EXCAVATION IN MIXED GROUND
CROSSOVER TBMs

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The Robbins Company
INTRODUCTION

• Most Tunnels do not have consistent and homogeneous geological conditions.
• Multiple fault zones are always present in tunnels.
  • Broken Ground, Mix of Rock & Soil, High pressure ground water.
• The industry has always looked for versatile tools to cope with such variations.
  • Time and Cost considerations.
• This presentation is a quick overview of TBM types which have been developed for such conditions.
• The term CROSSOVER has been coined to indicate the capability of these machines to be reconfigured in the tunnel with minimum impact to project schedule and cost.
THE CROSSOVER CONCEPT

PRESENTATION OUTLINE

+ What is a Crossover TBM?
+ Why Use Crossover TBMs?
+ Types of Crossover TBMs
+ Design and Examples for Large and Mid-Size Crossover TBMs
THE CROSSOVER CONCEPT

WHAT IS A CROSSOVER TBM?
THE CROSSOVER CONCEPT

WHAT IS A CROSSOVER TBM?

MACHINE TYPES

+ Flexibility to switch from one configuration to another
+ Based on ground conditions
+ Three main types of Crossover TBMs

<table>
<thead>
<tr>
<th>Machine Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard Rock/EPB</td>
<td>For excavation in mixed soils with rock</td>
</tr>
<tr>
<td>- Hard Rock/EPB</td>
<td></td>
</tr>
<tr>
<td>- Open or Closed configuration</td>
<td></td>
</tr>
<tr>
<td>- Hard Rock or Soft Ground</td>
<td></td>
</tr>
<tr>
<td>- Screw Conveyor</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Machine Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slurry/EPB</td>
<td>For excavation in mixed-to-soft ground under water pressure</td>
</tr>
<tr>
<td>- Slurry/EPB</td>
<td></td>
</tr>
<tr>
<td>- Equipped with screw conveyor</td>
<td></td>
</tr>
<tr>
<td>- Slurry system</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Machine Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard Rock/Slurry Shield</td>
<td>For excavation in hard rock and soft water-bearing ground.</td>
</tr>
<tr>
<td>- Hard Rock/Slurry Shield</td>
<td></td>
</tr>
<tr>
<td>- Highly adaptable to variety of ground conditions</td>
<td></td>
</tr>
</tbody>
</table>
WHAT IS A CROSSOVER TBM?
DEFINING CHARACTERISTICS

+ High torque/High speed Cutterhead
  + Two-speed gearbox
+ Crossover cutterhead
  + Single-direction or bi-directional
  + Convertible
  + Tools for different types of ground
+ Improved probe/grout drilling systems
+ Operation in “open, closed and semi-closed” configurations
  + EPB screw interchangeable with belt conveyor
+ Completely customizable based on the requirements of the project
THE CROSSOVER CONCEPT

WHY USE CROSSOVER TBMs?
THE CROSSOVER CONCEPT

WHY USE CROSSOVER TBMs?

MIXED GROUND EFFICIENCY

Modern-day Crossover machines are required to excavate different types of ground efficiently with one machine:

+ Want to excavate self supporting ground → *Open Configuration*
+ Want to excavate self supporting ground but want to mitigate underground water ingress → *Closed Configuration* (*Compressed air, Slurry, EPB, etc.*)
+ Want to excavate unstable ground → *Closed Configuration* (*Compressed air, Slurry, EPB, etc.*)
THE CROSSOVER CONCEPT

WHY USE CROSSOVER TBM$s$?

CONSIDERATIONS

+ Safety
  + Conversion work should be carried out in a confined space
+ Schedule
  + Conversion works can be time-consuming, so a detailed plan must be in place
+ Geological Information
  + To decide when and where to convert, reliable geological information is required
  + Adequate probe drilling is essential to determine the ground conditions ahead of a Crossover TBM
+ Cost
  + Upfront costs may be high, but overall savings are significant
  + Durability = savings in repair costs
  + Dual-configuration capabilities = use over multiple projects
CROSSOVER XRE
FOR MIXED HARD ROCK & SOFT GROUND
CROSSOVER BETWEEN HARD ROCK & EPB
CROSSOVER XRE TBM
OVERVIEW

+ Hard Rock/EPB
+ Open or Closed Configuration
+ Hard Rock or Soft Ground
+ Screw Conveyor and/or Belt Conveyor
CROSSOVER XRE TBM
GROUND CONDITIONS

+ Designed to excavate in open or closed configuration
+ Hard rock and/or soft, relatively impermeable ground including fault zones
+ Less well suited to permeable ground conditions such as sand and pebbles, though additives/polymer can be used to stabilize these conditions
+ Typically proposed for mixed face conditions
CROSSOVER XRE
HOW IT WORKS
& FEATURES
**CROSSOVER XRE TBM**

