TBM Design Considerations: Selection of Earth Pressure Balance or Slurry Pressure Balance Tunnel Boring Machines.

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ABSTRACT

In order to determine the specification of the machine to offer a Tunnel Boring Machine (TBM) supplier requires a minimum amount of information. This information is used in determining the specifications of the machine to be proposed as well as the level or type of face support required for the project. The focus of this paper is too list the required information for the design of a TBM and focus on the selection of the EPB or Slurry TBM method of face support based on the conditions of the project, from geology, alignment restrictions and local knowledge / support.

1. INTRODUCTION

In order to asses the type of machine required and the type of pressurized face support required for a project there is a minimum amount of information needed by the TBM supplier / designer. Keeping in mind that providing more information than the minimum will help to more quickly define the machine specifications and lead to a more informed / educated decision.

In order to determine the specifications for a TBM to be proposed for a project the TBM supplier requires certain information including but not limited to;

- geology
- site restrictions
- restrictions on use of products
- sensitivity of the buyer to overall cost
- alignment [both vertical and horizontal]
- local knowledge and experience
- availability of additives and costs
- Train Configuration

2. REQUIRED INFORMATION FOR DETERMINATION OF TBM REQUIREMENTS

In order to determine the type, specifications and requirements for a TBM the following information is required by the TBM manufacturers / designers in order to ensure a suitable machine is selected for the project.

2.01 Geology

The anticipated geological conditions along the alignment are critical to the selection of the machine. The type of soil, rock and the presence of water have a fundamental impact on machine selection. The type of information typically provided include, soil/rock type and description, soil/rock strength parameters, grain size curves for soils, permeability (both primary and secondary) and the level of water above the tunnel alignment – or the lack of water as well.

A simple change in the geology or the presence of water can change the type of machine from a simple open machine to a fully pressurized EPB or SPB type machine with complex operating parameters.

2.02 Tunnel Alignment

Other information critical to the selection of the TBM is the tunnel alignment. The TBM must be designed and built to be able to excavate the proposed tunnel along the pre-established line and grade. Items such as the minimum horizontal or vertical curve can have dramatic impact on the layout and configuration of the machine. A curve radius of 300m is negotiable by most styles or types of machines but if the radius tightens to 200m or less the design of the machine must be done carefully to ensure that the TBM and all of its ancillary equipment can negotiate the tighter curve.

Also, part of the alignment is the slope of the tunnel. Most metro or road and sewer tunnels have limited slopes based on their final use. However, there have been instances where slopes of 70% have been excavated. At this degree of incline (or decline) the TBM design has to consider the ergonomics of operation on a slope as well as the limitations of hydraulic systems.

Also of interest to the manufacturers and designers of TBMs is the depth of the tunnel which can influence ground load pressures on the skin of the machine and the overall length of the tunnel drive and how it is broken up.

A machine designed to mine a tunnel 1500m long is not the same as a machine designed to mine a tunnel 15,000m long. The operation and principles of the machine may be the same but the selection of individual components will change in order to achieve the longer required operating life for the longer tunnel.

The number of drives and their individual length will also influence machine design as frequent shafts will allow access to the cuttinghead for maintenance in a controlled environment where as widely spaced shafts (or none at all) may require additional measures (compressed air, mechanical face support doors etc.) to be available for accessing the cuttinghead in poor ground conditions.

2.03 Site Restrictions

Access to and the size of the job site will also impact the TBM selection. The size of the site, the ability to get cranes into the site to lift the TBM in and out of the shaft or portal will dictate the size of the individual pieces that the TBM can be shipped in.

The location of the site can also restrict the allowable shipping size of individual components. The smaller the individual component that can be shipped to site the more time is required for disassembly at the manufacturing plant and reassembly on site. Items to consider when locating a site are:

Available space:	is it suitable for the installation of the equipment and for effective operation of the job site.
Restricted access:	are the local roads leading to the site of sufficient size or capacity to allow the movement of large pieces of equipment and the removal of excavated material from the site in an efficient manner
Available Equipment:	is there a crane big enough locally to lift the maximum size of TBM component that will be sent.

