Hitting the Mark

Crossing the Guadalupe River with the Second Vertical-Curved Microtunnel in the United States

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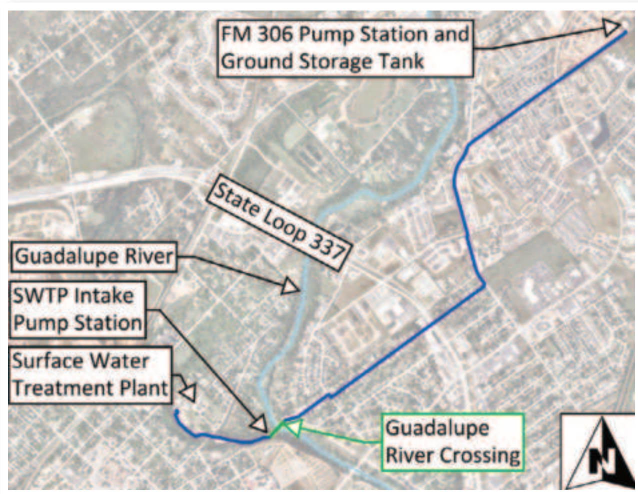


Figure 1. SWTP Discharge Water Line alignment and location of related improvements

INTRODUCTION

New Braunfels, Texas has experienced extraordinary growth over the past two decades, nearly tripling in size to a 2023 estimated population of over 105,000. This growth has come with challenges for New Braunfels Utilities (NBU), which provides the City of New Braunfels ("City") with electricity, water, and sewer infrastructure. NBU updated its Water Resources Plan in 2018 to prepare for the city's projected growth, with $600+ million in water and sewer capital improvement projects planned over the next five-year period.

This plan included the expansion of NBU's Surface Water Treatment Plant (SWTP) from an 8 million gallons per day (MGD) capacity to a 16 MGD capacity. NBU retained Plummer Associates, Inc. ("Plummer") to design the SWTP Discharge Water Line Project (shown in Figure 1) and Plummer retained Aldea Services, Inc., as its tunneling engineering subconsultant. The Project increases the SWTP's treated water transmission capacity using a waterline connecting the SWTP to NBU's FM 306 Pump Station and Ground Storage Tank, in anticipation of the future plant expansion.

PROJECT OVERVIEW AND ALIGNMENT

Plummer performed a desktop alignment study to determine the optimal pipeline route, which is shown in Figure 1. Plummer chose this route because it was the lowest cost option, was the only route that avoided conflict with future City drainage and pavement projects, and was the only route that did not require easement acquisition on privately-owned land, limiting potential delays and real estate cost uncertainty. However, the route did require the crossing of the Guadalupe River on a tight tolerance, which presented risks and challenges for the design team.

Based on the water modeling and alignment study, Plummer designed a pipeline consisting of approximately 10,000 linear feet (LF) of 30-inch diameter pipeline (with 413 LF at the Guadalupe River crossing, discussed below) and 2,785 LF of 24-inch diameter pipeline.

Ultimately, vertical-curved microtunneling was utilized for the crossing

GUADALUPE RIVER CROSSING ALIGNMENT AND GENERAL CHALLENGES

General Challenges

The chosen alignment was selected because it was the lowest cost option and limited private easement acquisition. However, the Guadalupe River crossing (shown in Figure 2) presented several design challenges:

1. The southwest side of the river had very tight clearance between the SWTP Raw Water Intake Pump Station (which had to remain in service throughout construction and could not be affected) and a 20-feet+ steep embankment.
2. The river crossing required a permit from the Texas General Land Office, which NBU indicated requires either a cased installation or that the pipeline be shut down annually to conduct leak testing. Because this project is vital to NBU's water supply, Plummer strongly preferred a cased installation.
3. The existing ground at the crossing location had a 20-foot surface elevation difference at the installation shaft locations, such that a horizontal installation could have required a shaft up to 60-feet deep adjacent to the pump station.

