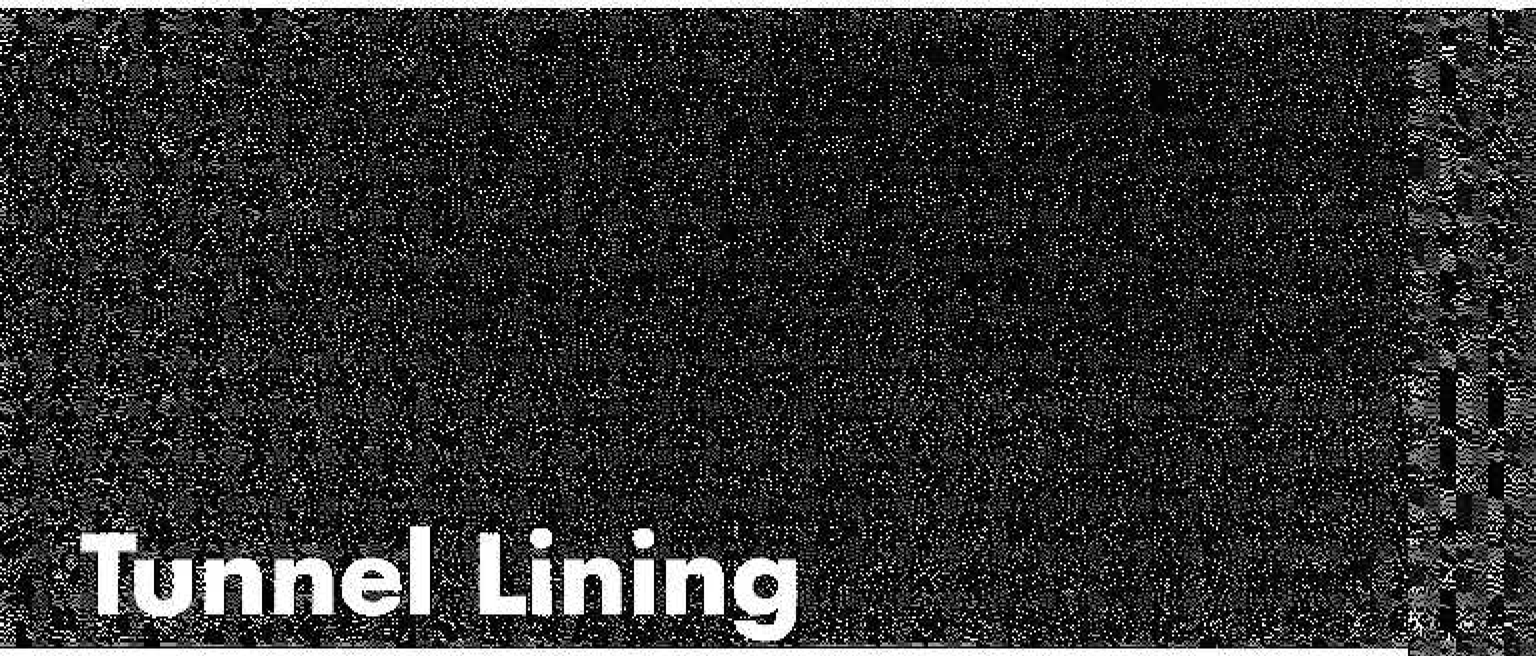

Tunnel Lining

Removal and Excavation by Controlled Blasting

By Jeff Hammer and John MacGregor

Abstract

The Twin Tunnels, originally constructed in 1964, have become a major choke point for traffic heading up to and returning from the Colorado high country along the I-70 corridor. To increase traffic flow, the Colorado Department of Transportation undertook the first widening of the East Bound Tunnel in 2013. After the successful completion of that project, CDOT began the widening of the West Bound Tunnel in 2014. Both projects had a limited schedule for tunnel construction of just nine months. The innovative blasting and demolition of the existing tunnel lining was a crucial component to the success of both projects. During the construction of the West Bound project in 2014 a large amount of surface bench blasting using conventional methods ran concurrently to the West Bound tunnel excavation to allow for enough room for the new tunnel portals.