Shaft Dimensions: what are the dimensions of the shaft, is there a head or tail tunnel, what room is available for assembly of the TBM for launch. All this will impact assembly and launch times on site. A TBM that can be set up in its full configuration at a portal can be assembled and launched to 100m bored in two months. If we remove the ability to fully assemble and give minimum space to erect and launch the TBM the two months can become six months impacting project schedule and completion.

2.04 Additives

Both EPB and SPB TBM operation require the use of additives in order to control the behaviour of the excavated material. In an EPB TBM additives include water, foam, polymer, bentonite or any combination of them. In an SPB TBM additives are primarily bentonite in a slurry but can also include special polymers and other agents that aid in the separation of finer grained soils such as clay from the bentonite slurry.

The availability of the additives in both quantity and price and the ability to be allowed to use the additives (in some durasdictions bentonite is considered a contaminant) may restrict the type of machine selected.

2.05 Buyer Experience and Local Knowledge / Support

The experience level of the contractor and the local work force can also dictate the preferred machine type. If local contractors and labourers have used one type of machine in the past then local infrastructure would be available to support this type of machine. A new style of machine may have a longer learning curve, require more outside assistance for longer after launch and local companies would not be as likely able to support such equipment.

2.06 Critical Structures

Presence of any Critical Structures (monuments, old buildings, proximity to other underground structures etc.) and the level of settlement that these structures can tolerate will force the use of a pressurized machine (EPB or SPB) on a project that would not otherwise require a pressurized TBM.

2.07 Project Time Table

The project time table may dictate the use of refurbished or already available equipment which may dictate machine type (what can the contractor get their hands on quickly in the required diameter).

The schedule may also force the use of multiple machines which in the case of the SPB machine can have a large impact on the surface treatment plant size.

The planners need to be aware of the schedule they are asking for and be aware of the impact on the type of equipment that will be available to the project because of a tight schedule. Rather than a custom built for purpose machine there may only be available machines that are adequate but not ideal for the anticipated conditions along the alignment.

Planners should also consider that the rate of advance of each type of machine will be different. EPB machines can take advantage of good conditions and go faster than a slurry machine whose advance rate will be more restricted by the slurry system behind it. However, the EPB machine will likely require more maintenance of the cuttinghead face. At the end of the day the EPB machine will have higher daily production but over the course of a week or month the SPB will catch up part of that advantage.

2.08 Items for TBM Design

The following items are not necessary for the selection of the TBM but will dictate the basic and in some cases the detailed design of the machine.

2.08.01 Tunnel Lining

The configuration of the tunnel lining will not affect the type of machine selected but it will dictate the design of the machine in the following areas:

- Machine Diameter
- Length of the Machine
- Segment Handling
- Segment Erection
- Stroke of Propulsion Cylinders
- Number / Quantity of Propulsion Cylinders
- Size of Muck Train (EPB)

The information required for the design and detailed design of the TBM is as follows:

- Segment Layout / Orientation
- Style of Segments (Left/Right or Universal)
- Quantity of Segments in Ring
- Maximum Segment Width
- Minimum Segment Width
- Taper
- Thickness
- Inside and Outside Diameters
- Joint Details (orientation / angle)

2.08.02 Train Configuration

The configuration or make-up of the train will impact the design of the TBM gantry (trailing support structure) and the materials handling equipment for the movement of segments and consumables. Items required include the following:

- Train Configuration (quantity and type of cars)
- Orientation of Train (where everything will go)
- Size of Muck Cars (Length x Width x Height)
- Size and Capacity of Locomotive
- Track Gauge
- Track Level / elevation from invert
- Rail Section Length
- Rail Size / weight

3. SELECTION OF FACE SUPPORT FOR PRESSURIZED EXCAVATION – EARTH PRESSURE BALANCE vs SLURRY PRESSURE BALANCE

Once information is available the most important selection for the TBM end user and the manufacturer is the type of face support that will be utilized. The two available methods of pressurized excavation are Earth Pressure Balance (EPB) and Slurry or Slurry Pressure Balance (SPB)

EPB and SPB machines have advantages and disadvantages. Each of which needs to be considered independently for each set of project conditions. A disadvantage that is minor for one project may be considered critical and be the main decision maker for the next project. The same goes for advantages, where on one project being able to mine faster is a good advantage but on another it may be irrelevant as other factors on site such as location, logistics etc. make going faster less important to the overall project completion.

