# Tunneling the Largest Water Line for the City of Houston

Michael A. Salinas[1], PE, Michael V. Liga[1], PhD, PE,
And Kevin Tran[2], PE
[1]Lockwood Andrews and Newnam Inc, and [2]City of Houston
Houston, Texas.

The City of Houston (City), along with four regional water authority partners and with partial funding by the Texas Water Development Board (TWDB), are currently in the design and construction for a series of water transmission main projects ranging in size from 120-inch to 54-inch diameter. When complete, the project will provide treated water to the City along with various Water Authorities including North Harris County Regional Water Authority (NHCRWA), Central Harris County Regional Water Authority (CHCRWA), West Harris County Regional Water Authority (WHCRWA), and North Fort Bend Water Authority (NFBWA).

Five of the 108-inch diameter NETL water line projects with a total approximate length of 41,000 linear feet have been released for construction with approximately 5,000 linear feet to be constructed via tunneling. The contractor has several means and methods to excavate the tunnel for this diameter water line, including but not limited to open face tunneling, tunnel boring machine (TBM) with face closure abilities, and a pressurized face TBM. Open face tunnel construction is typically performed when cohesive soils exist at the tunnel face and immediately surrounding the bore area and groundwater can be controlled. A TBM with face closure abilities is recommended where non-cohesive soils are encountered or mitigation of settlement is critical and groundwater can be adequately controlled. A pressurized face TBM may be required where saturated non-cohesive soils are encountered in the tunnel zone and dewatering is expected to be difficult or not possible. Subsurface chemical treatment to stabilize the in-situ soil is also an option to create a suitable stratum for tunneling operations in conjunction with a non-pressurized face TBM.

Open face tunnel construction is the preferred tunnel method where cohesive soils are encountered and no critical structures are present along the alignment. This tunneling method can include hand or mechanized mining within a tunnel shield or use of an open face TBM. Hand mining is the most commonly used tunnel method in the area. Hand mining may be considered where a non-cohesive strata is encountered and groundwater can be controlled; however, tunneling operations will proceed more cautiously to prevent ground loss as well as tunnel instability. It is also the slowest method. Prior to beginning open face tunnel construction, the groundwater table is required to be draw down. Excavated materials are placed into a muck cart and hauled out of the tunnel. Generally, the face of the tunnel is unsupported during hand mining operations in cohesive soils. If a non-cohesive strata is unexpectedly encountered, then the contractor can place breast boards at the face of the tunnel for support. To minimize settlement, the contractor is required to grout the annular space for every 4 feet of tunnel liner installed. A total of 11 liner plates will need to be bolted together to achieve a complete ring for this tunnel diameter. Contractors may consider placing temporary supports in the tunnel to prevent the liner from deforming in the vertical or horizontal plane during the tunneling operation.

A TBM with face closure abilities is recommended along the alignment where potential concern exists with mixed face conditions, tunnel stability and surface settlement. Groundwater conditions must also be favorable or adequately manageable. Several tunnels encounter mixed face conditions while crossing various right-of-ways (ROW's). Mitigating settlement under other entities ROW's is critical; thus, a closed face tunnel machine is recommended to ensure tunnel stability is maintained.

With a TBM that can close the face, the cutter head is driven by hydraulic motors via a drive shaft or planetary gear set. The cutter head can vary depending on the soils, and a window for spoils is open during excavation. For the cohesive soil encountered, the cutter head is manufactured with 6 blades consisting of cutter teeth (spade type) welded to each blade in a staggered formation. Not only will the blades provide a consistent and uniform excavation across the face during tunneling operations, but also ensure a full cut displacement is achieved. As the tunnel face is excavated, the spoils are transferred through the window into the shield and onto a conveyor system. The spoils are then transported into a muck cart and out of the tunnel. If running ground is encountered, the window at the face can be closed to prevent soil intrusion until groundwater can be controlled and excavation can continue. Stability plates are also included within the machine to provide stability and create a drag if necessary. These plates can also assist in steering the machine. A laser will be mounted in the shaft to ensure the tunnel stays on alignment.

There are two types of pressurized face TBM's: a Micro-Tunnel Boring Machine (MTBM) and an Earth Pressure Balance Machine (EPBM). Both machines have extensive setups, require a large operational footprint, and have limited availability in North America. An EPBM uses the existing soil and soil conditioning additives with an auger system to pressurize the face of the tunnel to counteract the soil and hydrostatic pressure. The machine lines, such as the slurry/foam and electrical lines, are connected and extended as the EPBM progresses forward to keep the drive shaft in production. The pump, motor, hydraulic and slurry lines are typically staged inside tunnels of this diameter. Backup pump and motor are used on the surface to maintain system operability in case of failure of the primary system. Where casing pipe is used for the primary liner, intermediate jacking stations (IJS) are required on longer drives to ensure there is adequate force to prevent the casing from getting stuck. The operator typically sits within the machine and directly monitors and responds to the system readouts, such as data from the pressure transducers, alignment sensors, and advancement rates among other available data. Remote monitoring of the system is also possible.

A MTBM is similar to an EPBM; however, a slurry is directly injected at the face of the tunnel to ensure tunnel stability rather than use an auger system. A steerable, rotating bi-directional cutter head is required for this tunnel method. A MTBM will also have the pump, motor, slurry and electrical lines inside of the tunnel as well as a backup pump and motor at the surface. As the tunnel is advanced, a variety of cables are connected and extended within the tunnel such as the slurry trunk lines, power equipment, booster pump, guidance system and communications trail. Unlike an EPBM, the MTBM operator monitors and operates the system remotely from a workstation on the surface. The operator is able to adjust many facets of the machine including the cutter head's location, rotation, torque, jetting, jacking thrusts, steering slurry flow and various pressures on a two monitor system. IJS are required on longer drives as well with this method when using casing pipe for the primary liner.

A tunnel underneath a TxDOT overpass (IH-69) has its own complications. A small portion of the alignment falls within a potentially petroleum contaminated area which limits liner options due to groundwater infiltration concerns. The proposed tunnel crosses a dense silty-sand soil strata underneath the bridge. A preliminary settlement analysis performed assuming the use of a TBM with face closure abilities indicated excessive settlement underneath the highway. Given the potential impact to the drilled shaft foundations, an EPBM was considered Given the availability and cost to procure a pressurized tunnel boring machine, an alternate using soil stabilization in conjunction with a TBM with face closure capabilities was evaluated. Detailed grouting requirements were developed in both the design and construction phase. Two types of grout solutions, sodium silicate and acrylate, were recommended to stabilize the sand strata. Successful application would essentially turn the native non-cohesive soil into a sandstone with low permeability. Using this method, the estimated settlement was reduced to 0.6 inches, enough to prevent impact to the drilled shaft foundations. However, in construction the contractor obtained approval to utilize an EPBM with jacked casing.

A 108-inch diameter tunnel has several means and methods available to consider for completing a tunnel in place. An approximate 5,000 linear feet out of the 41,000 linear feet of 108-inch water line is currently constructed via tunneling either by open face tunnel construction, TBM's with face closure abilities, and/or a pressurized face TBM. Approximately 46,000 linear feet of 108-inch water line remains to be released for construction with approximately 4,000 linear feet to via tunneling. We will continue evaluating each tunnel on a case by case basis to mitigate and minimize any settlement and instability concerns.