A LOOK INTO TUNNEL CONSTRUCTION
Ohio River Bridges East End Crossing

by

JOSEPH M. KAUFMAN JR.
University of Cincinnati
Civil Engineering Student
Class of 2018
Co-op with Walsh Construction

June 2016
Tunnels have carved through mountains, bored under waterways, and passed under streets in urban cities. Today, tunneling offers solutions to new civil engineering challenges experienced by evolving infrastructure needs. This paper will outline the structural construction process of the Ohio River Bridges - East End Crossing Tunnel project and provide a look into the loads and forces experienced by the construction equipment.

Alfred Nobel’s dynamite patent in the late 1800’s allowed tunneling to become a more practical construction practice through the use of Drilling and Blasting. Since then, tunneling has developed through three main techniques. The first is known as the New Austrian Tunneling Method (NATM), or Drill and Blast. This method begins with drilling the earth and using dynamite to blast the earth away. The excavation is usually stabilized with rock bolts and shotcrete. A structural concrete liner is usually constructed inside the tunnel. Drill and Blast is generally used for larger, irregular shaped tunnels.

A second tunnel method commonly used today is the Tunnel Boring Machine (TBM) method. A large circular cutting head positioned on the front face of a sliding train like machine is responsible for slowly grinding away the earth as the cutting heads rotate. Generally a precast concrete panel system is installed immediately at the tail end of the train, simultaneously to the cutting. This method was used in Japan’s Seikan tunnel, a 33 mile long channel, classifying it as the world’s longest tunnel.

The last method commonly utilized is the Cut and Cover technique. Instead of boring or blasting, a trench is excavated in soft soil and roofed over. A significant challenge in this method of tunneling is designing a strong enough roof system to avoid the top of the new tunnel from collapsing in. This method was used in NYC for much of the original subway system.

Most of the time tunnels are constructed in order to avoid overhead obstructions or to cut through harsh landscape. Louisville, Kentucky wanted to complete its I-265 highway system but ran into some problems at ground level. In their case, a historic land ordinance and continued opposition from the surrounding community persuaded the Kentucky Department of Transportation to tunnel under the historic landmark and hide the highway traffic from the local community. The Walsh Group and Vinci Construction joint ventured for the project involving two 1,680 ft long tunnels each providing up to three full lanes of traffic.

The tunnel roadway surface was designed to be about 60 feet below the existing grade. Geotechnical studies reported a composition of Louisville Limestone with accents of Waldron Shale. Large quantities of earth had to be removed from each end of the tunnel portals in order to excavate the tunnel channels. The challenge was overcome by creating “Approach” pits in the ground with a gentle slope for highway vehicle access. Because of the presence dolomitic material, blasting was selected as the most efficient method for the project excavation.
As part of this Drill and Blast method, Magnafrac, a packaged emulsion explosive, was loaded into drilled holes in the earth and then detonated. Once the limestone was blasted away on either side of the tunnel’s portals, a similar process was used to blast out each channel of the tunnels starting from one end and working to the other. Careful planning was crucial during the tunnel excavation. The horizontal blasting exposed loose overhead material and required immediate reinforcing to prevent rock fall and over-break. Twenty foot rock anchors were drilled and epoxied into the remaining earth above to stabilize loose rock. A six inch thick layer of shotcrete followed for a final smoothing stabilization coat. Once the tunnel was completely blasted and stabilized, construction continued from the ground up.

This tunnel was designed with a drainage system below the roadway to handle rainwater. A six inch mud mat was laid before pouring the twenty inch thick roadway surface (referred to as the “Invert”) which ensured a durable work surface. The rebar installers placed the top and bottom rebar mats including continuous dowels to extend above the road surface to eventually splice into the concrete liner overhead. A bulkhead was created to break the 1680 foot tunnel length into roughly six roadway pours. A Bidwell made concrete finishing an easy task.

**Picture 1.** South Portal of the tunnels under construction. Note the large excavation and close proximity to residential housing nearby. Surrounding structures were a concern during excavation and construction.

**Picture 2.** Pouring the Concrete Roadway Invert. Note the use of the Bidwell and the continuous dowels against the tunnel walls.
Once the Invert was poured, the arched concrete walls (referred to as the concrete “Liner”) could begin. The tunnel received additional shotcrete to give a closer profile of the tunnel shape for the concrete liner. The liner was required to be poured at least 16” thick. The tunnel was surveyed for areas that would produce too tight of a clearance and an excavator equipped with a carbide grinding tool ground away shotcrete as needed.

