Soft Ground Tunneling on a Mexico City Wastewater Project

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ABSTRACT: Ground settlement in Mexico City has caused the existing gravity feed wastewater system, built in 1975, to lose its slope. In addition to infiltration and corrosion, the system is severely undersized. To remedy the problems, the Mexico National Water Commission released a contract for a 7.8m ID × 62 km long pipeline known as the "Emisor Oriente" Wastewater Tunnel Project. To meet the demanding schedule, six Earth Pressure Balance (EPB) TBMs will be required. This paper will address the overall importance of the project to Mexico City as well as the unique design of the EPB TBMs needed for excavation of varying geology in pressures up to 10 bar. The current status of the project and any problems encountered to date will also be covered.

PROJECT BACKGROUND

Mexico City, a metropolis of over 22 million people, is sinking at the rate of 10 cm per year. The world's second largest city was founded by the Aztecs in the Valley of Mexico, on what was once an island in the middle of Lake Texcoco. Spanish conquistadors later drained the lake bed using a system of canals, but the soft lake clays remained underneath the city's infrastructure. A combination of booming population and compression on the city's main sewer lines has necessitated the construction of one of Mexico's largest infrastructure projects—a 62 km long pipeline known as the Emisor Oriente, or Eastern Wastewater, tunnel.

Mexico City's wastewater system is almost exclusively served by the Emisor Central, a 68 km long line built in 1975. Over the past three and a half decades, ground settlement has caused a decrease in slope in the gravity sewer line and a reduction in capacity. Severe corrosion and nearly continuous groundwater infiltration have also made it impossible for the Emisor Central to be inspected and maintained between 1995 and 2008.

Once inspection was made possible, it was found that the overall system capacity had been reduced by 40% since 1975—from 280 m^3/sec to just 165 m^3/sec in 2008. Over the same time period the city's population more than doubled from 10 million to over 20 million inhabitants, increasing demand on the system.

PROJECT DESCRIPTION AND LOCATION

Mexico's National Water Commission (CONAGUA) recommended immediate construction of a new line to help supplement the struggling system. The Emisor Oriente, or Eastern Wastewater Tunnel, will increase the city's current sewer capacity by 150 m^3/sec once complete in September 2012. The line will carry wastewater from Mexico City to several water treatment plants currently under construction in the state of Hidalgo (see Figure 1).

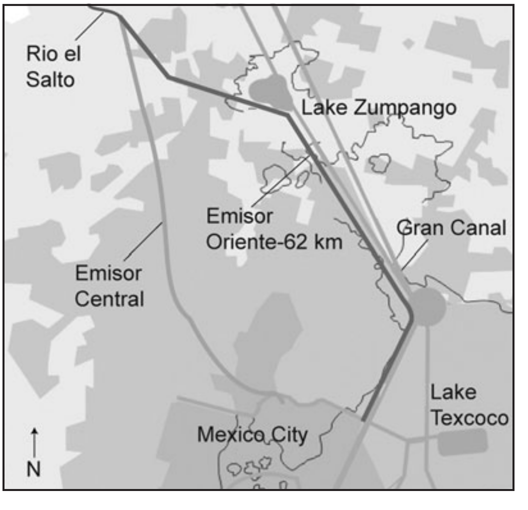

Figure 1. Emisor Oriente pipeline layout

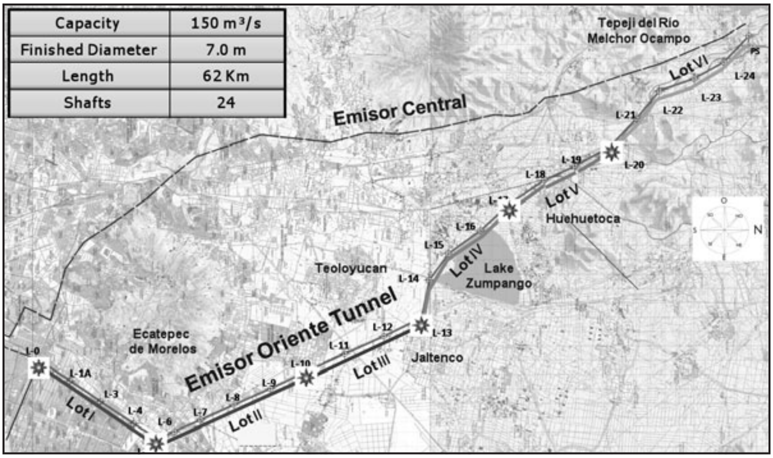

Figure 2. Detailed location of Emisor Oriente Tunnel. Main shafts shown as stars.