**HOW IT WORKS – MUCK REMOVAL & CONTROL**

+ Optimized towards the geology anticipated for the majority of the drive
+ TBM design becomes more complex in neutral geology
  + Optimized towards faster conversions between configurations
+ Screw conveyor for operation in closed configuration
+ Fitted with belt conveyor in open configuration
Generally XRE TBMs have mixed ground cutterheads:

+ Disc cutters
+ Soft ground tools
+ Combination of tools
+ Interchangeable
CROSSOVER XRE TBM
FEATURES- CUTTERHEAD

+ Variable speed cutterhead drive with two-speed gearboxes
  + Improve performance
  + Provide high torque at low RPM (soft ground)
  + Provide high RPM for better performance (hard rock)

+ Bidirectional vs. Single direction
  + Single direction is more efficient
  + Has skew cylinders to prevent roll
  + Minimizes wear in rock conditions

+ Bidirectional is still used
  + More efficient in soft ground
  + Prevents roll
CROSSOVER XRE TBM
FEATURES- CUTTERHEAD

Single Direction (Rock configuration)
- Disc cutters installed
- Muck chute and Hopper Installed

Bidirectional (Soft Ground configuration)
- Tools changed
- Larger opening ratio
**CROSSOVER XRE TBM**

**FEATURES - MACHINE**

**Probe Drilling & Ground Consolidation**

+ Crossover machines require probe drilling to determine what configuration the machine needs to be in:
  + A program of probe drilling is advised
  + Detailed grouting programs should be developed prior to tunneling
  + Canopy drill: allows you to consolidate ground with spiles or grouting ahead of and above the TBM
CURRENT DESIGNS

LARGE DIAMETER
13.77 m XRE TBM
## THE CROSSOVER CONCEPT

### CROSSOVER MACHINE DESIGN (Ø13.77m)

#### OPEN & EPB configuration

<table>
<thead>
<tr>
<th>FEATURES</th>
<th>Open configuration</th>
<th>Closed configuration (EPB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutterhead Rotation</td>
<td>Single-Directional</td>
<td>Bi-Directional</td>
</tr>
<tr>
<td>Chute</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Hopper</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Cutterhead Speed/Torque</td>
<td>High Speed/Low Torque</td>
<td>Low Speed/High Torque</td>
</tr>
<tr>
<td>Mixing Bars</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Rotary Union</td>
<td>Yes (Small Rotary Union for Water or Foam)</td>
<td>Yes (Large Rotary Union for Water, Additives, Hydraulic, Grease, and etc.)</td>
</tr>
<tr>
<td>Thrust Cylinder skew mechanism</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Mucking system</td>
<td>Belt conveyor in center</td>
<td>Screw conveyor in bottom</td>
</tr>
</tbody>
</table>
THE CROSSOVER CONCEPT

CROSSOVER MACHINE DESIGN (Ø13.77m)

CUTTERHEAD ROTATION

Open configuration
Single-Directional
Cutterhead

EPB configuration
Bi-Directional
Cutterhead
THE CROSSOVER CONCEPT

CROSSOVER MACHINE DESIGN (Ø13.77m)

CHUTE & HOPPER

Single Direction Cutterhead w/ Chute & Hopper
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CROSSOVER MACHINE DESIGN (Ø13.77m)

HIGH SPEED/LOW TORQUE & LOW SPEED/HIGH TORQUE

Two-Speed Gear Reducers

Speed – Torque Curve
THE Crossover CONCEPT

CROSSOVER MACHINE DESIGN (Ø13.77m)

THRUST CYLINDER SKEW MECHANISM (SKEW RING)
THE CROSSOVER CONCEPT

CROSSOVER MACHINE DESIGN (Ø13.77m)

MUCKING SYSTEM

Belt Conveyor at Center

Screw Conveyor at Bottom
XRE CASE STUDY
Túnel Emisor Poniente II (TEP II)
CROSSOVER CASE STUDIES

TÚNEL EMISOR PONIENTE (TEP) II
PROJECT BACKGROUND

PROJECT LOCATION MEXICO CITY
TUNNEL TYPE WASTEWATER
MACHINE TYPE CROSSED XRE
NO. OF MACHINES 1
TBM DIAMETER 8.7 M
TUNNEL LENGTH 5.9 KM
ASSEMBLY TYPE OFTA
GEOLOGY VOLCANIC ROCK, SOFT SANDS, CLAY
TIMELINE BEGAN BORING AUG 2015
CROSSOVER CASE STUDIES

