CHAPTER 4 – ROCK MASS STABILIZATION DEMONSTRATION PROJECTS

FLH demonstration projects to stabilize two rock mass sites were conducted in Colorado in 2006 and 2007. The first site was chosen to stabilize the western portal of the Poudre Canyon Tunnel, located along SH 14 west of Fort Collins, Colorado. The second site, a full production application sponsored by CDOT, involved a rock slope located on US 6 west of Golden, Colorado.

POUDRE CANYON TUNNEL STABILIZATION

In June 2006, FLH demonstrated the application of PUR injection for rock mass stabilization within the western portal of the Poudre Canyon Tunnel, located on highway SH 14 along the scenic Cache La Poudre River west of Fort Collins, CO, near mile marker 107.3 as shown in Figure 3. The tunnel is approximately 23 m (75 ft) long and was excavated using drill-and-blast methods to create a two-lane rectangular cut through a vertically foliated gneiss and metamorphic rock mass. Rockfall from the western portal had been an issue for the Colorado Department of Transportation (CDOT) for a number of years. Rock dowels (non-tensioned) had been drilled and placed at spot locations above the western portal in an attempt to mitigate the rockfall hazard. Figure 4 depicts the spot bolting locations. This site was chosen based on the history of rockfall, previous spot bolting, and open fractures that could be injected with PUR product.

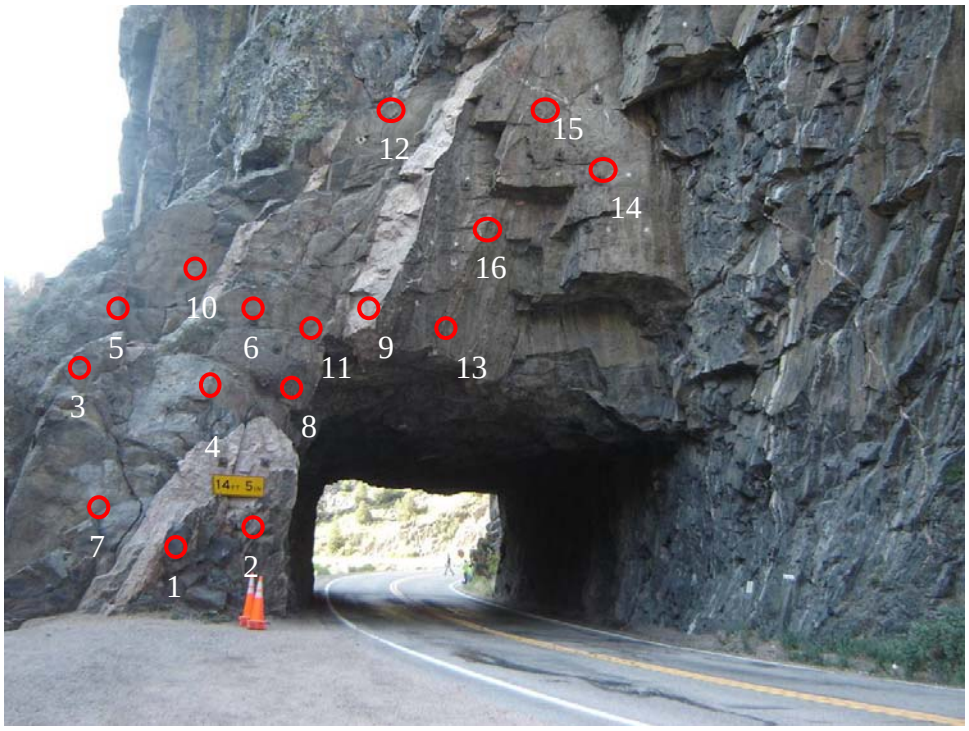

Figure 3. Photo. Western portal of the Poudre Canyon Tunnel with PUR injection hole sequence indicated in red (Approximate Locations).

Figure 4. Photo. Close-up of the foliation joint-defined blocks above the western portal and previous spot-bolting.

Construction Description

PUR injection services were provided by Micon Mining, Grand Junction, CO. Micon is the leading provider of PUR injection services to the underground mining industry, and has over 30 years experience with resin injection and rock mass stabilization in a wide range of rock types and application settings. The RokLok 70 PUR product was selected based on its strength, viscosity, mild-hydrophilic nature, and broad operating temperature range. Table 2 lists some of the pertinent physical properties of the RokLok 70 product.

