# **Drill & Blast:** Case History

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## ABSTRACT

Tunnel boring machines (TBM) are regularly specified to excavate hard rock tunnels, particularly near existing sensitive structures such as dams, where vibration damage is considered critical. The drill and blast tunnel method is not always considered to be an option. Depending on the length of the tunnel, the rock conditions and the proximity to critical structures, tunneling by drill and blast hand mining can be accomplished as safely as the TBM method yet can be more economical. Bradshaw Construction used the drill and blast hand mine method to successfully install a combined spill way and raw water main tunnel for the Rivanna Water & Sewer Authority at its New Ragged Mountain Dam in Charlottesville, VA. This paper gives a case history of the project and compares the economics of drill and blast hand mining with versus mechanized tunneling using a tunnel boring machine.

## EXISTING INFRASTRUCTURE & PROJECT HISTORY

In April 2012, the Rivanna Water and Sewer Authority (RWSA) awarded a contract for the New Ragged Mountain Dam project west of Charlottesville, VA. The purpose of the project was to increase the existing reservoirs storage capacity.

The work included constructing a new dam and spillway downstream of the existing dam, demolition and removal of portions of the existing dam and appurtenant structures, construction of a rock tunnel, foundation grouting, improvements to the I-64 embankment, slip lining the culvert beneath the I-64 embankment, and other general conditions.

All construction activities had to be completed without interruption of normal operations of the existing 18-inch raw water lines to the water treatment facility until the new raw water line is in service. RWSA obtained permits from the United States Army Corps of Engineers and the Commonwealth of Virginia Department of Environmental Quality for this project.

**SITE PLAN**

The installation and finishing of the rock tunnel was subcontracted to Bradshaw Construction Corporation, by Thalle Construction Company, the general contractor. This rock tunnel was 484 linear feet of 9'-6" minimum excavation, horseshoe tunnel supported by rock bolts and additional localized shotcrete support as needed. A new 36" DIP raw water main was installed within the tunnel to replace two existing 18" raw water mains buried within the existing dam. These provide drinking water for the City of Charlottesville. The remainder of the tunnel cross section was channelized to serve as the primary reservoir spillway.

Cutoff grouting was used to minimize reservoir seepage on the upper end of the tunnel. Tunnel excavation was specified as the hand mined method using controlled drilling and blasting.

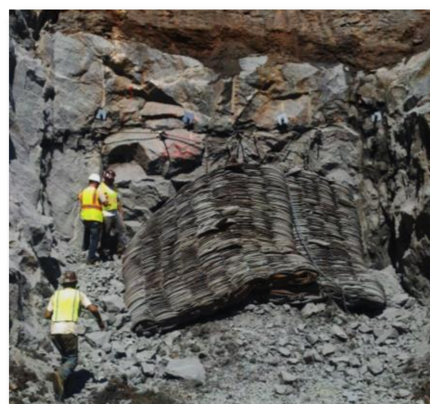
## PROJECT CONSTRAINTS

The project specifications required the following:

The tunnel contractor's personnel had to be experienced in drilling and blasting. The Tunnel Project Manager had to have at least 10 years of experience in rock tunnel construction by drilling and blasting and have successfully managed a similar tunnel project to completion within the last 6 years. The Tunnel Engineer had to have Bachelor of Science degree in civil, mining or geological engineering as well as both office and field experience in tunnel engineering of closely controlled and monitored tunnel excavations utilizing rock bolts and shotcrete as ground support. The Contractor's proposed blasting supervisor on each shift had to have a minimum of ten years of experience in tunnel excavation with the blasting methods and all licenses, as required.

Tunnel construction methods had to preserve the inherent strength of the rock mass surrounding the tunnel. The strength of the rock mass had to form the foundation of permanent support for the tunnel. Controlled blasting consistent with USBM RI-8507 required the particle velocities to be kept less than the limits below when measured at the nearest permanent structure.

The Peak Particle Velocity (PPV) limits were standard United States Bureau of Miners (USBM) safe blasting levels. These levels were established as a recommended vibration limit that would be highly unlikely to cause even cosmetic damage to fragile building materials such as drywall.



