CHAPTER 5 – RETAINING WALL DEMONSTRATION PROJECT

OVERVIEW

In September 2007, FLH evaluated the potential application of PUR injection for stabilizing dry-stack stone masonry retaining walls. Unlike typical rock mass applications, non-mortared rock retaining walls are highly porous, generally ranging from 5% to 30% open space depending on the size of stone placed in the structure, degree of masonry performed, and the overall quality of construction. The non-uniform, high-open space character of these structures can significantly complicate planned PUR delivery within targeted wall volumes. The decades-old structures, many of which are in serious disrepair and/or varying states of failure, are also highly sensitive to injection and PUR expansion pressures, potentially limiting the use of PUR products in wet environments. In addition, the often culturally sensitive nature of these structures further requires that evidence of repair be kept to a minimum, placing considerable emphasis on managing PUR overruns and cleanup.

The PUR product was injected behind a failing wall system with soft, open-spaced materials. The PUR product provided the following advantages to cement grouts by providing:

1. Greater viscosity which limited product migration keeping product behind the wall system and out of the nearby sensitive areas.
2. Provided very fast adhesion between the dry-stack boulders.
3. Provided greater tensile strength to the wall system that would not have been achievable with cement based grouts.

The South Fork demonstration project involved a short section of an approximate 180-m (600-ft) long dry-stack stone masonry retaining wall constructed approximately 60 years ago. The wall varies in height from 1 to 3.6 m (3 to 12 ft) and has sections that have seriously deteriorated, indicated by localized failed sections (repaired with timber lagging and gabions), rotating/bulging sections, missing foundation elements, and settlement/piping cavities along the top of the wall. Several years ago, in an effort to forestall eminent wall failure, approximately 90 m (300 ft) of the eastern section of the wall was reinforced with vertical and battered micropiles, installed along the back of the structure, and a shotcrete, mesh, and tie-back system installed along the face.

The PUR demonstration project focused on an equally unstable, approximate 18-m (60-ft) long section of the dry-stack wall immediately north of the micropile section. This wall section ranges in height from 1.8 to 3.6 m (6 to 12 ft) and is in a state of pending major failure evidenced by wall face rotation/bulging (approaching negative batter) and numerous sinkholes/depressions just behind the top of the wall, as shown in Figure 15.

Construction Description

Building on prior injection experiences, Micon Mining was again used as the contractor to provide PUR injection services. The RokLok 70 product previously used at the Poudre Canyon

Tunnel demonstration was again selected for its strength and mild hydrophilic and adhesion properties to reinforce the rock mass.

The contractor provided three experienced product installers. The equipment consisted of a two-component RokLok product and pumping capabilities. Jam-rods and a hand-held rotary drilling apparatus were also provided by the contractor. The project was scheduled to occur over a one week period in September 2007, with working days from Monday through Friday. An additional geotechnical drill rig was also on site in an attempt to determine if larger diameter holes would be necessary for PUR injection and to verify that PUR product had migrated to the back of the retaining structures by core drilling methods. Two samples obtained and tested from the geotechnical drilling indicated the subsurface materials behind the dry-stack wall consisted of silty sands with gravels, cobbles and boulders. The AASHTO materials classification was A-1-b silty sandy material, with less than 20% fines passing the #200 sieve as is further described in Appendix B.

Figure 15. Photo. Bulging dry-stack wall, looking northwest along the test section.

The demonstration project consisted of injecting 22 locations along the dry-stack wall with PUR over the course of three days. Initial injection was done using auger casing, but was abandoned in favor of the “jam-rods” – an effective injection system developed by the contractor for the project as shown in Figure 16. The jam-rod was less than 12 mm (0.50 in) in diameter with multiple apertures to allow the PUR product to flow outward. The jam-rod was placed in a similar manner to driving fence posts in the ground, as shown in Figure 17. The small diameter of the rod and granular nature of backfill enabled the rod to be driven relatively easily.