Table 2. Properties of Micon RokLok 70 polyurethane resin.

Micon RokLok 70	
Average Set Time	2 min.
90% Strength	1 hr.
Full Cure	48 hrs.
Density	70 pcf
Compressive Strength	10,200 psi (viscous yield)
Compressive Modulus	92,000 psi
Flexural Strength	10,900 psi
Flexural Modulus	313,000 psi
Tensile Strength	3,850 psi
Shear Strength	530 psi
Shear Modulus	7,100 psi
% Elongation	~17 %

The contractor provided three experienced product installers. The equipment necessary to complete the work consisted of an 18 m (60 ft) man-lift, an Ingersol Rand Air Compressor 600, and a pneumatic rotary-percussive Gardner Denver jackleg drill. The project was scheduled to occur over a two week period in June 2006. Due to traffic constraints within the canyon, the work was limited to Monday through Thursday. The proposed injection hole locations were marked in the field with paint spots. The contractor drilled each injection hole 3 to 3.5 m (10 to 12 ft) deep with the jackleg on the ground or out of the man-lift. Upon completion of a hole, an injection/packer port was placed or hammered into the hole and connected to the PUR pumping/mixing system for immediate injection. Sixteen holes were systematically drilled and injected with PUR in this manner over the course of five days, installing approximately 2,250 kg (5,000 lb) of product. One additional day was necessary for mobilization/demobilization.

Figure 5 depicts drilling the holes for the PUR injection with the hand operated jackleg drill. Figure 6 depicts installing the packer/injection port into the pre-drilled hole. Figures 7 and 8 illustrate the two component mixing process.

Figure 5. Photo. Jackleg drilling into western portal abutment (Hole # 1).

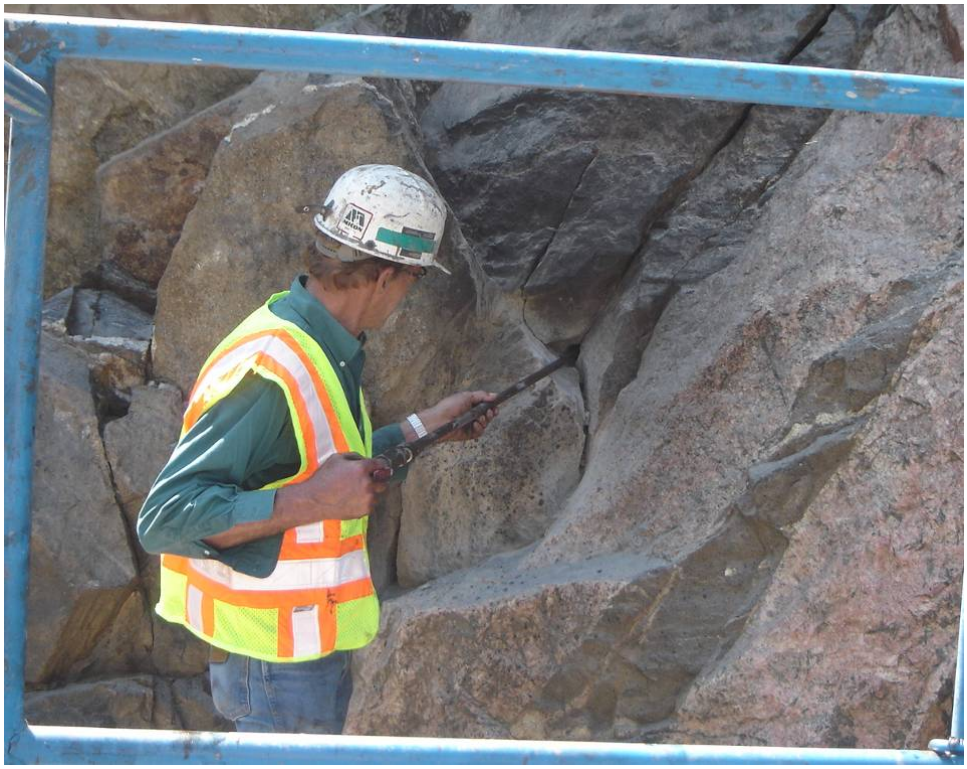

Figure 6. Photo. Insertion of the injection port/packer into drillhole.

Figure 7. Photo. Connection of PUR Component A and B hoses to injection port.

Figure 8. Photo. PUR Components A and B (red and blue barrels) and pumping system.