Project Overview

The Twin Tunnels now called the Veterans Memorial Tunnels are located approximately 35 miles west of Denver Colorado along the I-70 corridor near the town of Idaho Springs in Clear Creek County **(figure 1)**. The I-70 corridor is heavily trafficked all times of the year, especially during Colorado's ski season. Travelers to the ski resorts typically travel from the Denver International Airport to the resorts located as close as Loveland Pass and continuing to Avon, Colorado. The impact of skiing traffic was a major consideration in the project's short nine month schedule for each year. Tunnel closures started in the first week of April and ended on December 20 for each project.

The 2013 East Bound project involved widening the existing roadway to three lanes from Idaho Springs (mile post 241) to Floyd Hill (mile post 244) **(figure 2)**. Where I-70 proceeds up Floyd Hill the existing highway is already three lanes wide. The tunnel was enlarged from 32 ft (9.7 m) wide to 54 ft (16.5 m) wide.

The West Bound project included the area of the tunnel to Hidden Valley Exit (mile post 243.) The main construction area included the tunnels and approximately 1500 ft (457 m) on either side of the tunnel portals **(figure 3)**. The tunnel was enlarged from 32 ft (9.7 m) wide to 54 ft (16.5 m) wide.

Project Team

The Colorado Department of Transportation selected the Kraemer/Obayashi Joint Venture as the contractor to perform the construction of the project. Ed Kraemer and Sons was the lead partner and provided project management, local vendor and subcontractor ties, local field supervision, workforce, as well as previous experience with the owner. Obayashi Corporation via the North American operations unit provided tunnel project management, technical expertise, and field support for the tunneling phases. During 2013, the project scope was split up between tunnel construction and roadway construction. The more limited scope of the 2014 project consisted of tunnel construction and high wall rock cuts at the portals of the West Bound Tunnel.

The design team was led by Atkins North America. The tunnel designer was Parsons Brinkerhoff. Geotechnical survey and analysis was performed by Yeh and Associates. THK As-

Figure 1. Project location.

Figure 2. Project extents (2013).

Figure 3. Project extents (2014).

Project Name	I-70 Twin Tunnels Expansion	
Owner	Colorado Department of Transportation	
Designer	Atkins, Parsons Brinkerhoff, Yeh Associates, THK Associates	
Contractor	Kraemer / Obayashi Joint Venture	
Construction Management	HDR, Yeh Associates, Brierley Associates	
Location	Idaho Springs, Colorado	
Major Project Quantities	Eastbound (2013)	Westbound (2014)
Project Cost	$106-million	$55-million
Tunnel Lengths	635-FT (193-M)	681-FT (207-M)
Tunnel Excavations	19,400 CY (14,800 CM)	21,400 CY (16,400 CM)
Outside Rock Excavation	3500 CY (2680 CM)	52,000 CY (39,800 CM)

Table 1. Project Teams and Major Details

sociates provided the architectural and landscape design. The contract management team included HDR, Brierley Associates, and Yeh and Associates.

A list of organizations involved in the construction and design of the twin tunnels project is included in **table 1**.

Project Schedule

The Twin Tunnels Project scope originally contained the East Bound Tunnel and was scheduled for completion in the summer of 2014. This project contained several packages totaling $106 million for the widening to three lanes of the east bound I-70 corridor from Idaho Springs to Floyd Hill. Construction started at the twin tunnels in November 2012 to get ready for the traffic diversion. The roadway to the tunnel was shut down on April 1, 2013 and traffic was detoured around the mountain on existing County Road 314. The improvements to County Road 314 were completed from a previous project and contractor in 2012. The Twin Tunnels East Bound project was completed on time and on budget by the December 20, 2013 deadline.

The Twin Tunnels West Bound Project was a result of the success of the East Bound project. Existing infrastructure was already available to build the West Bound project and save CDOT money rather than waiting some indeterminate amount of time to do the excavation later. CDOT estimated that at least $8 million could be saved. The West Bound project was given a notice to proceed on March 12, 2014 and tunnel was closed for construction again on April 1, 2014. The project was completed on time and on budget and by the December 21, 2014 deadline.