The limits are as follows:

| Frequency | Maximum PPV |
|---|---|
| >40 Hz. | 2.00 in/sec |
| $\leq$40 Hz. | 0.75 in/sec |

The drill pattern and depth for controlled blasting were designed and modified to achieve the highest possible degree of smoothness. If these conditions were not met as determined by the Engineer, the Contractor had to modify his blasting procedures until the required results are met.

The tunnel line and grade and tunnel cross sections were to be surveyed at maximum 20-foot stations. Tunnel cross sections were to be plotted and submitted to the Engineer verifying that excavation clearances throughout the tunnel prior to commencing the application of any type of final lining.

All equipment, materials and personnel accessed the tunnel portal (spillway outlet) via a two-mile long, winding gravel mountain road. Minimal improvements were made to the access road to preserve the existing forest conditions and not to transform it into a highway. Any loads delivered on trailers longer that 25’ had to be transferred to smaller trucks at the project’s staging area, or in the case of cranes, excavators, etc., had to be driven onto site under their own power.

At the tunnel receiving portal (spillway inlet) to the general contractor was building the new raw water intake structure while the tunnel was being excavated. The final tunnel blast was within six-feet of freshly poured concrete structure.

Even for this remote project location, there were concerns for adjacent property and business owners. Fears were expressed by a local summer camp that served disabled children that blast vibrations and air blasts would frighten participants and the camps horses. These important public concerns required the effective use of controlled blasting.

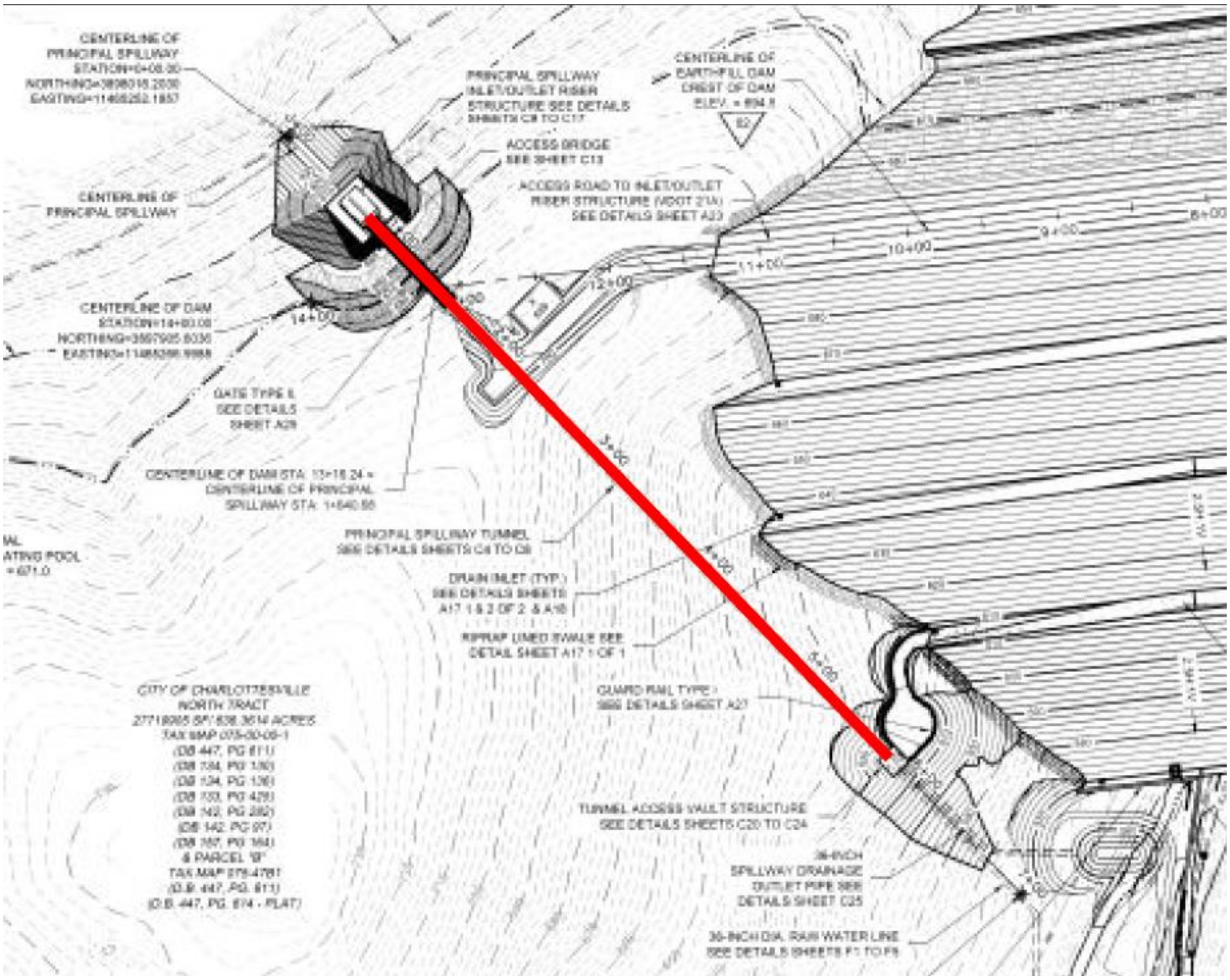
The owner and engineer prepared a rigorous and well thought out drilling and blasting specification. This included qualifications submitted with the bid demonstrating the proposed tunnel contractor had extensive experience using controlled drill and blast methods.