Construction Summary and Details

1. Sixteen, 38 mm (1.5 in) diameter holes were drilled from 3 to 3.5 m (10 to 12 ft) deep on the outside of the western tunnel portal and into the overlying rock mass. Drilling and PUR injection (including mobilization/demobilization) was completed in six working days.
2. Drilling was accomplished with a hand-operated jackleg drill, operated from a man-lift or directly from the ground. The systematic drilling and injection of the individual holes was generally completed within 30 minutes for each separate operation, resulting in minimal traffic delays.
3. Approximately 80 m^2 (850 ft^2) of portal area was treated to an estimated average depth of 3 m (10 ft), for a total approximate PUR grouted rock volume of 240 m^3 (8,500 ft^3).
4. Between 90 to 315 kg (200 and 700 lb) of PUR product was injected into each pre-drilled hole, for a total of more than 2,250 kg (5,000 lb) of PUR product used on the project. Each US standard 208-l (55-gal) barrel contains 225 kg (500 lb) of component product, therefore requiring approximately 12 total barrels of A/B components to complete the project.
5. Coupled, 1-m (3-ft) in length hollow injection rods, with a short packer/mixing assembly attached at the resin delivery end, were inserted to within 0.5 to 1 m (2 to 3 ft) of the back of the hole. Packers were generally seated fairly tightly during installation, but can accommodate up to 50 mm (2 in) diameter holes during pumping, if required. The innermost rod and attached packer assembly were resin-anchored within the hole by the conclusion of the injection process, and were abandoned in the hole by disconnecting at the coupler.

6. Relatively small volumes were pumped (4 to 8 l/min (1 to 4 gpm)) under low pressure (<0.34 MPa, <50 psi) until PUR overrun was observed. Pumping was then suspended for approximately 1 minute, allowing the PUR to begin to set prior to resuming pumping. Staging the pumping in this manner allows cracks to seal, thereby pushing the next volume of PUR delivered along other fracture and joint paths.
7. Work progressed from bottom-to-top. Initial PUR injection would flow down through the rock mass until the rapid set effectively sealed the lower portion of the rock mass. Continued pumping would then cause the PUR to migrate laterally and upward within the rock mass discontinuities surrounding the installation hole. In most cases, PUR migration was confined to an approximate 1.2 to 2.4 m (4 to 8 ft) radius around the installation hole. However, more persistent discontinuities with wide apertures could easily convey PUR 3 to 4.5 m (10 to15 ft) prior to initial set.
8. A majority of the rock mass discontinuities appeared to be filled with hard, non-expanded, dense resin. Foamed resin was seen coming from rock mass discontinuities located near the overlying slope surface and beneath slope vegetation, indicating sections with higher moisture contents as shown in Figures 9 and 10.
9. Despite the volume of resin pumped within the portal area, no rockfall occurred during or following PUR injection from injection pressures or resin expansion in wet zones. The staged injection and rapid set of the PUR is believed to quickly secure loose rock with minimal displacement.
10. Traffic was stopped during all drilling and injection operations, with average delays running about 30 minutes. Vehicles were kept well back from the injection operation to avoid fine PUR “strands”, occasionally squeezing from fine cracks during pumping, from landing on and affixing to car exteriors.
11. No significant overruns were encountered. Cleanup involved rapidly peeling PUR drips and runs from the rock mass prior to set, or chipping hardened overruns from the rock surface with hand tools as shown in Figure 11. Injection holes were plugged with dark-colored grout, rendering them virtually invisible throughout the portal area. A few months after the project was completed, following weathering of the thin veneers of PUR overrun left following cleanup, it was nearly impossible to see that any work had been done at the site.
12. The total cost of the project, less traffic control provided by CDOT Maintenance, was $42,000, or just over $18/kg ($8/lb) of installed PUR.

Table 3 depicts the drilling rate and injection rates for the PUR project for the Poudre Canyon Project.

Table 3. Drilling and PUR injection production rates on the Poudre Canyon project.