TEP II

GEOLOGY

<table>
<thead>
<tr>
<th>Color</th>
<th>Descriptions</th>
<th>Meters</th>
<th>Looks Like</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAVA</td>
<td>Large lava structural bodies. The rock is hard, fluidal, mostly healthy, but sometimes brecciated, RQD is 50 to 60%, but can be up 70 to 80%.</td>
<td>3,745</td>
<td></td>
</tr>
<tr>
<td>TUFF</td>
<td>Pumice with sandy particles moderately consolidated.</td>
<td>1,814</td>
<td></td>
</tr>
<tr>
<td>SAND</td>
<td>Sandy matrix, medium to good consolidation.</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>SOIL</td>
<td>Blocks and gaps of sand and tuffs, silty clay and soils.</td>
<td>280</td>
<td></td>
</tr>
</tbody>
</table>
CROSSOVER CASE STUDIES

TEP II

MACHINE DESIGN

TBM Shown in Rock configuration
CROSSOVER CASE STUDIES

TEP II
MACHINE DESIGN

TBM Shown in EPB configuration
CROSSOVER CASE STUDIES

TEP II
FEATURES

+ Functions in dual configurations (Rock & EPB)
+ Two-speed gearbox
+ Probe drill
+ Umbrella drill system
+ 20-inch disc cutters
+ Grippers and stabilizers
+ Roll control skew cylinders
CROSSOVER CASE STUDIES

TEP II
CURRENT STATUS

+ TBM has bored 2.6 km into an intermediate shaft
+ Crews successfully navigated fault zones
+ Best day of 42.8 m and best week of 185.1 m
Crossover XSE
For High Pressure Soft and Mixed Ground
Crossover Between Slurry & EPB
Crossover XSE TBM Overview

- Slurry/EPB
- Equipped with screw conveyor and slurry system
Crossover XSE TBM

Ground Conditions

- Designed for operation in soft ground containing water under pressure
- Particularly suitable if portions of the project are predicted to have water pressure over 5 bar
- Well-suited for sections of impermeable ground, such as clay (EPB Mode), and permeable soils such as sand and pebbles (Slurry Mode)
- The most universal of the Crossover Types, the XSE can bore in most types of ground, though it loses efficiency in hard rock
Crossover XSE

How it Works & Features
Crossover XSE TBM

How It Works

• Machine switches between EPB and Slurry configurations, depending on ground conditions
  • *In EPB Configuration*
    • Utilizes a screw conveyor for muck removal
  • *In Slurry Configuration*
    • Muck removal switches over to slurry pipes within machine shield
    • Surface slurry plant required – size dependent on size of slurry section
Crossover XSE TBM

How It Works

- XSE cutterhead can be outfitted with different tooling, depending on ground conditions
- For example, in mixed ground it can be outfitted with disc cutters and soft ground tools, or in softer ground just soft ground tools
Crossover XSE TBM

Features

- **Multi-directional cutterhead**
  - Cutterhead can go in any direction
  - For soft ground, a bi-directional cutterhead can work well
  - Single-direction cutterhead can also be used and can improve efficiency

- **Completely customizable machine**
  - Most customizable of all Crossover-type TBMs

- **Runs efficiently in most types of ground**
  - Doesn’t get stuck in any ground
  - Runs efficiently under high water pressure
  - Efficiency drops off in harder rock – this is where wear increases

- **Simple style of machine, with many potential add-ons**
  - Wide variety of customization and add-on systems, such as slurry recycling systems, and conveyor systems for muck removal
XSE CASE STUDY
BAKU METRO
Crossover XSE TBM

Case Study: Baku Metro

Project & Machine Specs:

- Contractor: Evrascon
- Project location: Baku, Azerbaijan
- Project type: Metro
- Machine type: XSE (Slurry/EPB)
- Machine diameter: 20.5 ft
- Ground conditions: Mixed ground (silt, clay, sandstone, limestone, at pressures up to 5 bar)
Crossover XSE TBM

Case Study: Baku Metro

What Makes this an XSE Machine?

- Has both screw conveyor and slurry piping
- As geology becomes more complex, the TBM can switch between configurations
- Designed for excavation in mixed ground containing water under pressure and complex sections
Crossover XSE TBM

Case Study: Baku Metro

Project Details:

- New tunnel will be part of a metro expansion in Baku
- Project has yet to start up
- Expansion will connect with older Soviet-era lines
- 5 lines, 74 miles of track and 76 stations planned for completion by 2030
Crossover XSE TBM

Case Study: Baku Metro
CONCLUSIONS
CONCLUSIONS

CROSSOVER TBMs

TAKEAWAY POINTS

+ The use of “Crossover” type machine allows for a more versatile machine and one that can excavate various geological conditions.
+ A good geological profile is required so the TBM can be designed with the correct features best suited for the project.
+ Special features can be added to the TBM to reduce the project risk. These features include:
  + Added wear resistant materials to the cutterhead, EPB screw, slurry piping
  + Addition of probe/grout drilling systems for ground consolidation and/or umbrella grouting
  + Added cutter monitoring systems to give the operator indications of the status of the cutters
  + Added logistical systems to make the conversion from one configuration to another quick and efficient
THANK YOU