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RESEARCH ON LAUNCHING TECHNOLOGY OF SHIELD TUNNEL IN HO CHI MINH METRO LINE 1

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The use of subway tunnel engineering technology has become more professional and refined with the growth of society and the advancement of science and technology. The initial construction process of a subway tunnel shield is the most critical part of the entire engineering system. Shield launching period construction is the most prone to accidents in the shield construction process, directly related to the smooth through the shield tunnel. The line 1 of Ho Chi Minh (HCM) Metro is the first subway line, the full length of 19.7 km, the underground road length of 2.6 km from km 0 + 615 to km 2 + 360, from Ben Thanh market, and then through the Sai Gon river and 14 station (including 3 underground stations and 11 elevated stations), reach Suoi Tien park and is located in Long Binh area station, underground building blocks including Ben Thanh market station to Opera House station interval, Opera House station, Opera House station to Ba Son station interval. This paper selects Shield launching period of Opera House station to Ba Son shaft interval as an example, analyze the key construction technology, construction control parameters and launching considerations of shield machine.

Keywords**:** HCM Metro Line 1, shield machine, launching shaft, soil improvement, precipitation, soft eye

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1. INTRODUCTION

The Subway tunnel is a relatively large part of the current investment in urban traffic intervals, but its project requires not only capital chain support, but also technology under suitable conditions. Subway tunnels are usually built in sections with a large number of busy people or the surrounding terrain is not easy for ordinary highways to construct [1]. Therefore, from the aspects of geology and terrain conditions, the construction of subway tunnels is more difficult than other traffic sections. The initial construction technology of shield tunneling is the most important link in the application of subway tunnel engineering technology. The complexity of building is significantly reduced on the basis of such construction technology.

The shield launching of shield tunneling means that the shield tunneling starts from positioning of the shield host in the shaft of installation or shaft of passing station. The cutter head pushes forward and penetrates into the soil, driving forward along the design line until conditions for removing the temporary segment are met. In the launching stage of shield tunneling, installation and debugging of shield tunneling equipment, installation and positioning of auxiliary equipment, initial positioning and tunneling control of shield tunneling, installation and debugging of shield tunneling guidance system and lastly treatment of tunnel openings were required. Engineering construction cases at home and abroad have shown that the tunnel launch segment is one of the most vulnerable areas for shield construction issues [2-5].

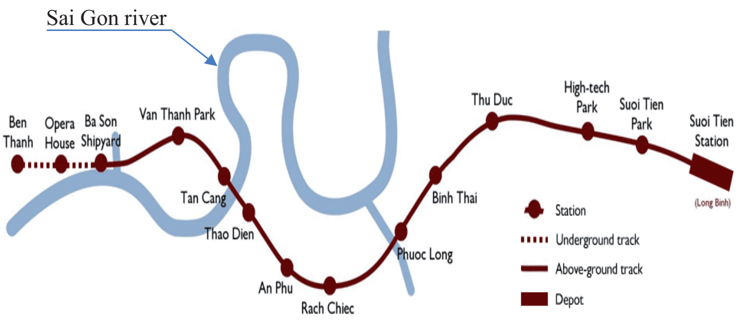

Fig.1 Map of Ho Chi Minh metro line 1 in Vietnam

The first phase of the project, Ho Chi Minh City Rail Transit Line 1 (HCMC MRTL1), is an important inter-town skeleton line linking the railway network from Ben Thanh to Suoi Tien in Ho Chi Minh City, and is also an important passage through Ho Chi Minh City for passenger transport. This line is completed will be deemed to be "Vietnam civil transportation of a great leap forward". Planners expect the route to serve more than 160000 passengers daily upon launch, increasing to 635000 by 2030 and 800000 by 2040. All stations along the route are expected to accommodate the disabled, with automatic ticket vending machines, telephone booths, restrooms, subway doors and information bulletins accessible to the handicapped and visually impaired [6]. It is expected that the daily operation time of this line will be 20 hours, and the interval time of vehicles will be 5 minutes, an end-to-end time of around 29 minutes [7]. The opening of HCMC MRTL1 is expected to ease traffic pressure in Ho Chi Minh City. The project schematic diagram is shown in Figure 1 [8].