PUR Poudre Canyon Production							
Drilling Rates				PUR Injection Rates			
Date	Hole Number	Depth (ft)	Time (min.)	Date	Hole Number	PUR Product Injected (lb)	Time (min.)
06/19/06	1	12	40	06/20/06	1	300	20
	2	12	15		2	450	17
	3	12	35		3	200	10
	4	12	30		4	200	15
06/20/06	5	10	30	06/21/06	5	200	10
	6	10	20		6	700	50
	7	10	30		7	600	40
06/21/06	8	12	35		8	200	20
	9	12	30	06/22/06	9	350	25
	10	12	30		10	250	10
06/22/06	11	12	40		11	150	60
	12	12	40	06/26/06	12	200	30
	13	12	35		13	200	40
06/26/06	14	10	40	06/27/06	14	500	35
	15	10	30		15	250	40
	16	10	40		16	400	60

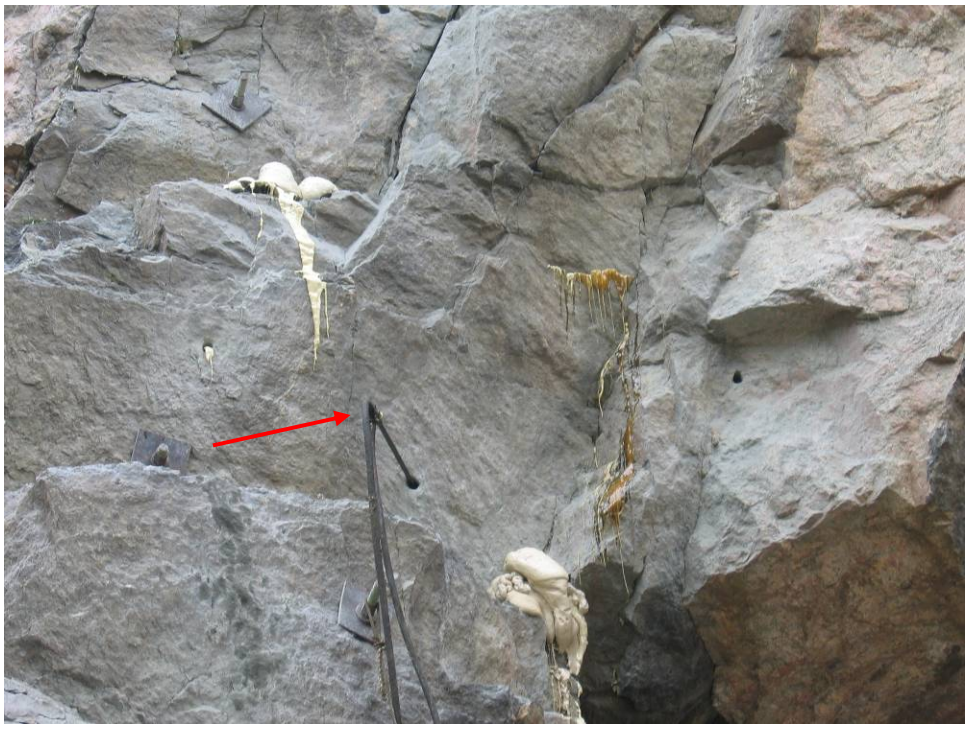

Figure 9. Photo. Migration of PUR from below the injection point # 11 (red arrow), upward through the rock mass. Note that some of the resin is foaming due to moisture in the surface fractures.

Figure 10. Photo. Cured PUR product infilling a discontinuity within rock mass.

Figure 11. Photo. Rapid removal of expanded PUR product immediately following injection and prior to set. Removal typically requires hand tools following set.

Verification drilling was not conducted to determine the level of volumetric coverage that may have been attained or the nature of the resin product within discontinuities (hard resin or foamed resin). Resin set time tests on rock samples at the site, coupled with visual observation of the progression of the resin throughout the rock mass (and out several of the supposedly fully-grouted bolt installation holes) indicated that a substantial volume of the rock mass was secured. Figure 12 depicts a section of the project site where single stage PU was used to seal the fracture so PUR product would inject deeper into the rock mass. This performance assessment was sufficient for CDOT to recommend the use of this product on other state highway projects during the summer of 2007.

Figure 12. Photo. Single-component PU product used to seal fractures in order to inject PUR product into rock fractures.

CLEAR CREEK CANYON ROCK MASS STABILIZATION

In July 2007, the Colorado Department of Transportation (CDOT) used PUR technology on a rockfall/rock slope mitigation project along highway US 6 in Clear Creek Canyon west of Golden, Colorado. PUR was used to supplement tensioned rock bolting that had been specified for the project. Figures 13 and 14 depict the approximate locations of selected PUR holes.