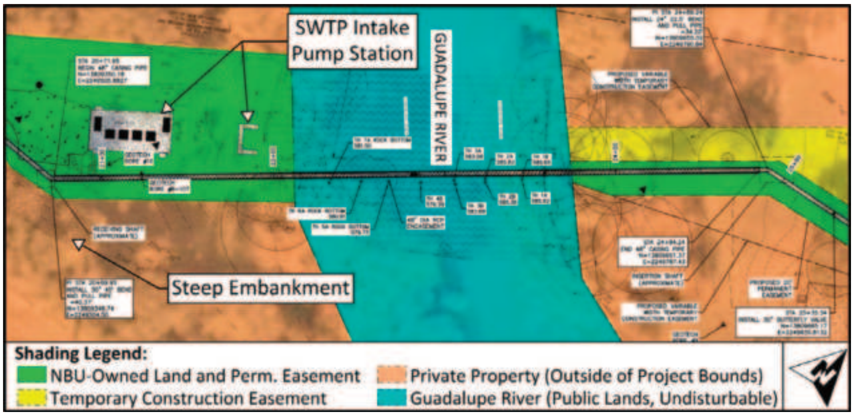


Figure 2. SWTP Discharge Water Line Guadalupe River crossing alignment

TRENCHLESS METHODS CONSIDERED

Three trenchless methods were considered for the river crossing:

1. Horizontal Auger Boring (HAB)
2. Horizontal Directional Drilling (HDD)
3. Vertical-Curved Microtunneling (MT).

Ultimately, vertical-curved microtunneling was utilized for the crossing.

Horizontal Auger Boring (HAB)

HAB employs an auger boring machine to jack steel casing segments forward while removing the spoils through a rotating auger chain positioned within the casing pipe and fitted to a cutter head at the front of the casing. The rotating cutter head excavates the soil in front of the casing, which is then transported back to the jacking pit where the soil is removed by hand or machine. HAB had several drawbacks that eliminated it as an option:

1. It is not generally steerable and therefore line and grade are set during initial set up.
2. It is typically limited to stable soils above the water table or soils that can be actively dewatered.
3. It can have issues in harder rock without specialized attachments.
4. Because HAB is linear, the shafts would be 25 feet deeper than with curved installations, which would increase costs, pump station damage risks, risks for line and grade issues, and risks of encountering difficult-to-excavate rock.

Horizontal Directional Drilling (HDD)

HDD is a steerable method that uses a surface-launched drilling rig to install the pipeline in three stages:

1. Pilot Drilling: A small diameter pilot hole is drilled along the drill path, with directional control achieved using a steerable drilling bit or assembly.
2. Pre-Reaming: The pilot hole is enlarged to the required diameter by pre-reaming using at least one pass with a reamer tool/attachment.
3. Pullback: The pipeline is pulled back through the enlarged and clear bore hole.

HDD allows for over 3000 feet between entry and exit pits, minimal surface disturbance and adjacent land impacts, smaller shafts/pits than some other technologies, and as minimized excavation, dewatering, and shoring efforts. It is also possible to steer away from encountered obstacles. However, because HDD requires extensive longitudinal laydown area for pipe layout, has few options for the installation of large-diameter pipe, and does not have positive tunnel support during the potential several passes that may be required during Pre-Reaming, it was removed as an option.

Vertical-Curved Microtunneling (MT)

In a vertical-curved microtunnel, a slurry microtunnel boring machine (MTBM) is used to trenchlessly install pipelines. During construction, the MTBM excavates the ground material and is simultaneously jacked into the ground. The jacks are then retracted, and the slurry lines and control cables are disconnected so that a joint of carrier or casing pipe can be lowered into the shaft and inserted in the jacking frame. Lines and hoses are then reconnected and the pipe/MTBM are advanced another drive stroke. This process is repeated until the MTBM reaches the reception shaft.