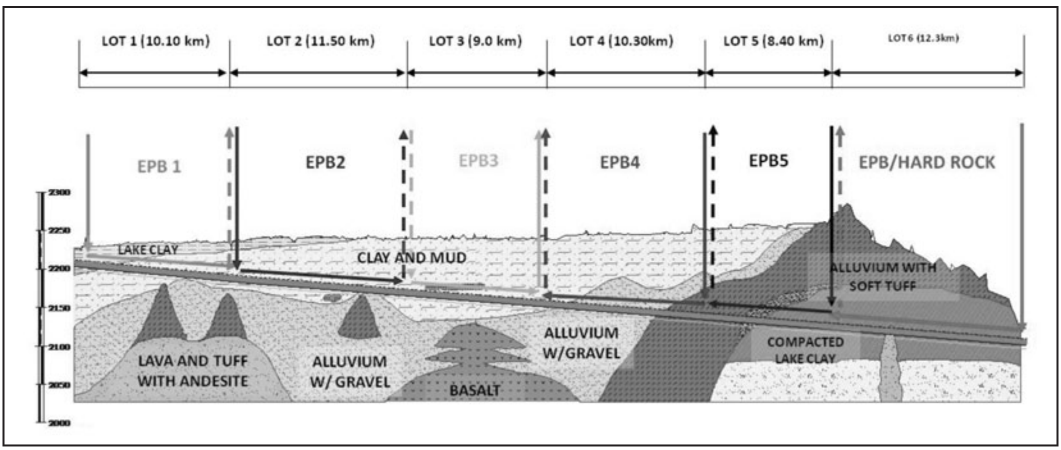

Figure 3. Geological profile of the Emisor Oriente Tunnel

The construction of the line was divided into six lots—lots 1, 2, and 6 under Mexican contractor Ingenieros Civiles Asociados (ICA) S.A. de C.V, and lots 3, 4, and 5 under Carso Infraestructura y Construcción, S.A. de C.V. All six lots will be bored with EPB machines— Robbins was awarded lots 3,4 and 5 which will be bored using three 8.93m diameter EPB TBMs (see Figure 2).

GEOLOGICAL CONDITIONS

The Robbins machines are set to bore in alternating sections of compacted sand, gravel and clay with basalt rock, and are designed accordingly. The geology of the Valley of Mexico is also unique in that large boulders up to 600 mm in diameter are predicted throughout the drives. The particular set of geologic characteristics is found only in Mexico and in certain areas of Japan. The varied conditions consist of sections of lake clays, alluvium, and lava with tuff and andesite (see Figures 3–4).

PROJECT APPROACH

The three Earth Pressure Balance Machines supplied by Robbins will be 8.93 m in diameter. All of the machines were optimally designed for mixed ground conditions (see Figure 5 and Table 1).

Cutterhead Design

The machines are utilizing mixed ground, back-loading cutterheads for the variable geology. The design allows for a change in cutting tools between sections of soft ground and rock.

The seven-piece spoke-type cutterheads will utilize six outer segments plus a hexagonal-shaped center section to maximize the opening ratio of the face. The machines were designed with the largest possible opening ratios to ensure a smooth flow of muck into the cutterhead chamber.

Crews will switch out between carbide knife-edge bits and 17-inch, carbide disc cutters depending on the ground conditions. A number of small shafts, spaced every 3 km between the larger launch shafts, will be used to perform cutter inspection and changes. Specialized wear detection bits will lose pressure at specified wear points to notify crews a cutting tool change is needed. The knife edge bits are arranged at several different heights to allow for effective excavation at various levels of wear.