2. PROJECT PROFILE

This project is Opera House station ~ Ba Son station section of HCMC MRTL1 underground construction section. The interval tunnel has an outer diameter of 6650mm and an inner diameter of 6050mm [9]. This tunnelling was carried out by an Earth Pressure Balance (EPB) Tunnel Boring Machine (TBM) [10] from Japan Tunnel Systems Corporation (JTSC), with an outer shield body and cutter head diameter of 6790 mm and 6780 mm, respectively [11-14].

The formation parameters mainly located between Opera House station and Ba Son station in the underground construction bid section of Ba Son station are shown in Figure 2 [14].

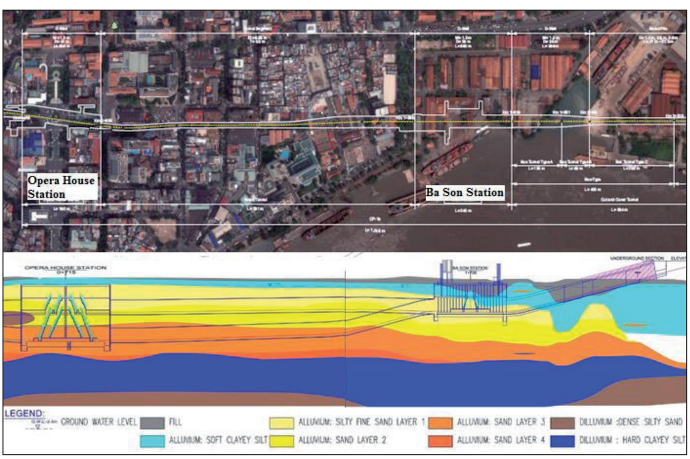

Fig.2 Subsoil condition of underground section

From the study of Boring log and soil sections (Geotechnical report for Line 1 Ben Thanh-Suoi Tien, package's underground, 3-2009), subsurface materials along the vicinity of project site are classified as fill; alluvium & diluvium [10, 14].

Soil layers, however, are summarised as follows: fill (Silty Sand, Clayey Silt etc.), alluvium (Soft Clayey Silt, Silty Fine Sand Layer 1, Sand Layer 2, Sand Layer 3, Sand Layer 4), diluvium (Hard Clayey Silt, Silty Sand Dense).

Subsoil material in this region of Ho Chi Minh City is mainly constituted from alluvial deposits above approximately 30.00m ~ 40.00m [10] from the accumulation of particles carried and deposited by the Saigon River. Ground levels along the route of the alignment are fairly flat, as is typical of most of the urban area of Ho Chi Minh City. Levels are generally around +1,5m to +2,5m. Another aquifer lies in the sandy clay layer 40 m below ground level [14]. During the geological survey along the project the piezometers were installed for ground water observation. The ground water condition is hydrostatic from 2.5m to 4.0m below ground surface level [14]. Location of Ba Son area is right adjacent to Saigon River, so the underground water level is affected by tide so much.

3. KEY CONSTRUCTION TECHNOLOGY

The launching operation series of shield tunnel were divided into three stages: before launching work, launching work and test section operation, as shown in Figure 3.

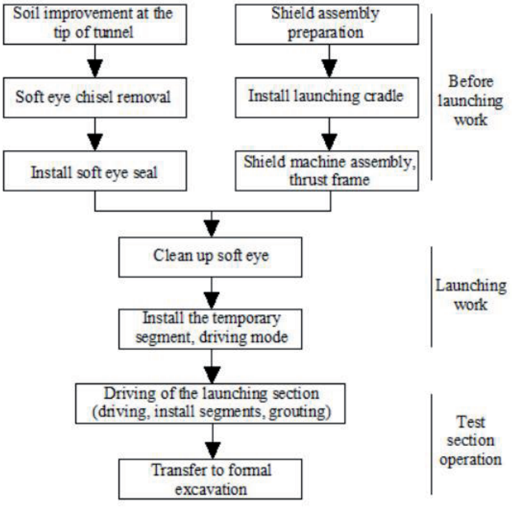

Fig.3 Process launching of Shield flow diagram

3.1. BEFORE LAUNCHING WORK

3.1.1. SOIL IMPROVEMENT, SOFT EYE INSPECTION, LAUNCHING SHAFT PRECIPITATION

The shield launch was a major danger source for shield tunnelling, and incidents such as water gushing and sand gushing and the instability of the tunnel frequently occur, so that changes should be made at the tip of the tunnel soil. The soil improvement at the tip of tunnel of the project were achieve the following effects: 1) The soil mass after improvement has good uniformity and independent stability, and the soft eye was tested for the effect of no flowing water and quicksand. 2) The unconfined compressive strength of the reinforced soil was above 0.6Mpa. 3) Permeability coefficient $\leqslant 1.0\times10^{-7}$cm/Sec can prevent underground confined water from entering the excavation surface (Testing standard: ASTM D2166 and ASTM D5084) [15,16].