## GEOLOGY

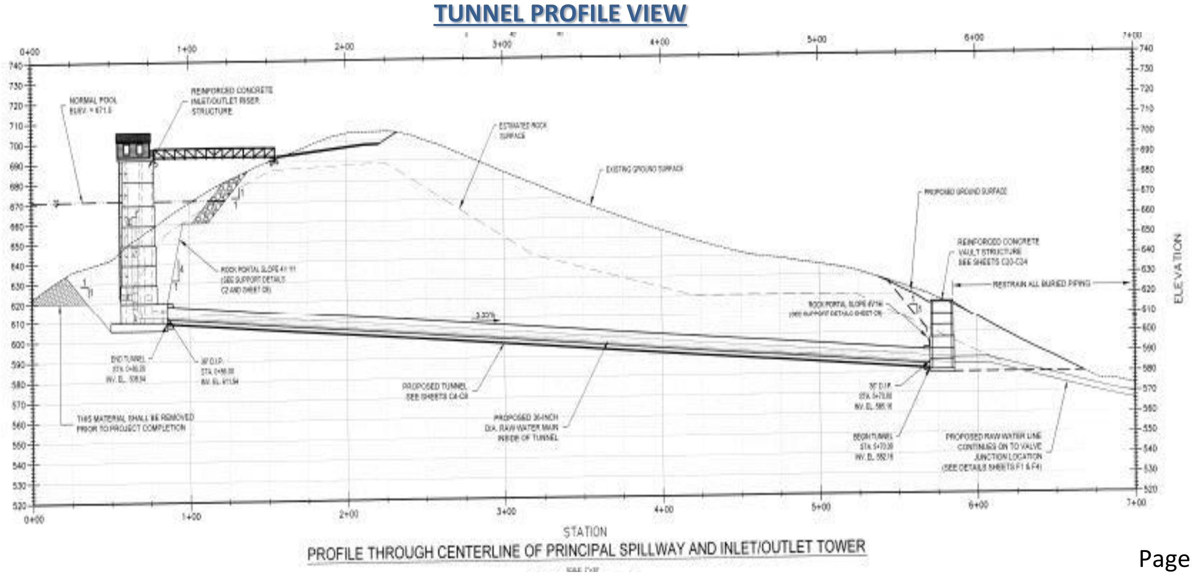
The site is located in the Blue Ridge Physiographic Province of Virginia. The geotechnical investigation found the rock at tunnel level to be granitic gneiss. It was strong to very strong with low hydraulic conductivity. The unconfined compressive strength ranged from 7,000 to 28,000 psi. RQD was typically 90-100% except at the portals where the rock had weathered.

## PROJECT DRAWINGS

**TUNNEL PLAN VIEW**




**TUNNEL PROFILE VIEW**



## DRILL & BLAST CONSTRUCTION

Tunneling began with the installation of portal supports. The Inlet portal required three (3) rows with eleven (11) 15’-25’ #11 epoxy coated rock bolts tensioned to 75 kips. The Outlet portal design required one (1) row with four (4) similar type and length rock bolts. Due to a seam of decomposed rock encountered at the Inlet portal, significant additional bolting was required to secure the overhang. 2” of shotcrete was applied to all surfaces.