Original Tunnel Construction

The original Twin Tunnels were constructed and finished both at the same time in 1964. The original tunnels were constructed using methods and equipment of the era **(figure 4)**. The original excavation support system of the tunnel was provided by steel sets. The steel sets were WF10X39 and were placed at 5 ft (1.5 m) on center. It was assumed that the original tunnel was excavated in 6 ft (1.8 m) to 10 ft (3 m) advance on full face rounds. This support was cast into the final tunnel lining.

The final lining of the original Twin Tunnels consisted of rebar reinforcing and a poured concrete lining. During the pre-construction phase the West Bound Tunnel was tested to determine the thickness of the original lining. The results of the evaluation revealed the concrete lining was at least 24 inches (635 mm) thick. The testing was performed by drilling with rotary-hammer and concrete bit through the lining until hitting rock or voids.

The new study on the Twin Tunnel's concrete lining revealed that the lining was in fact at least 24 inches (635 mm) thick. The original construction documents indicated that the lining was to be at a minimum of 18 inches (457 mm) thick. The original construction documents also indicated that the rebar in the concrete was to include a top and bottom mat. The rebar mats were specified as #5 bars longitudinal at an 8 inches (229 mm) and #6 bars at an 8 inches (229 mm) spacing.

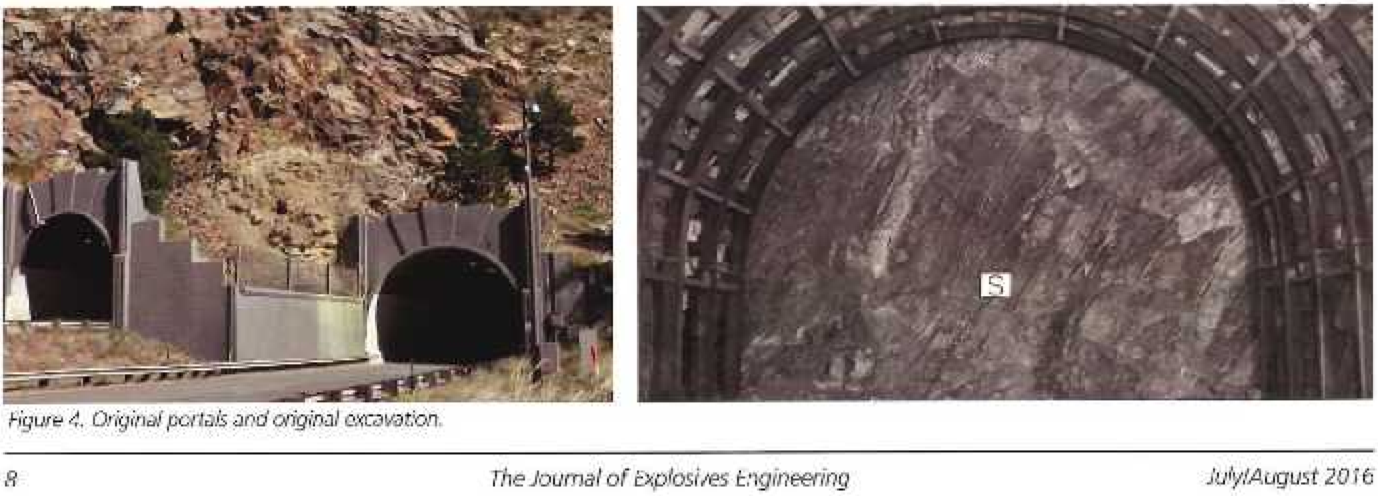

Figure 4. Original portals and original excavation.

Figure 5. Saw cut operations and liner removal.

Project Challenges

During a preconstruction survey, the construction team identified several major challenges to the tunneling operations. The first major challenge was the project's short schedule for tunneling of just nine months. The project tunneling duration started each year on April 1 and concluded December 20. The tunnel project scope included excavating the newly widened tunnel, placing the final lining, and making a roadway ready for the general public. It was a major undertaking to excavate a tunnel and also to have the final lining ready to go in nine months.

The removal of the existing tunnel linings was also identified as a serious challenge. Past project record searches by the construction team only generated a handful of projects to have same criteria for lining removal and tunnel expansion. Almost all of these projects were railway tunnels in which tunnel height increased and did not include extensive tunnel lining removals. The construction team decided to remove the tunnel lining using conventional concrete removal methods.