High pressure jet grouting pile construction occupies less land, that has low vibration, low noise, fast construction and reasonable cost [17-19], so it was selected as the soil improvement method of this project. The East-end of Ba Son railway station was reinforced with 3500@2300×2750 triple pipe high pressure jet grouting pile, with a reinforcement range of 10.7×11.13×17.3m, as shown in Figure 4 and Figure 5.

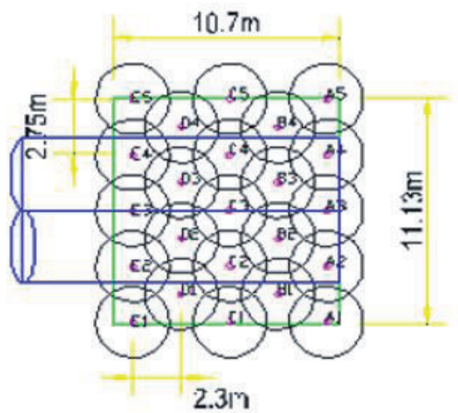

Fig. 4 Location and layout of jet grouting pile

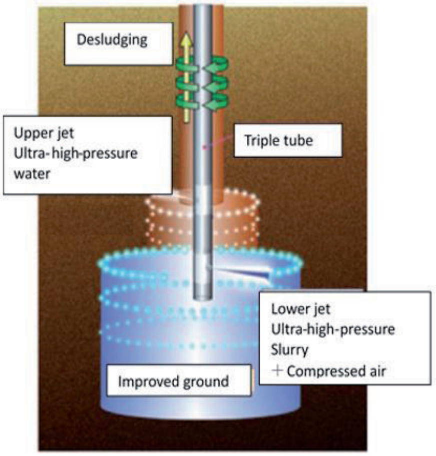

Fig.5 Schematic diagram of Jet grouting

Fifteen horizontal holes were drilled and water leaks were tested within the soft eye region while three vertical holes were randomly drilled within the region of soil improvement, cores were extracted with a core strength, uniformity and water content were analysed. Often, before the soft eye can be broken, a solid is inserted to fulfil the design specifications.

In the process of shield machine launching arrive in soft soil such as silt and silt, lowering the water level at the tip of tunnel can effectively reduce the occurrence of water leakage and sand gushing in the soft eye, and the cost was lower than other measures, such as increasing the water-stopping curtain, adjusting the soil improvement method at the tip of tunnel and enlarging the soil improvement range at the tip of tunnel [20-21].

According to the engineering geological conditions of the Ba Son station and similar to the characteristics of the Saigon river, the well precipitation will be shielded, the water level will be lowered outside the foundation pit below to the soft eye at the bottom to ensure soft eye break and shield launch restrictions when it is secure and safe.

3.1.2. INSTALL LAUNCHING CRADLE, SHIELD ASSEMBLY MODE, INSTALL THRUST FRAME

The shield length of Japan Tunnel Systems Corporation (JTSC) shield machine was up to 8.5m (Tip of Fish Plate~Tail End) [10]. The launching cradle, divided into three parts with a total length of 12.45 m, was used to help the shield machine to successfully mount and launch the shield machine, as shown in Figure 6 and Figure 7.