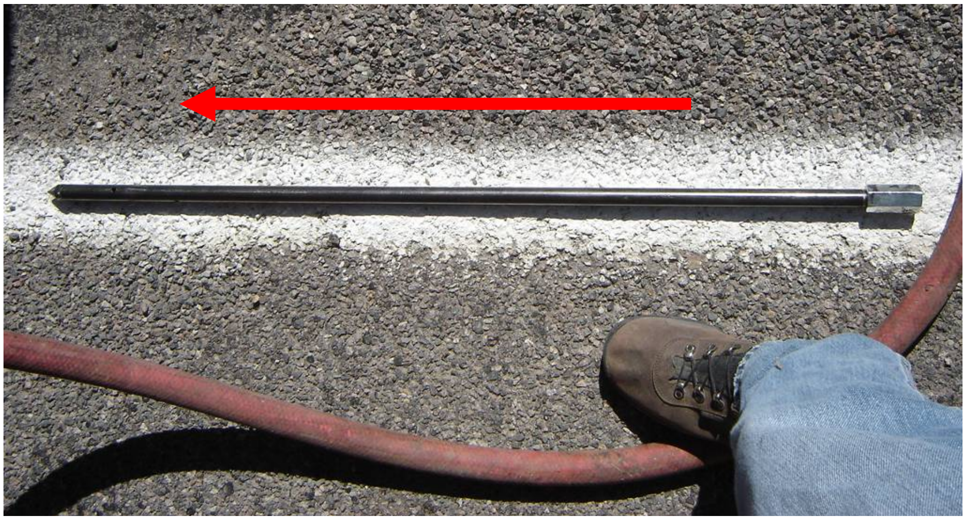

Figure 16. Photo. Jam-rod used to inject PUR product. Connection on right allows addition of extension rods, as needed. Injection ports are along the lower third of the jam-rod. Arrow indicates flow direction of product out of end port.

Figure 17. Photo. Driving jam-rod just behind visible wall settlement zone with fence post driver. Arrows indicate areas of wall displacement and settlement.

The injection locations varied from (0.6 to 1.5 m (2 to 5 ft) behind the face of wall as shown in Figure 18, and consisted of driving the jam-rod to depths ranging from 0.9 to 2.4 m (3 to 8 ft). Once the rod had been placed, pump lines were attached to the jam-rod, as shown in Figure 19, and the two-component product was pumped at pressures between 0 to 0.15 MPa (0 to 25 psi). Pumping time intervals ranged from 2 to 60 minutes, and resulted in 22 to 250 kg (50 to 500 lb) of product being injected. Pumping ceased when either slight wall movements were visually detected or product flow was spotted from the wall face or ground surface. Small rocks and/or screwdrivers were used as crude "tell-tales" to monitor when PUR injection pressures were beginning to outwardly deflect the wall structure as shown in Figure 20.

Figure 18. Photo. Jam-rods placed along the top of a well-built, well performing section of the study wall. No signs of wall settlement allowed placement of the injection rods closer to the wall face.

Figure 19. Photo. PUR A and B components are pumped separately to the top of the jam rod assembly. Mixing occurs within the injection rod assembly via a spiraled insert prior to product injection within the rock mass.

Figure 20. Photo. Blue arrows indicate location of balanced rocks used as "tell-tales" to detect outward wall deflection.

Cleanup of PUR overrun, if done prior to full set (within a few minutes after the PUR injection), consists of simply peeling the materials off the rock face and placing into garbage bags for disposal. PUR materials that encounter water will foam to a certain degree and are easier to peel off than non-foamed resin (foamed PUR prior to cleanup shown in Figure 21). PUR products that do not encounter water will peel off easily in the first few minutes of set; however, after a few minutes or hours the material will have to be chipped off with a hammer. The dry-stack walls at the demonstration site had large void areas, which enabled viewing of the PUR product inside the interlocking boulders as shown in Figure 22. The PUR product was injected after a period of heavy precipitation and the product did foam for one to two days when it encountered the subsurface moisture. After a few days the PUR product foamed much less as the subsurface began to dry out.

Figure 21. Photo. PUR that has foamed due to high moisture within the wall rock mass. This material can be readily peeled off the rock face and bagged for disposal.

Figure 22. Photo. PUR product distribution within large void in dry-stack wall. This location was initially injected via jam-rods behind the wall the day after steady rains passed through the area, resulting in foaming of the PUR. Subsequent face injection days later, when the wall rock had dried substantially, resulted in non-foamed resin coverage of the interior rocks. The foamed PUR provides for consolidation, whereas the non-foamed product provides for rock-on-rock adhesion.

Two coreholes were advanced behind the wall to characterize PUR coverage deeper in the wall mass. In one boring, foamed PUR was visible in the core sample and illustrated the permeation of the product between the backfill boulders as shown in Figure 23.

PUR product was also injected between the facing rocks with a hand-held injection nozzle. This method led to numerous product overruns and required additional cleanup as shown in Figure 24. Figure 25 depicts an elevation view of the dry-stack wall at the end of mitigation.

Figure 23. Photo. Light-colored, foamed PUR in core sample.

Figure 24. Photo. PUR injection directly between wall facing rocks using a hand-held injection nozzle.

Figure 25. Photo. Elevation view of the South Fork dry-stack wall following completion of PUR injection. PUR overruns are nearly invisible from this distance.

