice, is also implemented between diaphragm wall and the TBM as presented in Fig 9. It is composed of a ring structure, a sealing flange and a rubber seal. This structure is installed to limit the inflow of encountered materials and groundwater through the annular gap between a cutter head and a shield body.

On the other hand, the length of ground improvement of TBM receiving at the station is significant larger. As a TBM cutter is larger than a shield body, there is a potential evident of soils and water inflow inside the station box through the gap induced by overcut. Principally, when the cutter face of the TBM is closed to the diaphragm wall and the tail skin is fully embedded in the ground

improvement zone, the gap must be filled by tail void grouting (primary grouting) immediately prior to TBM breakthrough the station. Consequently, ground improvement length for this part needs to be extended from the minimum requirement to 11.5m corresponding to a total length of TBM with one ring of tunnel lining.

Prior to commencement of jet grouting works at specified location, a pre-condition survey is carried out to determine the feasibility of the proposed arrangement. The jet grouting method utilized in these zones is a double-fluid jet grouting system. After the completion of grouting, core drillings are essential to be conducted to examine the quality and strength of the cored samples by the unconfined compressive strength test and it shall meet the design requirement as specified in Table 2. Additionally, horizontal probe drillings shall be made inside the treated ground in order to evaluate the efficiency of the grout plug (Fig 13). Finally, the successful break-in of a TBM during the construction of one stations of Orange Line (East Section) Project is presented in Fig 14.

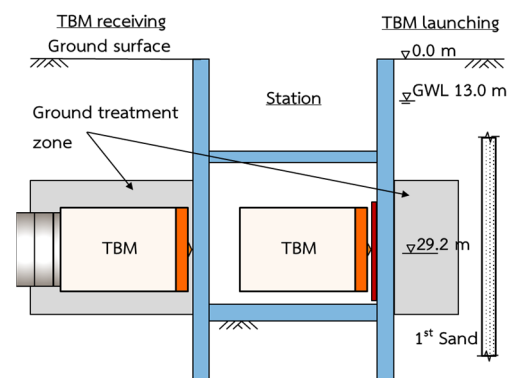


Figure 8 Longitudinal section

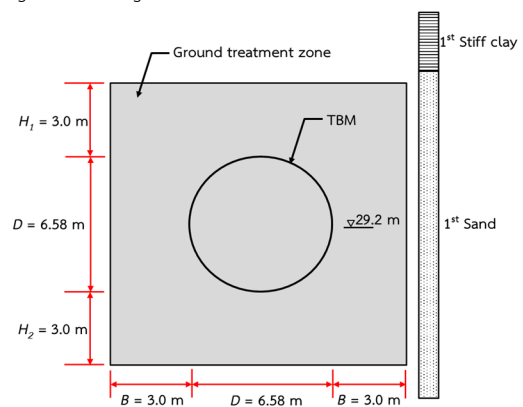


Figure 9 Section of ground improvement for TBM launching & receiving

Table 4 Design dimensions of ground improvement block

Case	Calculation	Minimum requirement	Design (m)	
			Launching	Receiving
Length	Bending stress, $t_1$	4.5		
	Punching shear, $t_2$	1.7	4.5	10.5
	Arc sliding, $t_3$	4.2		
Section	Top thickness, $H_1$	2.0	3.0	3.0
	Side thickness, $B$	1.6	3.0	3.0
	Bottom thickness, $H_2$	2.0	3.0	3.0

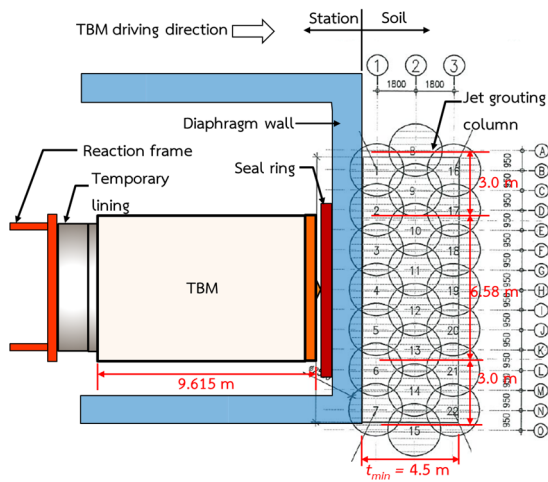


Figure 10 Plan of ground improvement for TBM launching

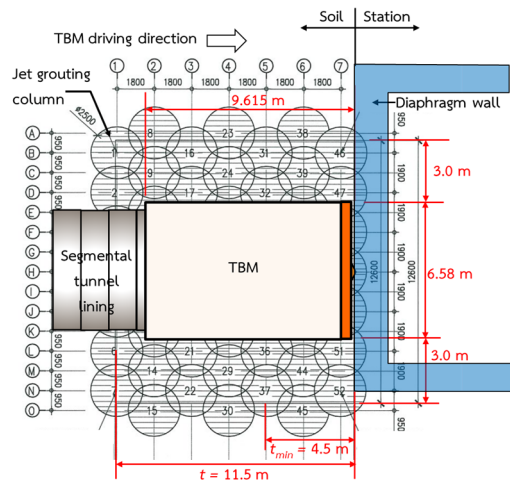


Figure 12 Plan of ground improvement for receiving



Figure 11 Preparation for TBM launching work



Figure 13 Horizontal probe



Figure 14 TBM break-in during the construction of MRT Orange Line Project

## 5. CONCLUSIONS

This paper reveals the application of ground improvement for launching and receiving of shield machines for the MRT Orange Line Project. Utilization of the jet grouting technique is to enhance soil properties and to minimize the impact of high underground water. The Design concepts, material properties, suitable dimensions, a construction method and verification of the ground improvement block related to various geological conditions are crucial factors, which can contribute significantly to a safety during construction and successful construction projects.

## 6. ACKNOWLEDGMENTS

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