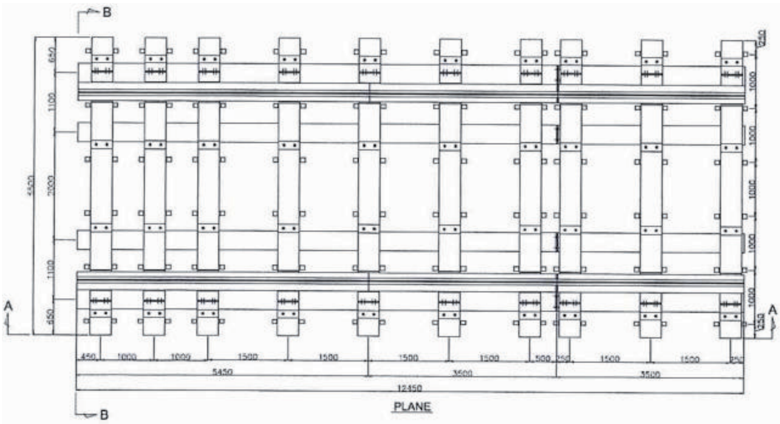

Fig. 6 Plane view of launching cradle

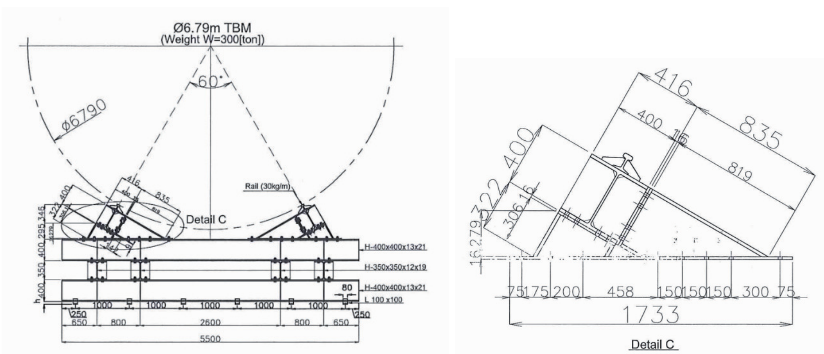

Fig. 7 Cross section of launching cradle

The sequence of shield machine platform down the well were: launching cradle →laying track→ battery car→No.5 platform of shield machine→No.4 platform of shield machine→No.3 platform of shield machine→No.2 platform of shield machine →No.1 platform of shield machine→bridge frame → screw conveyor → dismantle the track above cradle.

In the process of shield launching, the support of thrust frame played an important role. The setting environment of initial thrust support were roughly divided into two types: one was the launching well and the other one launching at the station. The project were launching in the station. The form of thrust frame were shown in Figure 8.

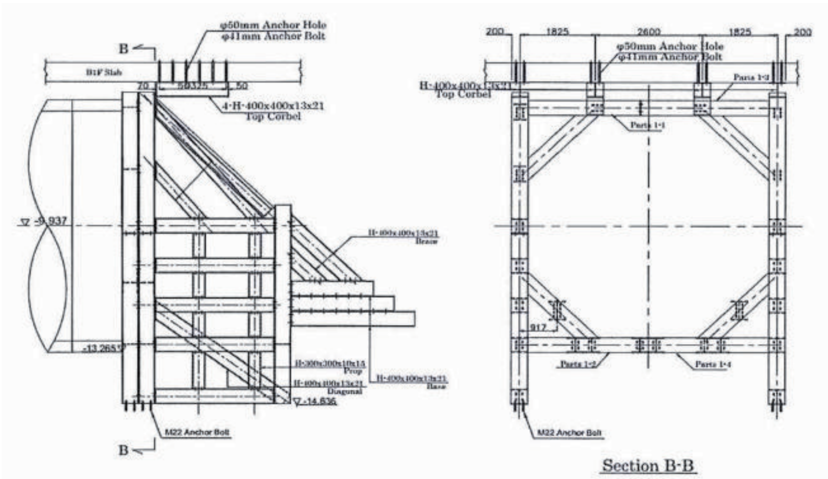

Fig. 8 Schematic diagram of thrust frame installation

3.1.3. SOFT EYE SEAL INSTALLATION, SOFT EYE CHISEL REMOVAL

The soft eye was sealed with rubber seal and retainers. At first Installation of entrance ring, the ring shall be lifted up by two chain blocks and one mini-crane simultaneously. The entrance ring is fixed temporarily and checked to ensure correct position by surveyor, adjusted if required. The entrance ring is fixed on diaphragm wall as closely as possible for reducing gap between ring and wall.

Drilling and setting chemical anchor bolt: M20 chemical bolt pitching 4.5^0 is designed according to drawing of entrance ring. Accord with technical data of Hilti RE-500, 24mm diameter and 170mm depth of drilling hole is used for M20 chemical bolt.

Sealing gap: Gap between diaphragm wall and tunnel eye will be sealed by non-shrink cement mortar. This is to prevent leakage of water/sand or grout through the gap during Shield Machine launching and backfill grouting operation.

