Meta Description: Shield Tunneling Procedures by air-cushioned slurry balanced shield tunneling

Shield Tunneling: Air-Cushioned Slurry Balanced Shield Machine

Shield Tunneling:

A tunnel is an underground passageway, dug through the surrounding earth and enclosed except for entrance and exit. The first tunneling shield was developed by Marc Isambard Brunel in January 1818 beneath the Thames River in London. The Bangabandhu Tunnel Project under the Karnaphuli river is designed as a single layer 4-lane dual-carriageway with two shield tunnels.

Tunnel Boring Machine(TBM):

The Tunnel Boring Machine (TB) used during the excavation works for the Tunnel construction under Karnaphuli River is air-cushion slurry pressure balanced shield machine, manufactured by Tianhe Mechanical Equipment Manufacturing Company Limited (CCCCTH). The diameter of the Cutterhead was 12.12m with a 13.6m long shield section.

The manufacturing of the TBM used for the tunnel was initiated in March 2017 by preparation of drawing of cutterhead, shield skins, erector, trolly structure, segment handling system and segment feeder and piping plan for the main body. The full design was finalized at the end of July 2017. The order for the manufacturing of this slurry shield TBM was placed in April 2017 by CCCC during the design stage of the Project. The production stage was 120 days from the middle of May 2017 after the purchase of plates for the main body. It took 100 days more for the assembly, commissioning and factory acceptance test up to end of December 2017

The main components of the TBM are the followings:

- Shield Body (front, middle and tail shield)
- Cutters & Copy cutter
- Drive System
- Grease & Lubrication System of Main Bearing
- Agitator
- Air Pressure Control System of Air Chamber
- Propulsion System
- Segment Erector
- Cooling Water System
- Waste Water Discharge System
- Slurry Transportation System
- Man-lock
- Pipeline extension System
- Synchronous Grouting System
- Segment Storage & Transportation
- Secondary Grouting System
- Air Compressing System
- Industrial-Controlled Compressor System
- Emergency Generating Set
- Main Ventilation System
- Auxiliary Ventilation System
- Guidance System

Shield Machine Assembly Scheme:

Each shield is divided with four parts-Upper Block, Left and Right Block and Lower Block. For Shield Machine Lifting, 500t Super Crawler Crane are used for Hoisting and assembling in the working well.

The sequence of installation of Shield Machine are as follows.

1.First of all, the Lower bracket of the steel sleeve is hoisted in place;
2.Front (F2) & Middle Shield (B3) Lower part is hoisted down to the shaft;
3.Drive part is hoisted down to the shaft and assembling;
4.Front Shield Left (F3) & Right (F4) and Upper (F1) Block are hoisted down to the shaft;

Cutter Head:

The Cutter head is assembled on the Ground. Two Crawler cranes are used to turn over the cutterhead and lower into the working shaft. The overall lifting weight of the cutterhead is 220T. There are two types of Cutter Head for Soft Ground Shield Machine.

- Spoke Type;
- Plate Type;

The cutting wheel is equipped with different kinds of Cutting Tools:

- Scrapers/Main Cutter-282 ;
- Preceding/ Primary Cutter-159;
- Shell Cutter-25;
- Wear Detector-2;
- Double Edge Heavy Duty Tearing Cutter-12
- Peripheral Protection Cutter-25;
- Fish Tail Cutter-1;

TBM Supporting Trolley Assembly Scheme:

After Shield assembling, the match trolley is assembled in order to the on-site assembly of 1# , 2#, 3# and 4# according to the reserved lifting hole (Length 20mXWidth 7.5m) at C&C section.

1. Cutter Head:700mm
2. Trolley-1: 14.35m
3. Trolley-2: 17.65m
4. Trolley-3: 14.50m
5. Trolley-4: 16.80m
6.

Preceding Works of TBM Launch: Vertical Freezing Reinforcement:

Vertical Freezing Reinforcement is a way to reinforced soil which can assist before the TBM launch. The working shaft end is consolidated by means of Ø1200@800 triple-tube HP chemical churning piles. In order to avoid cutter disc wear when the shield starts, vertical Freezing Reinforcement is used.The thickness of the freezing wall is 1.5 m, the width is 16.0 m, and the freezing depth is 25 m. The first row of holes is 400 mm from the side line of the concrete groove wall, the distance between the holes is 800 mm, including 21 ones. The second row is 800 mm apart from the first row, staggered with the first row in plum blossom shape in 20 holes.

On the back side of the Cutter Head of this Shield Machine, a Shield Partition is installed. The Space between the Partition and the Cutter Head is named “SLURRY CABIN”. The slurry made of water, clay and additives is pressed into the Slurry Cabin through the Pipeline and the slurry fills the entire Slurry Cabin with a certain pressure to form a slurry pressure chamber. When the Shield Machine advances, the earth and sand cut by the cutters is mixed by the stirring device to form high-density slurry which is sent to the Slurry Treatment Plant on the ground by means of fluid transportation and the soil and water are separated and then back to the Slurry Cabin.

Preceding Works of TBM Launch: Installation & Debugging of Slurry Station:

Before Shield Tunneling starts, fresh Slurry should be prepared and stored in the slurry tank. Raw materials of slurry are bentonite and water, and the proportion of bentonite and water (mix ratio) is 1/0.135.The raw materials are mixed with high-speed rotary mixer after being put into the preparation barrel. After mixing, the slurry is stored in a slurry storage pool for standby and will be pumped into the slurry circulating pool after 24h for use. The multi lane Road Tunnel under the River Karnaphuli mainly passes through the cohesive soil and sand layer interbedded from shallow to deep and the whole section, fine sand layer is excavated. Add 45t Bentonite to each of the 10 rings after tunneling. When mixing, add the clay slurry which is stored in the previous period to reduce the amount of bentonite.