The underground cave-like tunnels naturally were very wet. Keeping water out of the structural system was very important. The shotcrete helped divert surface water, but more protection was required to ensure the concrete construction’s lifelong integrity. The solution included installing a yellow 1/8 inch thick PVC membrane along the entire length of the tunnels. This membrane was installed in about six foot segments and then fused together at the seams to create one continuous waterproof membrane.

![Picture 3. Waterproofing membrane installation. Note the finished Invert slab, the installation of the waterproof membrane over the smoothed shotcrete surface and the use of the red gantry system for the waterproofing installation crew.](image1)

The rebar crew followed the waterproofing crew to set the rebar mats into place. In order to assist with mounting the rebar arches overhead, the crew drilled anchors into the rock surface through the waterproof membrane and had to patch and seal every anchor hole drilled through the membrane.

![Picture 4. Rebar installation. Note the rod anchors installed in the waterproof lining and white gantry system for the rebar installation crew.](image2)
The concrete form system was designed by Everest Equipment Company and was the key element for this project’s success. The form acted as a support to allow concrete to be poured between the outside face of the form system and inside face of the excavated tunnel surface. The result: a thick structural concrete layer. The form system was able to pour forty foot sections at a time and support over 550 cubic yards worth of concrete which was required during some pours. The form carrier underneath served as a working platform. As one panel was completed, the form carrier was rolled forward forty foot and set up to pour the next panel. This jump-form technique continued for the length of the tunnel.

**Picture 5.** The concrete form system. This picture is taken during a live concrete pour. The concrete truck fed the concrete pump which delivered the concrete to various ports around the form system to fill the void. Note the use of a plywood and steel-bar bulkhead around the perimeter of the form to contain the concrete within the boundaries of the void.

As thousands of pounds of concrete material was pumped through this form, it was important to understand the forces involved during the concrete pour. This next section takes a look at what those forces were, and how they were successfully transferred to the form system.

**Picture 6.** Calculated load forces and expected stress forces. Note the asymmetric loading case due to the sloping Invert road surface. (Courtesy of Walsh/Vinci Construction and Everest Equipment Co.)
The form was filled with concrete from bottom to top. As the material began to pile up between the form and the rock wall, the concrete material produced a horizontal inward force on the form system, noted with the red arrows in Picture 6. To counteract this horizontal force, several dowels were drilled in the Invert to prevent the bottom of the form system from kicking in.

The system was also determined to be at risk of floating as the material piled up at the base of the form. The term “floating” takes into consideration the upward force of the stacked concrete material along the sides of the form system, suggesting an uplift force greater than the weight of the carrier. If floating were to occur, hundreds of cubic yards of concrete would spill out of the bottom of the form. To counteract the floating force, several “spuds” were placed through the form system and adjusted to press against the outside edge of the rock face, providing a strong oppositional force.

![Picture 7. Concrete Form System. Note Spuds, delivery ports and Invert pins located throughout the form.](image)

The weight of 550 cubic yards of concrete is a lot of force for a structure to withstand. Looking at concrete curing properties, the actual weight required to support becomes more realistic. As concrete begins to cure, the material solidifies and becomes self-supporting. This concept of liquid head was key in managing the risk by controlling the pour speed to 10 vertical feet of material an hour.

Once the concrete was tested for cure, the form was released and progressed to the next forty foot panel. Understanding the various forces acting on the form system allowed the workers to safely complete the tunnel liner. Finishing work mobilized after the completion of the structural concrete lining. This included barrier wall, sidewalk, electrical lighting, emergency response systems and tiling. The East End Tunnel project is a prime example of the Drill and Blast tunnel construction technique and is scheduled to open to traffic in the fall of 2016.
Structural concrete is complete. Tunnel finishes such as barrier wall, tile, overhead electrical, and sprinkler systems are being installed. The tunnel scheduled to open in the fall of 2016.

Works Cited

Walsh Construction, Civil Engineer, P.E.


All real photographs were personally taken on the jobsite. Courtesy of Walsh/Vinci Construction.