Casting concrete out of entrance ring: The temporary concrete (24Mpa) is built to safeguard the entrance ring. The thickness of the concrete is the same as the the width of entrance ring, 500mm. Although, placing concrete is twice. The first concrete for casting is from B2F to the tunnel core. The second casting concrete is 250mm from the tunnel core to the elevation below the bottom of the B1 slap. The gap 250mm shall be fill up by grouting by non-shrink cement mortar through 02 holes Ø50mm on B1 slab.

Installation of rubber seal and retainers: rubber seal will be lifted up by chain block and installed on main frame. The 9mm retainer-1 is bolted between retainer-2 and rubber seal for avoiding leakage from rubber and frame of entrance ring. The sequence of rubber seal and retainers installed and are shown as Figure 9. Flappers of entrance ring shall be swayed up and greased for protection.

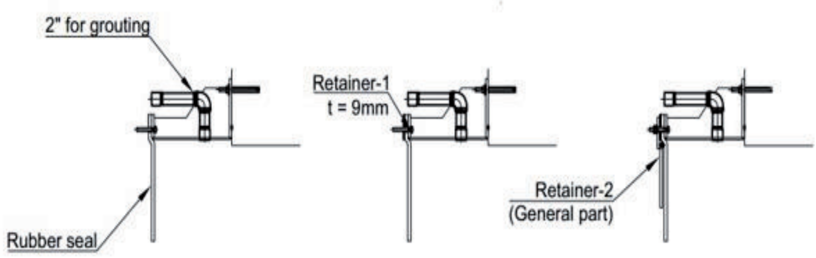

Fig. 9 Schematic diagram of Seal of soft eye

The type of the retaining structure of the soft eye was 1000mm thick underground diaphragm wall. The excavation of the soft eye was carried out manually by using a pneumatic pick. The excavation sequence of the soft eye was carried out in strict accordance with the figure, as shown in Figure 10.

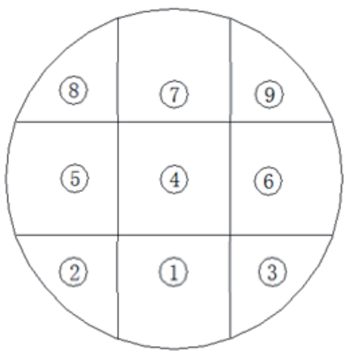

Fig. 10 Cut block of soft eye

Initial breaking of DW: The sequence of breaking is from bottom to top. The first step is removing cover of diaphragm wall to expose inner rebar layer, then cut inner rebar. The second step is to break concrete about 40cm where broken face and record are monitored every day during breaking, grouting if water leakage exceeds 100 ml/min.

Final breaking of DW: The sequence of breaking is from bottom to top. Breaking diaphragm wall concrete to reveal the outer rebar layer, and cutting the outer rebar layer. The central area of breaking area (diameter around 1.1m and depth around 0.45m) will be broken for fish plate of Shield Machine.

After diaphragm wall broken completely, all follow-up works shall be done as soon as possible to reduce risk.

3.2. LAUNCHING WORK

Clean up of the soft eye: after the completion of the installation and debugging of the shield tunneling machine, the shield tunneling machine were pushed to 1.0m away from the soft eye. Then quickly clean the soft eye.

Assembly of propelling and temporary segments rings: the shield machine initially installed 8 temporary segments rings (all of which were closed loop segments) between the thrust frame and the official segment in the tunnel eye. The number of segments of each temporary segment was the same as that of the standard segment, and they were placed on the bracket in turn, as shown in Figure 11.