Preceding Works TBM launch: Installation of Steel Sleeve:

Before TBM Launch, the Shield Machine is sealed with the Steel sleeve. The Steel Sleeve is a 20mm thick Steel Plate on which is provided with a rib plate to maintain its stiffness. A pressure balance is built in advance within the sleeve and then the TBM passes through the portal to finish launching. The Counterforce bracket provides a counter-force for TBM during TBM launch. Sand is filled in the sleeve to provide force of friction and resist against twisting. An Anti-torque Rib is welded on the TBM to resist against torque.

- The Outer Diameter of the Steel Sleeve=12924mm
- The Inner Diameter of the Steel Sleeve=12484mm
- The Clearance between the Steel Sleeve & the TBM body =182mm

Tunneling Parameter Control During TBM Advancing:

There are three important Parameters should be monitoring during TBM Advancing and mining. For instance:
Face Pressure;
Primary Grout Injection;
Grease & Lubricant Injection;
Apart from that it should be also monitoring others parameters through Arigatawa View;

- Average Stroke(=Actual Stroke)=1760 mm;
- CHS: 0.99 rpm;
- Maximum Stroke(Out of 4 Values)=1800 mm;
- Advance Speed(NPR)=26mm/min(Limit 20~30);
- Rotation Direction: Clockwise/Anti-clockwise;
- PEN=(NPR/CHS)=15.99 mm
- Force: 97131 KN
- Force: 97131 KN
- Density Inlet D2 & Outlet D1
- Flowmeter F1 & F2

Face Pressure:

Formation Pressure on the Shield Machine including Earth Pressure and Water Pressure is known as Face Pressure. Establishing and Maintaining Correct Face Pressure for the Ground and Groundwater Conditions is very important to the safe operation of TBM. If inadequate face pressure is applied, this will lead to excessive Ground Settlement and may result in collapse of the tunnel face.Over 100 incidents in last 10 years over EPB and Slurry Shield Drives. The cave-in might have been caused by a mistaken calculation of target Face Pressure or more likely an unforeseeable change in soil conditions.
Primary/Annular Grout Injection:

Face Pressure not only the factor in settlement, need to consider loss at tail void. Synchronous grouting is an important measure to prevent stratum settlement. There are six Grout Injection Points at the Shield Tail.
Two parameters are control to ensure the backfilling quality of grout during Construction:
Grout Pressure;
Grout Volume;
Grout Volume: The theoretical volume of the construction gap between the cutter head and the segment is:
$V = \pi/4 \times (12.16^2-11.80^2) \times 2\ m^3/ring$
The Injection Volume Q of the Backfilling Grout can usually be estimated by the following Formula:,

$Q=V\alpha$, where, V= Theoretical Volume
α= For Example,
If the Soil is Mucky Silty Clay, the injection rate should be110%
Hence,
$Q=V\alpha$
$=13.55X1.1$
$=14.9$ cum
Or,
If the Soil Stratum is Silt Fine Sand, the
Injection rate will be 130%
Hence,
$Q=V\alpha$
$=13.55X1.3$
$=17.6$ cum

Shield Tunneling Construction

Shield Tunneling Construction divided into four stages. For Instance

- Launching Stage (-7 ~ +3 Ring):
- Initial Driving Stage (+4 ~ +22 Ring)
- Initial Driving Stage (+23 ~ +80 Ring)
- Final Driving Stage (After Negative Rings Removed)

1. After the completion of TBM and steel sleeve installation -7 and -6 were assembled and connected and pushed to the circular ring at the steel sleeve end.
2.Then dense sand filling within the sleeve and slurry pressure establishment in the slurry pond. Then TBM breaks the underground diaphragm wall and enters the consolidated soil moving forward towards the portal.
3.Start Synchronous Grouting and Tail grease system.
4.After TBM advancement 2.0, Assembling -5 ring and installation of 1st Group of Splayed wheel by 1#lorry
5.After the 80 rings of tunneling were finished, the locomotive will be double marshaled, the Y-Switch and double track will be installed in the connecting area between launching shaft and tunnel.
6.The temporary rings will be removed.
7.Grout will be transported by locomotive in the tunnel and finally stored in the Primary Grout tank in TBM.

Malfunction of TBM

Tunnel Boring Machine (TBM) tunneling projects are frequently hit with delays which can cause adverse effects, extending schedules and incurring additional costs.There are four reasons that play instrumental behind the Malfunction of TBM Advancing.

- Hydraulic Malfunction
- Hydraulic Malfunction
- Electric Malfunction.
- Others Malfunction.

Tunnel Lining:

There are 23 Points in Total and 8 positions can be chosen for the key position of the next ring:

Hyperbaric Intervention of Cutter Head Replacement

During Shield Tunneling, a CHI has been carried out due to Cutter Head Torque being reduced from 3500 KN.m to 5000 KN.m. The Diver removed and Replaced of 3 Peripheral Scrapers on the right side of #1 Spoke, the left side of 3# spoke and the right side of #4 spoke. As a result, the Thrust force of the Shield Machine has gradually increased from 6000T to 13000T.

To sum up, shield tunneling construction depends on groundwater conditions, the length and diameter of the tunnel drive, depth of the tunnel and appropriate risk management. I do believe that we ought to remain in touch with sophisticated techniques to build a tunnel by air-cushioned slurry balanced Shield machine and it will foster and robust our life and usher in a new era of our regime as well.