The design also allows for bearing and seal removal from either the front or back of the cutterhead. Twenty-five injection ports spaced around the periphery of the machine will be used for injection of various additives depending on ground conditions, and for probe drilling (see Figure 6).

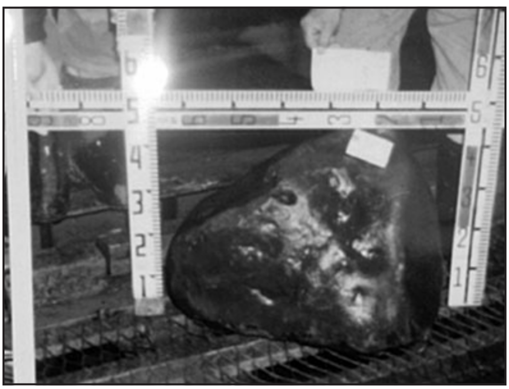

Figure 4. Boulders taken from similar ground at the Sapporo Metro Project, Japan

Screw Conveyor and Muck Removal

Each machine will be fitted with a ribbon-type screw conveyor 900 mm in diameter. The screw conveyors allow boulders up to two-thirds the screw diameter (up to 600 mm) to travel up the shaft, where they are disposed of through a boulder collecting gate. Each of the three machines may encounter pressures of up to 10 bar, necessitating a two-screw setup with a ribbon screw and shaft-type screw in order to smoothly regulate pressure (see Figure 7).

Muck will be deposited from the screw to a rubber belt conveyor mounted on the trailing gear, which transfers to a side-mounted continuous conveyor. The continuous conveyor carries the muck to a 150 m long vertical belt conveyor located at the

Table 1. Specifications for Emisor Oriente EPB TBMs

8.93 m Diameter EPB TBMs	
Excavation Diameter Cutterhead for Soil Cutterhead for Rock	 8,910 mm 8,930 mm
Main Cutting Tools	Special knife-edge bit (soil) Single and Double-row Disc Cutters (rock)
Cutterhead Drive	Electric, variable speed
Cutterhead Power	1,900 kW
Machine Thrust	84,000 kN
Stroke	2,300 mm
Max Torque	17,900 kNm
Screw Conveyor #1	Ribbon type, 900 mm diameter
Screw Conveyor #2	Shaft type, 900 mm diameter
Articulation	Active
Segments	Reinforced concrete, 400 mm thick
Back-filling System	Two-Liquid Type