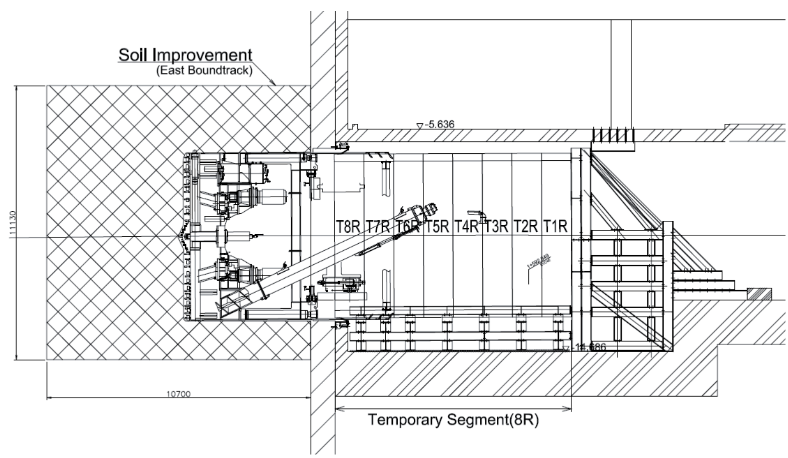

Fig. 11 Location map of temporary segment rings

The outer side adopts steel wire drawing knot, and when necessary, the temporary segment rings tube piece can be fixed by means of wooden wedge on the triangular support of the launching frame, so as to ensure that the tube piece was not float and shift or produce side rolling phenomenon in the process of transferring thrust. Assemble the T1R ring before the shield launching, then jack the T1R toward thrust frame and erect T2R, jack T1R and T2R and bolt to thrust frame. After cleaning the soft eye, jack shield machine toward Dwall and erect T3R and T4R, the T5R ring was pushed forward, and the T5R ring was assembled when the cylinder stroke of shield was pushed up to 1900mm. The T5R ring was driven for 150 minutes (Shield machine shall start excavate the soil improvement area from T5R), and the segment was assembled for 40 minutes, that takes 190 minutes to advance from T5R ring to T6R ring. These operations continue until ring T8R and then proceed to the test section.

3.3. TEST SECTION OPERATION

At the initial stage of the project, the tunneling length was set as 84m (70R) as the test section (In other projects, before 100 ring are usually provisions as the test section). The following factors were mainly considered:

(1) Length of shield machine and rear trolley.

(2) The need to arrange double line switch in the working well.

(3) The friction between the segment and the soil were sufficient to support the normal driving of the shield machine.

Taking the first 84m as the driving test section, the following objectives were achieved by setting up the test section:

(1) Master the adjustment and control methods of various parameters of shield driving in the strata in this interval.

(2) Measurement and statistics of thrust and torque under different formation conditions; The control characteristics of attitude of shield machine; Selection of grouting parameters and optimization of slurry ratio; Problems and solutions in synchronous grouting; Adaptability of various cutting tools.

(3) Based on this, timely and detailed analysis were made on the formation displacement law and structural stress condition under various propulsion parameters in different strata, as well as the influence of construction on the ground environment, and timely feedback and adjustment of construction parameters.

4. CONSTRUCTION PARAMETER CONTROL

4.1. LAUNCHING CONTROL OF SHIELD MACHINE

Launching attitude of shield: when shield was launching, its hinge angle was zero. The axis of shield center coincides with the tunnel design center line, and it was usually raised upto 20mm along the vertical direction.

Shield attitude control before leaving the launching cradle: shield before leaving the launching cradle along the scheduled starting basic path straight line, through the choice of advancing jack when necessary to shield posture to make minor adjustments, during this period of shield must cut their burrows and solid, with slow, low earth pressure for propulsion principle in order to ensure the stability of the shield posture (Soil improvement area shall be driven through after 5R). The thrust speed of shield was controlled within 8mm/min, and the rotary speed of cutter head was controlled below 0.9rpm.

Attitude control after the shield machine leaves the base: the shield tail has been in a relatively free state after leaving the base support structure. The attitude of the shield were adjusted through the reasonable selection of the shield propulsion jack, and when necessary, the hinge function was used to adjust at the same time, so that the shield was gradually pushed along the tunnel design axis. In the launching stage, due to the small thrust of the shield tunneling machine, in order to prevent the phenomenon of "kowtow" of the shield tunneling machine, the lower side jack is used to push forward while adding upward torque. The advance speed of the 6-ring backing structure can be gradually increased to within 10~25mm/min, and the rotary speed of the cutter head can be controlled at 0.9rpm. During this period, ground monitoring measurement and manual recheck measurement of tunnel construction were strengthened, and various parameters was adjusted accordingly.

4.2. LAUNCHING ESTABLISHMENT OF SOIL PRESSURE

In order to reach the equilibrium condition of soil pressure after the cutter disc cuts into the soil, the soil pressure was established after entering the soil improvement area. The earth pressure calculated according to rankin's principle ranged between 0.05 and 0.10Mpa. As it was in the launching position, the earth pressure were set between 0.15 ~ 0.25Mpa in order to prevent the occurrence of water gushing and sand gushing and take into account the integrity of the seal of soft eye.