During microtunneling, the excavated envelope was lubricated using bentonite injected via grout ports in the microtunnel pipe during pipeline installation to fill the annular space between the outside of

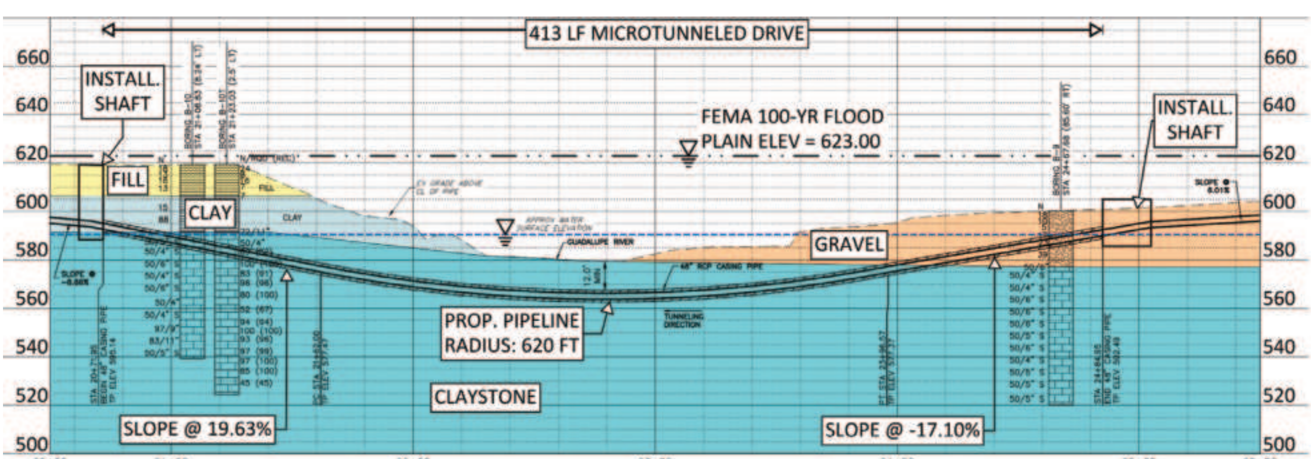


Figure 3. Guadalupe River crossing profile (1H:1V scale) with ground conditions shown (southwest bank is on left)

the pipe and the excavated surface. Upon completion of the microtunnel drive, the space between the jacked pipe and the surrounding soil was grouted.

However, the MTBM provides positive tunnel support, is highly accurate, and can be installed in the mixed soil conditions found in this crossing; additionally, the curved alignment minimized shaft depths. Therefore, the design team opted to utilize a vertical-curved microtunneling installation for the crossing of the Guadalupe River.

The curved alignment design required special consideration of eccentric/non-uniform jacking forces, minimum allowable radius, maximum allowable pipe length, minimum required overcut, and maximum allowable joint deflection on curve to maintain water tightness. As shown in the pipeline crossing profile in Figure 3 (at a 1:1 horizontal-to-vertical scale), the tunnel was installed on a 19.73 percent downslope, through a tight 620-foot radius curve and recovered on a 17.10 percent upslope.

GUADALUPE RIVER CROSSING ANTICIPATED (BASELINE) GROUND CONDITIONS AND CHALLENGES

Geotechnical Baseline Report

The design team anticipated that the Guadalupe River crossing would have geotechnical risks, and thus created a Geotechnical Baseline Report (GBR), which is a contract document that establishes a statement of the baseline subsurface conditions the Contractor can expect to encounter during construction. The GBR was this project's sole document for geotechnical interpretation, reflecting the design team's interpolation between geotechnical borehole data, engineering judgment, past construction experience, and the Owner's attitude towards risk. The GBR baselines are used to judge the merits of any differing site condition claims, regardless of how the Contractor bid the work.

Anticipated Ground Conditions

In general, the tunnel was constructed through stratigraphy consisting of clay, claystone, and gravel (shown in Figure 3). On the northeast bank of the river, gravel alluvium with potential cobbles was the anticipated ground for the entirety of the shaft and for the last 100 LF of the tunnel. On the southwest bank of the river, fill underlain by clay was the anticipated ground for the shaft with the initial launch made into approximately 15 feet of clay followed by a transition into bedrock.

The Pecan Gap Chalk, described as a bluish gray, weak to very weak calcareous Claystone, was the predominant bedrock formation encountered during construction of the Project with the upper 5-10 feet of the rock expected to be weathered. Approximately 300 feet of the tunnel was anticipated to be entirely within the Pecan Gap Chalk, including the apex of the vertical curve.