3.01 Advantages of EPB TBMs

The EPB TBM has numerous advantages a few of which are listed here. Those listed are in direct comparison to the SPB TBM and the same will be the case following for the SPB advantages.

- Overall simpler system to learn, operate and maintain
- In case of face collapse amount of ground loss is limited
- Able to take advantages of self-supporting grounds
- Better overall production rates are possible over SPB TBMs
- Lower capital cost
- Smaller site and launch shaft
- Lower consumption of additives (no slurry circuit)

3.02 Advantages of SPB TBMs

A few of the main Advantages of the SPB over the use of an EPB machine are as follows:

- Required pressure is determined / controlled by system
- Lower torque
- Lower Cuttinghead Power
- Contaminated muck is not exposed until it reaches the surface
- Able to integrate rock crusher
- Cleaner Tunnel Environment

3.03 Similarities of Design

It should be noted that the basic design of an EPB TBM and a SPB TBM are quite similar. The overall appearance and many of the systems from one type are used directly on the other with limited or no change to design. These similarities include:

- Main structures
- Propulsion
- Trailing Gantry Structure
- Segment Erector and handling

3.04 Settlement Control

The selection of EPB or SPB is all based on the requirement to maintain control of the excavation face in order to prevent settlement. As shown in the preceding Section 2 there are various reasons to control settlements to within certain limits.

Both types of machine can maintain very good control over settlement when operated correctly. The SPB TBM maintains control over settlement by control of the slurry pressure, flow and density in the cuttinghead chamber. While the EPB TBM maintains control of settlement by control of the EPB Pressure in the Cuttinghead Chamber during excavation which is done with matching rates of extraction of material to advance.

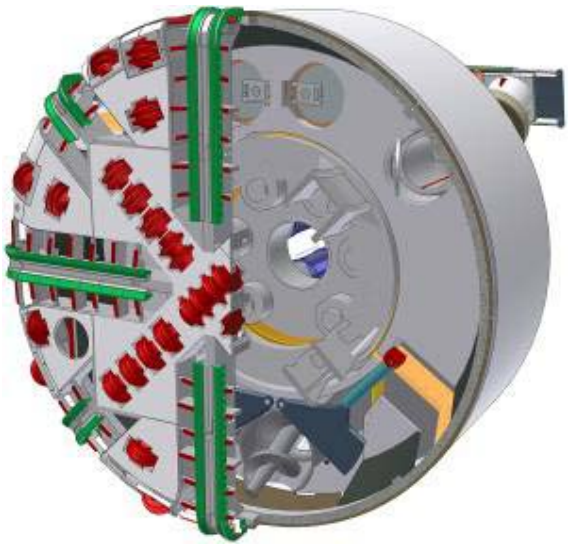
In both types of machines the control that is maintained by the machine is for the face only. Control of settlement however, does not stop with the face. In most cases secondary settlement (settlement after the machine has passed) is far greater than settlement experienced as the machine mines past a given point. This secondary settlement must be controlled by good backfill grouting around the segments. This is something often overlooked and is the topic outside of this paper.