At each end the tunnel cross section was enlarged by over blasting to create a five-foot long transition complete with additional shotcrete, rebar, and waterstops. This isolated the tunnel from the reservoir at the Inlet and the backfill at the Outlet.

Tunnel drilling and blasting was based on a pattern of 8’ deep drill holes on 2’ spacing. The dynamite pounds per delay ranged from 16 to 40 for each range using a powder factor between 8 and 12 pounds per cy. Holes were drilled with an air powered 2 boom jumbo. Mucking of the tunnel was by a 2 cy scoop tram.

Blasts were monitored using solar powered remote seismographs with cellular communications. The first was installed on the western end of the existing dam closest to the tunnel to monitor the vibrations transmitted to the dam by the blasting operation. The seismic trigger was set at 0.1 in/sec, well below the allowable USBM levels. This trigger level was rarely reached despite being less than 600’ from the blast location. In fact, the seismograph was triggered far more often by haul trucks passing by it than blasting operations.

As the tunnel excavation approached the on-going construction of the Inlet Structure, a second seismograph was installed on the structure footer. Vibrations at this location only exceeded the USBM limit once when the blast was 15’ from the structure with only 8’ of rock separating it from the tunnel.

The blasting pattern and depth was adjusted to complete the tunnel given the close proximity.  No damage whatsoever from vibration, flyrock or otherwise was found on the Inlet Structure, not even to the protruding waterstop.

## TUNNEL SUPPORTS

Rock bolts and welded wire fabric was installed in only one 15' section of the tunnel as it was mined.  Once the tunnel was completed, additional supports were installed.  The final tunnels supports consisted of the following:

- 372' of Type 1 - spot rock bolts
- 100' of Type 2 - rock bolts, 4" WWF and 2" of shotcrete
- 12' of Type 3 - lattice girders, No. 4 rebar on 12" cc and 6" of shotcrete

## TUNNEL CUTOFF GROUTING

Tunnel cutoff grout was specified to tie the tunnel into the Dam's surface installed grout curtain wall. DeNeef polyurethane was the specified grout.  Using the 2 boom jumbo, 1.5" diameter holes were drilled 12' deep.  There were seventeen (17) primary and seventeen (17) secondary grout holes for the three collars.  However, the polyurethane grout could not be pressured into the massive rock where it was originally planned, so it was moved to the Inlet end of the tunnel where poor rock conditions were encountered.

## ECONOMIC COMPARISON

Drill and blast hand mined tunnels were once the norm for rock tunnel excavation.  Over the past 50 years tunnel boring machines (TBMs) have supplanted that method primarily for economic reasons. And while drill and blast tunneling is still used regularly to create starter tunnels for TBMs, many consider it a potentially dangerous and destructive excavation method.  It is truly becoming a lost art for many of today's design engineers and owners.

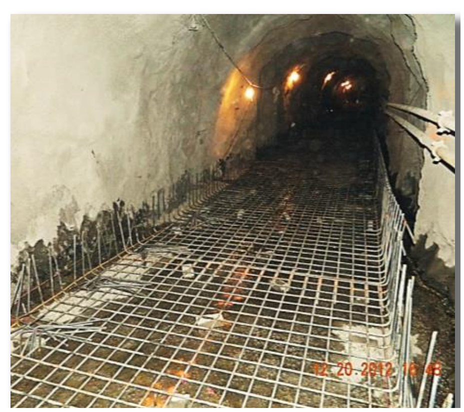
From our experience, drill and blast tunneling becomes economically preferred to TBM tunneling when: 1) tunnel lengths are generally less than 2,000 linear feet, 2) rock conditions are too variable, hard or abrasive for even the modern TBMs to excavate efficiently, and 3) when something other than a circular shape or relatively straight tunnel is required.

For this project, drilling and blasting was permitted by the Army Corp of Engineers (COE) and specified by the design engineer. However, prior to this project COE rejected drilling and blasting proposed by the engineer for a similar size tunnel. Apparently, the COE feared vibration from blasting would damage the existing dam core. This over ruled any economic considerations between the two tunneling methods.