GEOTECHNICAL CHALLENGES

Many potential geotechnical challenges were anticipated during construction. These challenges included:

CURVE GEOTECHNICAL CONDITIONS: One of the biggest considerations for a vertical-curved microtunnel is ensuring that the tunneling medium is conducive to excavating a curve. At the curve apex, the geotechnical conditions require subsurface material that is strong enough for the MTBM to "bite into" and make the curve, but not too hard to prohibit the curve itself. Additionally, if the tunnel is to be excavated through more than one tunneling medium, it is important that the material strengths do not have a large differential. However, the Pecan Gap Chalk found near the Guadalupe River proved the ideal curve material.

MIXED GROUND CONDITIONS DURING TUNNELING (CLAY TO CLAYSTONE TO GRAVEL): Mixed ground types encountered during construction can be problematic during tunneling. The microtunnel profile (Figure 3) passed through ground types with different properties and behavioral characteristics. During microtunneling, with the Claystone in the invert and gravel encountered above, the machine will likely advance slowly while cutting the claystone as it continues to draw in the less stable soil above; this can lead to over-excavation and settlement at the ground surface or voids which can create potential long-term instability problems.

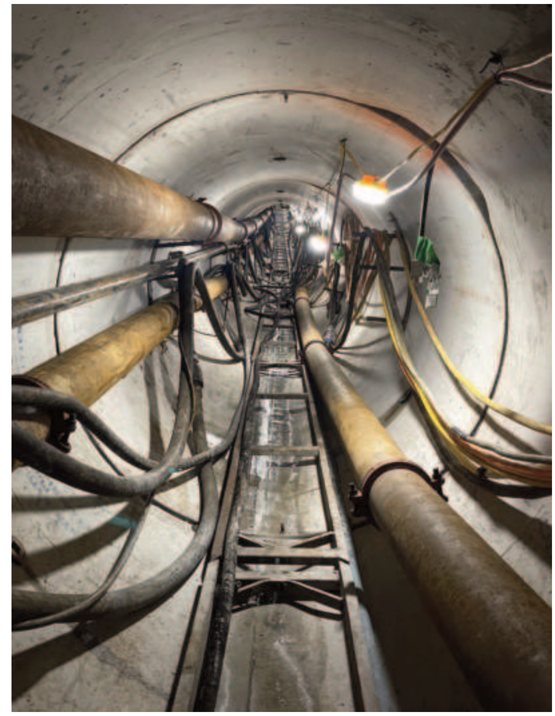


Figure 4. View of the downslope of the tunnel approaching the apex of the curve

Figure 6. Jacking frame and casing pipe wihin installation shaft

Figure 5. RCP hydraulic joint configuration

CONSTRUCTION

The Guadalupe River crossing was constructed on the following schedule:

Launch Shaft Installation:	08/01/22 – 08/26/22
Receiving Pit Installation:	10/10/22 – 10/14/22
Pre-Construction Conference:	10/13/22
Microtunnel Launch and Installation:	10/15/22 – 12/13/22
Carrier Pipe Installation:	12/14/22 – 12/16/22
Water Line in Service:	03/07/23
Substantial Completion:	04/18/23

STICKY CLAY: The microtunnel was advanced through both the Pecan Gap chalk and the Clay above the chalk, both of which are composed of high plasticity calcareous clay with medium to high stickiness potential; this can cause clogging of equipment, impede spoils removal from the MTBM cutter head, and create other complications that slow or stop construction progress. In such cases, additives can be used to limit the reactions that cause stickiness and clogging.

UNKNOWN TOP OF ROCK (TOR) ELEVATION AT THE RIVER: During design, the two available borings were on either side of the river. To determine how deep the tunnel needed to be to avoid the risk of river water infiltration, a probing investigation was conducted across the river. For this effort, a surveying team manually drove rods into the river bottom at regular intervals and took survey shots and pictures to obtain the TOR elevation. Once the TOR was confirmed, the clear cover above the tunnel crown could be defined and used to guide the design.

TIGHT CURVE RADIUS: There was very little flexibility in locating the shafts, and therefore, the curve radius of 620 feet was both necessary and a very tight curve to complete for 48-inch diameter pipe. Consequently, regular technical conversations with the hydraulic joint manufacturer were scheduled to ensure the curve radius was feasible. The extremity of the curve can be seen in Figure 4.