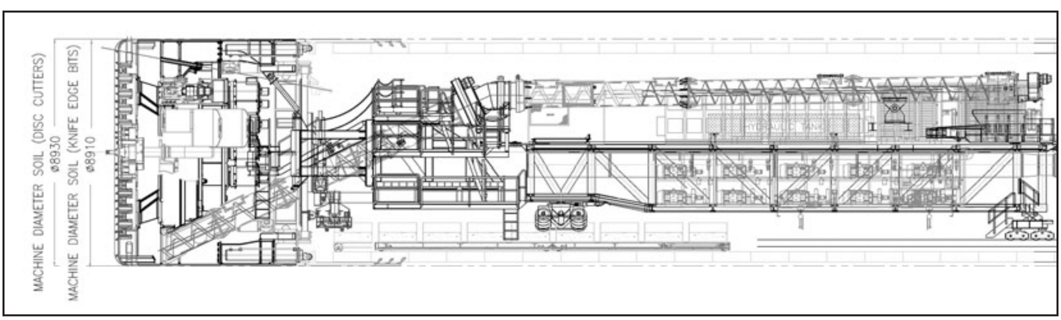

Figure 5. EPB TBM general assembly

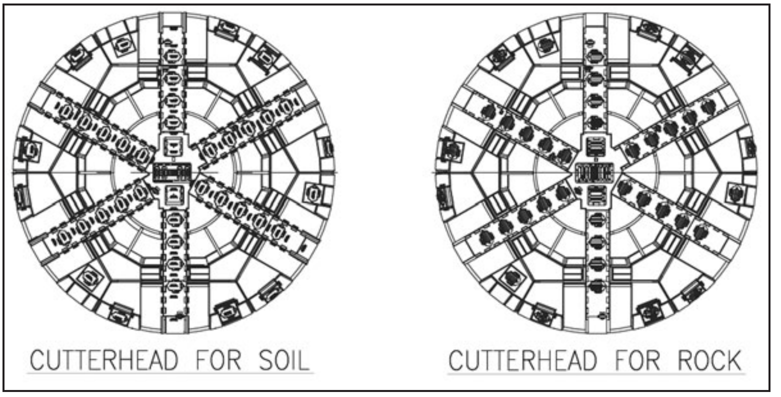

Figure 6. Cutterhead design with interchangeable cutting tools for soil and hard rock

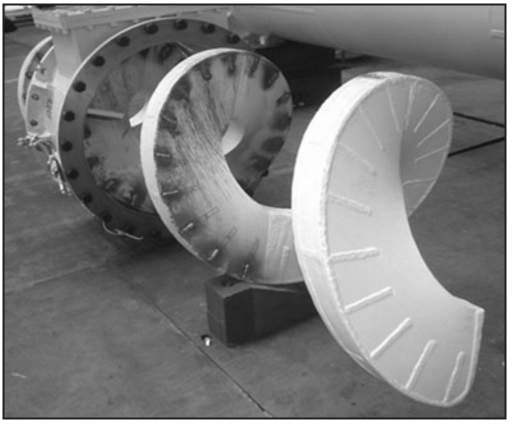

Figure 7. Example ribbon-type screw conveyor

Figure 8. Partial cutterhead assembly

launch shaft. Once at the surface, a radial stacker will deposit muck in a kidney-shaped pile for temporary storage. This system will be used on all three lots.

The three continuous conveyor systems, also provided by The Robbins Company, consist of 762 mm wide fabric belt at a 3,200 m length and 900 MTPH capacity. Approximately 22% of the conveyor systems will be traveling through curves, with a minimum 700 m curve radius. To better handle curves, the systems will utilize patented self-adjusting curve idlers. The idlers help by pivoting to accommodate changing load tensions around curves. The pivoting action is also favorable because it does not unnecessarily alter the carrying capacity of the conveyor or the belt tension.

Articulation

For accurate tunneling through curves, each machine will feature active articulation. Active articulation engages articulation cylinders between the front and rear shields to steer the machine independently of the thrust cylinders. The process allows the thrust cylinders to react evenly against all sides of the segment ring during a TBM stroke in a curve. Typical configurations, which use flat joints to articulate the shield, are capable of making 2 to 3 degree curve adjustments over the length of the segment or stroke.

Another reason active articulation was chose for this project was the risk of segment deformation, or racking. A common cause of project delays, deformation toccurs most commonly when the passive articulation system is used in curves. Passive articulation does not utilize articulation cylinders independent of the machine's thrust cylinders, so the TBM reacts against sides of the segments unevenly in curves.

Segments and Back-filling System

The machines will line the tunnels with reinforced concrete segments 400 mm thick, in a 7+1

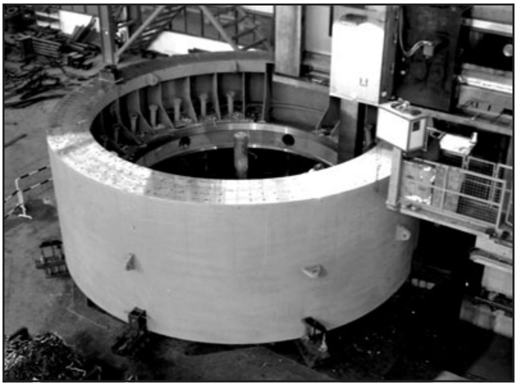

Figure 9. Forward shield assembly

Figure 10. Back-up system assembly

arrangement. Each segment is 1,500 mm in length and weighs approximately 60 kN. The finished tunnel diameter will be 7,800 mm.