4.3. SOFT EYE SEALING SLURRY

After the sealing of the exposed shield of the one ring was completed, the grouting operation started. Completely closed soil to prevent soil erosion and land subsidence.

5. NOTES FOR LAUNCHING SHIELD MACHINE

(1) Shield seal brush and advance grouting hole were coated with shield tail seal grease.

(2) The shield launching slowly. As the equipment was running-in stage, the control of thrust and torque were paid attention too, as well as the effective use of grease in all parts. The total driving thrust were controlled below the bearing capacity of the thrust frame (Loading acting on thrust frame:

24000kN, Shield Machine self-weight: 3000kN), while ensuring that the torque generated by cutting tool cutting into the formation under this thrust was less than that provided by the launching frame.
(3) The tool head was applyed by grease and sealing device before launching to avoid damage to the soft eye sealing device. Also oil was applyed to the base before launching to reduce the thrust resistance of shield.
(4) The starting frame's guide rail was straight, the elevation, spacing and central axis were strictly controlled and the end face of the reference ring was perpendicular to the middle line of the line. After the installation of the shield machine, the attitude of the shield machine was re-measured before it was sent out.
(5) Prevent shield from rotating and floating up. When the shield was drived into the tunnel eye, the soil was strengthened with higher strength on the front. Because there was no friction between the shield and the stratum, the shield was easy to rotate, so the attitude control of the shield was strengthened. If it was found that the shield has a large angle, was adjusted by adopting the measure of positive and negative rotation of the big cutter disc. When the shield was just entering the tunnel eye, the driving speed were slow. Water was added to the soil to reduce the frontal pressure of the shield when the blade was cutting the soil, so as to prevent the shield from floating up. Meanwhile, observations on the backing support were strengthened to improve the backing steel support as much as possible. Weld the torsion-proof device on the lower half of the shield tail near the track of the launching frame, and cut off the torsion-proof device before the ear shield tail enters the curtain after the cutter disc completely enters the soil.
(6) In the launching stage, due to the small thrust and soft formation of the shield machine, the attitude of the shield machine was adjusted, and the lower side jack was used to add the upward torque while pushing forward to prevent the shield machine from kowtowing.

6. CONCLUSION

(1) To sum up, the initial shield design phase is the most significant component of the entire engineering system. In the meantime, the initiation of test tunnelling and other shield steps are critical starting points for the rapid and secure development of shield connections in subway tunnels.
(2) Shield launching construction is the key stage in the process of shield construction, due to its boundary condition is different from normal shield tunneling and prone to accidents. However, as long as the characteristics of the launch method can be fully understood, it is important to fully demonstrate the applicability, protection and economy of the various methods according to the actual

conditions of the project prior to construction and to choose the required method. Strengthening construction management and process control in the construction process to ensure the construction quality of each link can basically avoid engineering accidents.

(3) The launching success of shield machine was mainly determined by the launching conditions and construction technology. In the early stage of engineering geological exploration, engineering hydrology exploration and so on put forward accurate parameters; At the same time, comprehensive and meticulous control were strengthened in every link of the launching technical construction to ensure that various treatment measures meet the technical requirements.

(4) Before the shield machine launching from Ba Son station to Opera House station in the underground construction section of HCM MRTL1, the project Department actively responded to the NK-JARTS-PBJ-JRC-JTC-TEC-TEDI South-TRICC (NJPT Association)'s "Acceptance of Shield Machine Launching Conditions", the provisions of the combination with the engineering geological condition and equipment status, formulated a series of specific measures, from the technical preparation, personnel selection, type selection of shield, site layout, foundation reinforcement, on-site safety civilization construction to shield from initial field drill take positive aspects such as a large number of preparatory work, to ensure the safety of shield originating and smoothly.

(5) The application of this technology in the project of Ho Chi Minh Metro Line 1 proves the rationality and feasibility of this technology and provides reference for similar projects in the future. In future work, it will for Soft Clayey Silt, Silty Fine Sand, Silty Sand Dense, such further explore and study the construction parameter control under different geological conditions, in order to improve the tunneling efficiency and make the shield tunnel starting technology studied in this paper more practicality.

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LIST OF FIGURES AND TABLES:

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