VERTICAL-CURVED MICROTUNNEL CONSIDERATIONS AND DECISIONS

Carrier Pipe Material

Ductile iron pipe (DIP) is the carrier pipe material for the rest of the project and was also originally planned the river crossing. However, discussions with DIP manufacturers revealed that while DIP can be deflected at each pipeline joint during open cut installation and in certain curved trenchless installations, given this project's severe vertical curve and pipe diameter, they did not feel comfortable rating it for use in this trenchless application. Therefore, Plummer instead utilized high-density polyethylene (HDPE), which allowed for installation on a sharp curve.

Casing Pipe Material

To achieve the curve, it was necessary to use precast reinforced concrete pipe (RCP) with hydraulic joints for the casing/jacking pipe. Hydraulic joints are composed of a mechanically fixed hydraulic joint attached to the pipe joint wall (see the black ring in Figure 4). Hydraulic joints utilize a pressure transmission ring that enables the jacked pipes to pass through curved alignments with no reduction in allowable jacking force or pipe length and provides real time monitoring to ensure pipes are not overloaded during jacking. The only significant design modification from standard MT jacking pipe is the inclusion of a cavity in the pipe's bell. This cavity ensures that the steel fittings (shown at top left of the joint in Figure 5) at the ends of the hydraulic hose are not clamped between the pipe joints.

Optimization of the Curve Radius

The alignment radius proved to be a challenge for the project as the launch and receiving locations were limited. Developing the curve radius was a balance of alignment length, carrier pipe diameter, casing pipe diameter, maintaining the adequate cover between the base of the river and the top of the casing pipe and the minimum curve radius capacity of the

Figure 7. Site constraints limited launch and receiving pit locations

Figure 8. Installation was generally smooth except for sticky clays

hydraulic joints. Changing any of those elements resulted in additional capacity and clearance checks of the other elements.

Project was successful because of proactive steps taken to ensure that risks were properly considered

Tunneling Pre-Construction Conference

Because a vertical-curved microtunnel is novel within the United States, a separate pre-construction conference was held specifically for the river crossing. This meeting allowed impacted parties to discuss the crossing and ensured that parties were on the same page before installation. Further, it opened dialogue that allowed the tunneling subcontractor to feel informed and supported throughout construction. Ultimately, this was particularly valuable prior to the highest-risk portion of the project.

No major issues were encountered during construction; at times, swelling clay slowed the advancement of the MTBM, but the Contractor countered that by using additives to overcome the stickiness of the clay. Otherwise, installation was a generally smooth process.

CONCLUSION

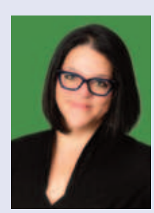
A vertical-curved microtunnel was used on the Guadalupe River crossing, which allowed for the cased installation of a water main on line and grade. This installation method minimized project risk and the curved installation reduced shaft installation costs. However, the higher design effort and overall construction costs means this method is not optimal for most trenchless installations but is preferred under the right circumstances.

Ultimately, the project was successful because of the proactive steps taken to ensure that risks were properly considered and addressed. This was aided by close communication between the owner, engineers, contractors, and construction manager; this started between the client and consultants during design and continued between the client, consultants, and contractors during pipeline construction.

ABOUT THE AUTHORS:

Robert Weinert, P.E., has nine years of engineering experience on water and wastewater pipelines from 6-inch to 72-inch diameter, as well as pump and lift stations. He is currently the president of the Oklahoma City branch of the American Society of Civil Engineers, has a B.S. in Mechanical Engineering from Baylor University, and is a licensed professional engineer in Oklahoma and Texas.

Jesse Guerra, P.E., has 32 years of experience, 26 of which includes working for a major utility (with several of those years directly responsible for construction of the utility's $400M CIP). His projects include water distribution, wastewater collection, production, wastewater treatment, recycled water facilities, lift stations, water booster stations, and large diameter wastewater outfall mains.



Ashley Heckman, P.E., is a geologist and tunnel engineer with nearly 25 years of experience in performing geologic characterization, tunnel lining analysis and design, site inspection, condition assessment and construction management. Her tunneling experience includes microtunneling (MT), horizontal directional drilling (HDD), horizontal auger boring (HAB), NATM, EPBM, Rock TBM, tunnel inspection, and tunnel rehabilitation.