Micon Mining from, Grand Junction, CO was procured by CDOT for the PUR injection services. Three experienced product installers were provided by the contractor. The equipment consisted of an 18 m (60 ft) man lift, an air compressor, and a pneumatic rotary-percussive jackleg drill. The project was scheduled to occur over a two week period in July 2007, with working days from Monday through Thursday due to traffic constraints within the canyon. The contractor drilled each hole from 1.5 to 2.7 m (5 to 9 ft) deep with the jackleg drill out of the man lift.

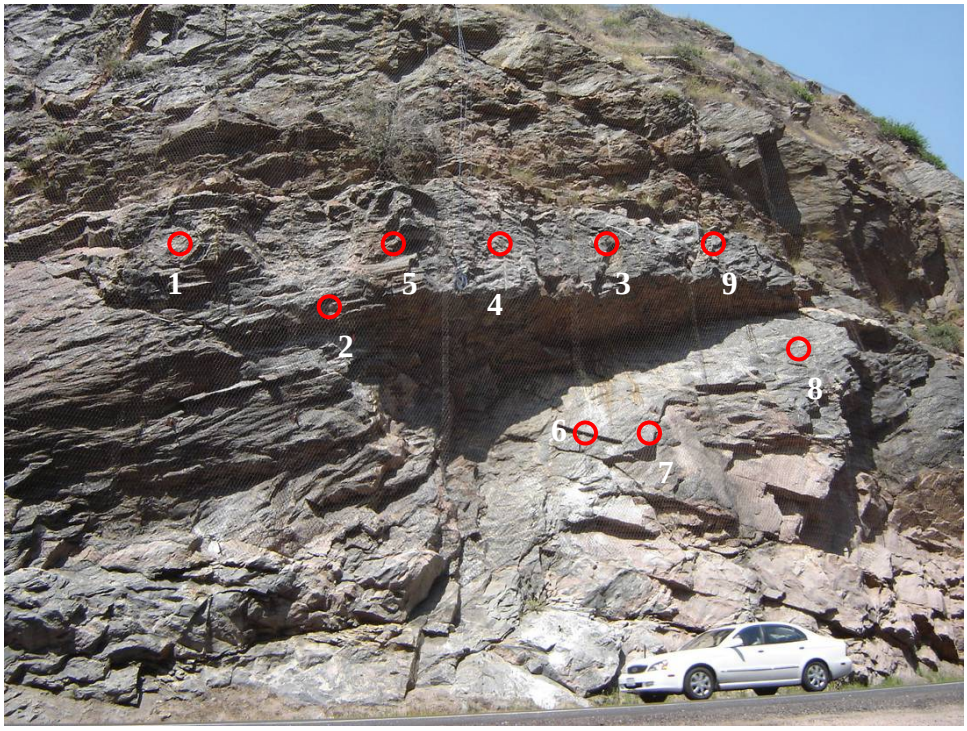

Figure 13. Photo. Approximate locations of selected PUR injection holes.

Figure 14. Photo. Approximate locations of selected PUR injection holes.

Upon completion of a hole, an injection/packer port was placed or hammered into the hole and connected to the PUR pumping/mixing system for immediate injection. Sixteen holes were systematically drilled and injected with PUR over the course of five working days installing approximately 2,250 kg (5,000 lb) of product.

Table 4 below provides the production rates for the drilling and injection of the PUR for the project.

Table 4. Production rates for PUR on the US 6 Project.

US 6 PUR Injection Project							
Drilling Rates				**PUR Injection Rates**			
Date	Hole Number	Depth (ft)	Time (min.)	Date	Hole Number	PUR Product Injected (lb)	Time (min.)
07/24/07	1	9	60	07/25/07	1	70	40
07/25/07	2	9	20		2	20	10
	3	10	35		3	20	40
	4	9	60	07/26/07	4	50	25
	5	9	30		5	50	25
	6	9	40		6	50	10
07/26/07	7	9	20		7	50	10
	8	9	20		8	850	50
	9	9	20		9	50	20
07/27/07	10	9	35	07/27/07	10	1,500	55
	11	9	40		11	150	5
	12	9	30		12	350	10
	13	9	15		13	450	30
07/30/07	3-1	6.5	20	07/30/07	3-1	1100	105
	3-2	5	20		3-2	150	50
	3-3	5	15		3-3	150	20

No subsequent testing was done to verify the effectiveness of the PUR product, but no rockfall issues have been reported to date. In this instance the PUR was used as a supplemental support measure to the primary tensioned rock bolt installations.