The construction team chose to cut the lining into manageable sections and remove each section with an excavator mounted hydraulic hammer **(figure 5)** The plan included cutting the concrete lining longitudinally in three cuts the full

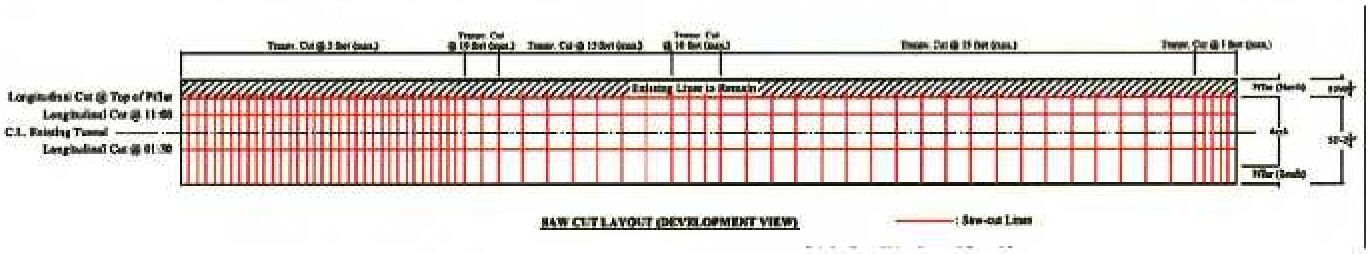

Figure 6. East Bound (2013) planned saw cut lines (plan view).

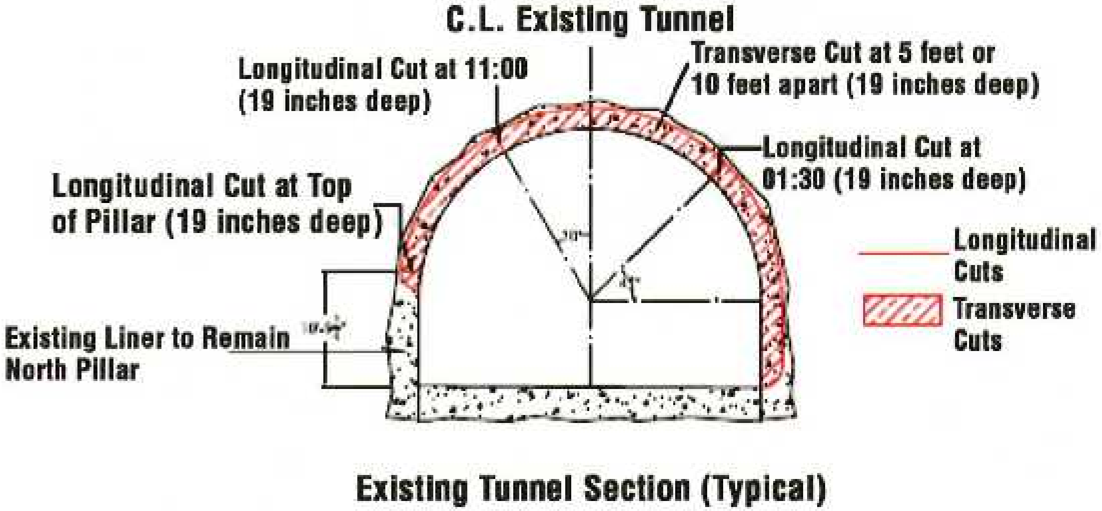

Figure 7. East Bound (2013) saw cut plan (tunnel section).

length of the tunnel. The lining was also cut in transverse sections at 5 ft (1.75 m) to 10 ft (3 m) intervals depending on anticipated ground conditions **(figure 6,7)**. As shown in the figures a lot of cutting was going to be required.

This approach soon ran into a major conflict with another construction challenge. While the method of cutting the concrete lining was working and the tunnel lining was being removed this process was taking a significant amount of time. Time studies of tunnel excavation operations conducted by the contractor concluded the cycle time was 46-52 hours per tunnel round of advancement. This cycle time would not fit into the tunnel construction schedule developed at bid time.