To back-fill any voids behind the segments and minimize ground settlement, the machines are utilizing two-liquid back-filling. Two-component backfill, made up of cement plus an accelerant, is used to harden ground rapidly. Grout is injected and the two separate components are mixed where the completed rings exit the tail shield. The mixture fills the annulus between the completed segment rings and surrounding soil. Volume and pressure of the backfill grout injection are constantly monitored and controlled to minimize surface subsidence, a concern in tunnels with low cover and in urban areas. After each injection, water is forced through the pipes to prevent clogging.

PROJECT SPECIFICATIONS

Current Status of Machines

The machines were designed by Robbins with manufacturing done in various Robbins manufacturing plants worldwide. Various components were subassembled and shipped for full workshop assembly in a Robbins workshop located in Corpus Christi, Texas, USA. The Corpus Christi workshop in Texas was selected due to its close proximity to the jobsite. Large assemblies will be loaded onto a barge and shipped directly to a Mexican port for ease of transportation to the jobsite. As of November 2009, partial cutterhead assembly for the Lot 4 machine had been completed, as well as assembly of the Lot 3 forward shield and back-up system (see Figures 8–10).

Shaft Construction

The three 16 m diameter launch shafts are 80 m, 100 m, and 150 m deep. Machine launch and breakthrough will be as follows:

Figure 11. Slurry wall construction, Shaft 20, November 2009

- Lot 3 EPB TBM starting from shaft 13 and boring upwards to shaft 10.
- Lot 4 EPB TBM starting from shaft 17 and boring upwards to shaft 13.
- Lot 5 EPB TBM starting from shaft 20 and boring upwards to shaft 17.

Shaft construction is currently underway. At the surface, shaft construction begins by building slurry walls. Several of the slurry walls for the excavation support, including shaft 20, are being excavated using a hydromill (see Figures 11–12). Once the slurry walls are constructed, most of the shafts are being excavated conventionally using a backhoe. Stable ground below the slurry walls is supported using wire mesh and shotcrete. Material is removed from the bottom of a shaft using a crawler crane (see Figure 13). To excavate each shaft dewatering is also needed. Outside each shaft are four installed pumping stations that operate during the course of excavation. Volumes of water being pumped are as follows:

- Shaft 13—5 liters per second
- Shaft 17—2 to 3 liters per second
- Shaft 20—2 to 3 liters per second

Figure 12. Hydro excavator machine, shaft 20

CURRENT SCHEDULE

After assembly is completed, the machines will be shipped to the jobsites in Spring 2010 where they will be lowered into separate deep shafts using mobile boom cranes. Each machine will start from a different 16 m diameter shaft at either 80 m, 100 m, or 150 m deep. Current schedule milestones are documented in Table 2.

Partially assembled machine components weighing as much as 120 metric tons will be lowered down the shafts to reduce assembly time underground. The 14.5 m long ribbon screw must be altered since its length exceeds available space in the shaft. The screw will be lowered in two halves and welded together through an inspection hatch on the casing. Once the ribbon screw has been installed the machine will be pushed a minimum of 30 m into a pre-excavated starting chamber. This arrangement will make space for installation of the machine's rear shield, bridge section, and the shaft-type screw conveyor. A shortened back-up system, including electrical cabinets, transformers, and the hydraulic system will also be assembled. Upon completion the TBM will bore forward approximately 50 m with a temporary mucking system until the remaining 65 m of back-up equipment can be installed.

Figure 13. Shaft 13, November 2009

Table 2. Current scheduling milestones for Emisor Oriente project

	Lot 3	Lot 4	Lot 5
Forward shield assembly	Nov-09	Dec-09	Jan-10
Rear shield assembly	Dec-09	Jan-10	Feb-10
Main drive assembly	Dec-09	Dec-09	Jan-10
Back-up system assembly	Dec-09	Dec-09	Jan-10
Conveyor system	Dec-09	Jan-10	Feb-10
Cutterhead assembly	Jan-10	Dec-09	Feb-10
Final testing	Jan-10	Feb-10	Mar-10
Delivery to jobsite	Feb-10	Mar-10	Mar-10

REFERENCES

Willis, D. (2009). Robbins Trio dig deep in Mexico. *World Tunnelling,* April, 12.