4. SELECTION OF TYPE OF FACE SUPPORT

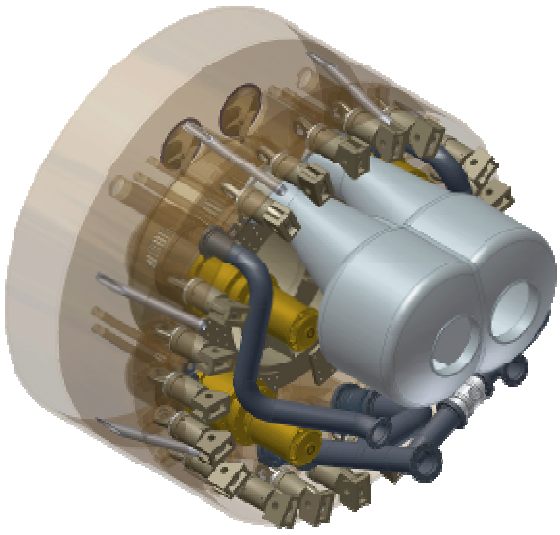
4.01 Comparison of EPB and Slurry

As can be seen in the above chart the use of either the EPB TBM or the SPB TBM is possible in a full range of ground conditions. Traditionally the EPB machine has been selected for finer grained soils and the SPB for coarser grainded soils. In recent years the increased development of additives and additive injection systems has allowed the two types of machines to excavate a broader range of soil conditions to the point where the type of soil is no longer the most critical item in the decision making process of EPB vs SPB

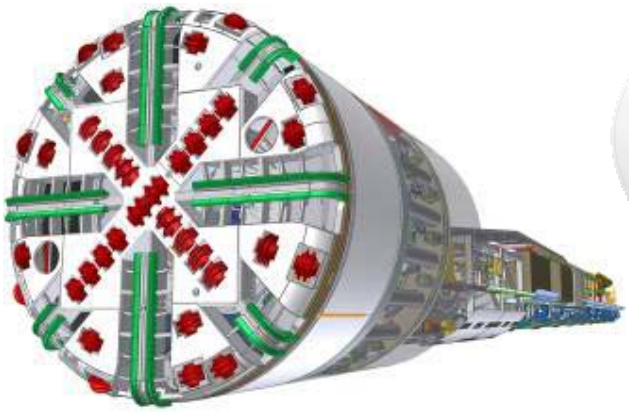
6m EPB TBM

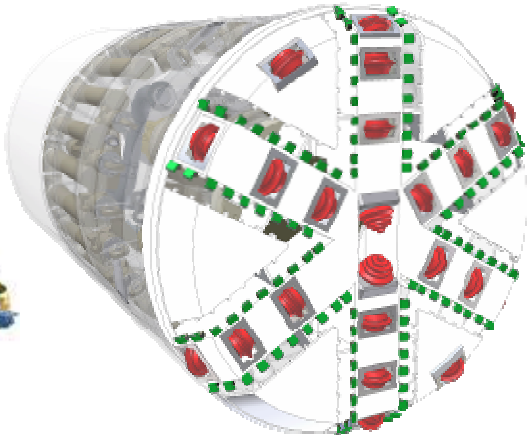


6m SPB TBM



6m EPB TBM **6m SPB TBM**





4.02 Criteria for Selection

Areas for comparison between the two types of face support /machines are numerous. Some of the more common areas to consider include:

- Overall site power requirements
- Capital cost of equipment
- Disposal of excavated material
- Local experience
- Calculation of support pressure for settlement control
- Use and availability of additives
- Required site size
- Speed of excavation

The ratings of each type of TBM (EPB or SPB) under each of these categories as well as others needs to be considered for each project. The final decision for one project may be based on the criteria of site size that was not critical for a previous project because of its location. Each criteria used must be independently considered and then a rating as to how critical each criteria is must also be done to provide a "weighted" rating for the specific project.

4.03 Conclusions and Recommendations

In order to make the decision on the selection of Earth Pressure Balance vs Slurry Pressure Balance we must consider all the selection criteria. Nothing can be put aside as inconsequential without a minimum level review. Items which are unimportant to the decision process on one job may be critical to the decision process on another project or any where in between.

To recommend EPB or SPB for a project without a complete review of all available information and a study of each of the selection criteria in detail would not be an advisable course of action. To eliminate one method over the other or to set a preference should only be done after due consideration has been given.

Both Earth Pressure Balance Tunnel Boring Machines and Slurry Pressure Balance Tunnel Boring Machines have their uses in modern tunnelling and both methods of pressurized face support should be given consideration during the selection process of a project.