Blasting Innovation

Early on in the construction feasibility phase of the project the contractor asked internally, "could the lining be removed by explosives?" The opinion from industry experts was not positive. Several tests were performed by blasting sections of the wall out from the top of the arch down. The wall of the lining was still connected to the invert of the tunnel and caused severe rifling of blasted material. This material flew into the blast screen placed at both tunnel ends. While the blast screens across the portals of the tunnel blocked most flyrock from escaping, occasionally some would escape. This method was also not reducing time required for demolition of the existing lining. The construction team believed that the steel sets cast into the tunnel lining were too strong for this method to work.

Then an alternate idea was attempted. The concrete wall was cut by a concrete saw at the invert. This method severed the connection of the steel sets and the concrete lining at the bottom of the wall near the tunnel invert. The archway was removed by a hydraulic hammer. This allowed for enough relief for the rock to move the wall and demolish the concrete at the same time. To further improve the method, it was discovered that if the lining was cut at the keystone of the arch and cut at the base of the wall near the invert, the blast could be timed in such a way that the lining folded in on itself. The blasting forces were sufficient to demolish the concrete matrix holding the remainder of the old tunnel ground support and the mass flow of rock had enough force to bend all of the steel sets.

The blasting products used at the Twin Tunnel Projects are listed in **table 2**.

The final iteration of the most efficient method to prepare the lining for demolition consisted of three concrete cuts made longitudinally. Two cuts were made near the keystone or top most portion of the arch. One cut was made in the tunnel lining wall as close to the invert as possible. Then the rock mass was drilled out. All drilling was done parallel to the center line of the tunnel or parallel to the concrete wall.

The blast sequence to remove the concrete lining and the rock mass behind it was developed to work in three steps **(figure 8)**. The arch keystone was blasted first. Then the wall of the arch was blasted as close to the invert as possible. Finally the main portion of the round was blasted in a chevron pattern.

Product Type	Product Name
Packaged Emulsion	1-1/2"x16" DynoAP (1-1/4"x16" DynoAP)
Packaged Trim Dynamite	7/8"x48" DynoSplit D
Blasting Caps	EZDet 25/700 ms
Surface Delays	EZTL 9ms, 17ms, 25ms,42ms
Det Chord	Primachord 5, 25gr
Lead In Line	NONEL Leadline

Table 2. Explosive products list.

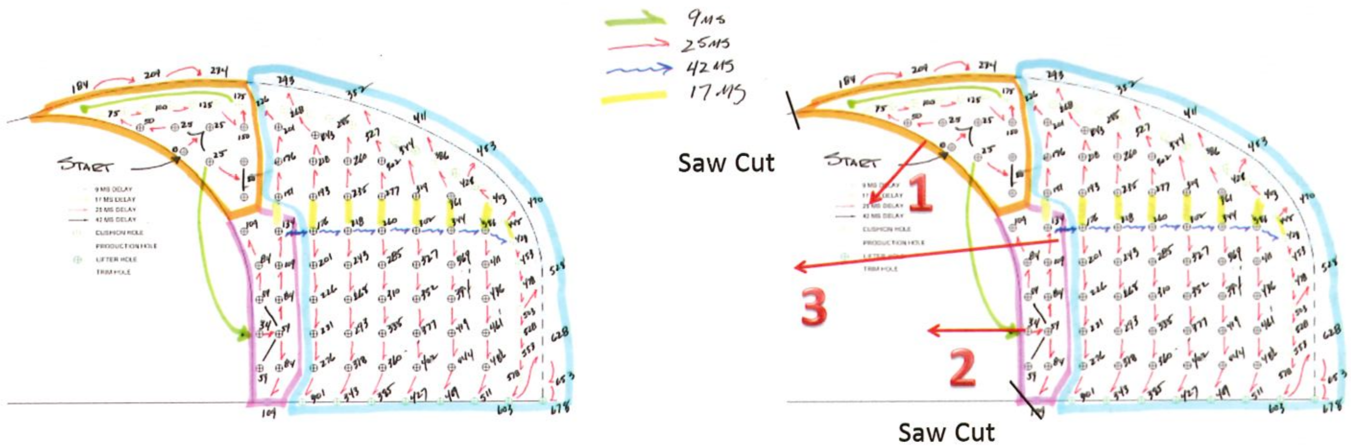

Figure 8. Blast timing and blast progression.