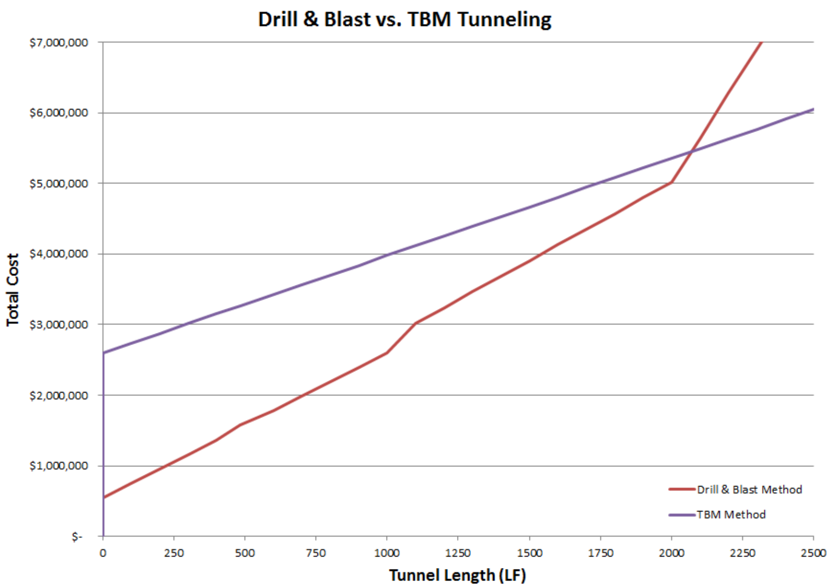
By allowing drilling and blasting on this project, substantial cost was saved over the use of a TBM. The factors affecting this were:

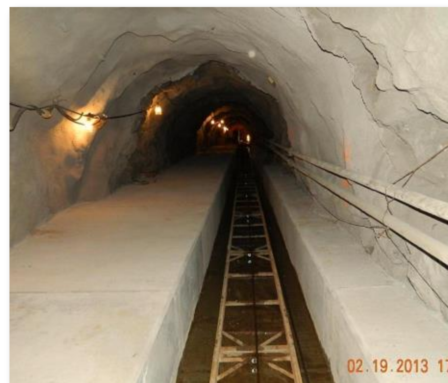
1. Tunnel length only 484’
2. Inability to recover a TBM from the receiving portal
3. Difficult access to launch portal limiting the size and weight of equipment used
4. Limited availability of TBMs that could excavate the 9’-6” diameter tunnel
5. Readily available equipment necessary to mechanize the drilling and mucking
6. Flexibility in dealing with high variability rock conditions
7. Use of controlled blasting techniques can minimize or eliminate vibration concerns

The Achilles’ heel of TBM tunneling is the substantial setup time and committed equipment cost when spread over tunnels less than 2,000 linear feet. Our cost analysis of the TBM tunneling versus drill and blast hand mining is shown below. This graph shows the cross over point at which TBM tunneling becomes the economical choice. There is limited availability of hard rock TBMs of the diameter and capability necessary for utility tunneling. This analysis assumes a fixed rental for the TBM from a third party vendor because the rental period is so short. If a tunnel contractor happens to own a suitable TBM, then the cross-over point maybe less depending on what their internal rental charges are.



For this project, the drill and blast hand mine method was clearly less costly than mobilizing and launching a TBM. The TBM method would have been quicker even over this short tunnel (estimated at 3 months versus 5 months). However, the TBM method costs 1.5 times the drill and blast method.




## CONCLUSION

Drilling and blasting hand mining has been in use for well over 100 years. It is extremely cost effective for tunnels under 2,000’ in length. And while TBMs are clearly the faster excavation method, they are rarely as flexible with geologic conditions or providing the preferred horseshoe tunnel cross section for utility tunnels such as this one. Drilling and blasting’s perceived risks can be controlled by experienced contractors and engineers as this project clearly shows. So in spite of the concerns for vibrations, transport and handling of explosives and unfounded public fears, this project demonstrates successful and economic use of tunnel drilling and blasting in the 21st century.