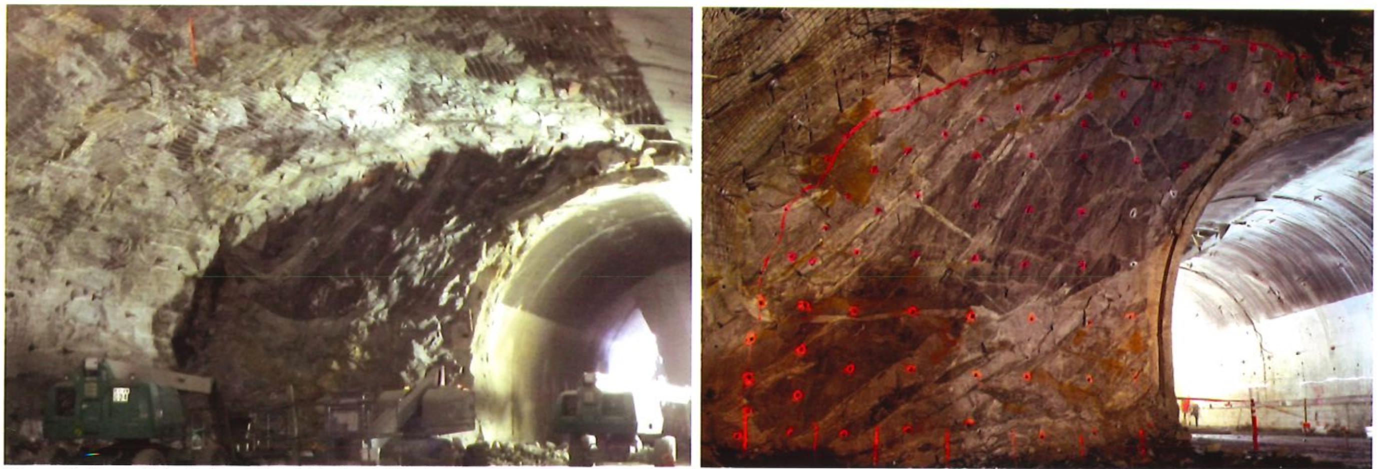

Figure 9. Tunnel blasted profile, drilled out blasting pattern.

This method was the solution to two above mentioned project challenges. Both the project schedule and the method of removing the concrete lining were addressed. The Tunnel excavation cycle time was reduced to 24-32 hours for the East Bound Project (2013) and further reduced to 18-22 hours for the West Bound Project (2014).

This blasting plan relied on very accurate drilling to be successful. The contractor selected Atlas Copco E2C dual boom drill jumbos with the Rig Control System with the Tunnel Manager blasting pattern design software to handle the drill outs. The contractor programmed the drill patterns and could adjust the pattern to handle changing ground conditions and to optimize energy management.

The accuracy of the drilling was most clear when coupled with smooth-wall trim techniques. The trim pattern was adjusted for ground conditions and normally was drilled on a 24 inches (610 mm) to 30 inches (762 mm) spacing. The buffer row was adjusted from 28 inches (711 mm) to 36 inches (914 mm) from the trim row and the spacing was placed on a 30 inches (762 mm) to 40 inches (1020 mm). The middle of the round was drilled out on a 42 inches (1070 mm) box pattern. During the West Bound (2014) project the drilling control contributed to easier bolt-ups, greatly reduced overbreak, and faster tunnel excavation cycle time **(figure 9)**.

Rock mass consisted of Precambrian-age quartz-feldspar gneiss and biotite gneiss. UCS testing compressive strength ranged from 7000 psi (48.3 MPa) to 18,000 psi (124 MPa). Generally the tunnel consisted of hard competent rock. Powder factor for tunneling with lining removal ranged from 2.0 lbs/yd^3 (1.2 kg/m^3) to 3.0 lbs/yd^3 (1.8 kg/m^3).

Conclusion

Excavation design became a crucial part of the success of the Twin Tunnels projects. Blasting wasn't just the technique employed for the simple removal of the rock. The innovative blasting method saved time for the project schedule by removing the lining without the need for extensive and slow mechanical concrete removal. Engineering the blast to remove the lining was the critical step for the success of the excavation phase of the Twin Tunnels Project.

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