Construction Summary and Details

1. Injection work began along the top of the wall, sequentially injecting several holes drilled with a 76 mm (3 in) diameter auger and cased with 50 mm (2 in) ID PVC casing. Holes were advanced on 1.5 m (5 ft) centers, 0.9 to 1.5 m (3 to 5 ft) behind the wall face, and to the estimated bottom of the wall, ranging 2.4 to 3.6 m (8 to 12 ft). Little or no wall rock was encountered during drilling, suggesting wall construction consisted of a near-uniform-thickness course of roughly masoned stones (as opposed to more conventional trapezoidal gravity wall construction techniques). The auger method resulted in oversized holes, requiring installation of a crude injection rod packer near the collar of the hole, consisting of rags and PUR, to contain resin during injection. The weight of the drill rig, down-pressure on the auger, and drilling vibrations combined to seriously distort the upper wall rock courses. This approach was abandoned after the first day to avoid distressing the already unstable wall prior to injection.
2. PUR injection began at the site following several days of intermittent rain and periods of steady drizzle. As a result, PUR product injected to the back toe of the wall foamed substantially, fully filling voids in the lower wall structure within 0.6 to 1.2 m (2 to 4 ft) of the injection hole. Staged pumping at 2 to 4 liters per minute at nominal pressures (1 to 2 gpm at <25 psi) resulted in the upward migration of PUR into the wall mass, similar to the manner in which PUR migrated through the rock mass at the Poudre Canyon site. However, once the lower wall voids were filled, PUR expansion due to high moisture in the wall created sufficient back-pressure to jack the wall out from the injection hole.

Minor wall deformations were observed, and in one instance half-moon cracking developed at the top of the wall radiating several ft from the injection hole and parallel to the face. This prompted a different approach to injection management.

3. Small-diameter hollow injection jam-rods were then manually driven on intervening 1.5-m (5-ft) centers, within 0.9 m (3 ft) of the wall face, and to a depth of approximately mid-wall-height. PUR injection proceeded as before, with steady, small volumes injected over the course of several minutes. PUR flowed down through the wall mass, first appearing in the face at the wall foundation. Continued pumping filled the back of the wall to the estimated rod tip depth, at which time pumping was stopped to avoid over-pressuring the wall. This approach allowed fast insertion of the injection rods (approximately 5 minutes each), delivered PUR to targeted zones within the wall, and allowed for better injection pressure management in the wet conditions.
4. The upper 0.9 to 1.2 m (3 to 5 ft) of wall was then injected by simply hand-placing an injection rod within the openings between capstones. PUR flowed downward several ft before setting and causing subsequent pumping to flow out the face. This work was done one day later when the upper facing stones were mostly dry, so very little resin foaming occurred. Visual inspection indicated that the dense resin actually coated the interior rock surfaces and rock-on-rock contact points, rather than fill the open voids. This method resulted in minor overruns through the face that were removed.
5. Injection directly into the face was also evaluated using a short 450 mm (18 in) injection "wand". This method can very quickly inject resin throughout the wall mass, but resulted in significant face drips and overruns as the injection gun was moved from one placement to the next. Improvements to the injection tooling could overcome much of this problem
6. Over the course of three days, 18 m (60 ft) of wall, averaging 2.7 m (9 ft) in height was injected with 1,800 kg (4,000 lb) of PUR. It is estimated that approximately 57 m^3 (2,000 ft^3) of wall structure was treated. Of this volume, approximately 11 m^3 (400 ft^3) was estimated to be open void space within the backfill and behind the dry-stack boulders. In addition approximately 1.7 m^3 (60 ft^3) of non-foamed resin was injected, likely filling approximately 20 to 25% volume of open void space within the wall. Note, in a classical soil context, we are not referring to soil void ratios. The open void space is not to be confused with soil void space which is a ratio of volume of voids to volume of solids within a soil matrix. The PUR product does not readily permeate moist soils like a cement grout which migrates within the soil matrix. The PUR will typically foam and seal off in the presence of any moisture, but will migrate through the open void pathways within the dry-stack boulders.
7. Core drilling confirmed PUR void filling in the back of the wall. Follow-up geophysical investigations, including 3-D seismic tomography and ground penetrating radar (GPR) surveys before and after PUR injection, were also conducted. Although GPR proved unsuccessful in delineating PUR ground improvements, seismic tomography was able to detect significant increases in wall velocity, suggesting improved cohesion within the wall rock mass. Results of the seismic investigations are provided in Appendix C.
8. Wall cleanup required vigilance during resin injection to quickly locate and remove PUR overruns, to the extent possible. The hard, non-foamed resin could be seen as drips, runs and small area coatings over a significant portion of the wall face. It is anticipated that this material will eventually weather away due to the strong southern exposure of the wall face and UV susceptibility of PUR. The foamed PUR was easier to remove, but left a

visual impact along the wall where it fully filled face voids. Overall, the PUR overruns are only visible when standing directly in front of the wall. No signs of the injection program were visible from below the wall along the Rio Grande River or from nearby pedestrian access points.

9. Based on the lessons learned during the demonstration, this section of wall could have been treated in less than two days – with work progressing at about 1.5 m/hr (5 ft/hr). The total cost of the project, less traffic control provided by CDOT Maintenance, was $32,000, or about $18/kg ($7 to $8/lb) of installed PUR.

Table 5 depicts the PUR injection rates for the PUR project for the South Fork Retaining Wall. Performance testing, including some manner of loading experiment, was not conducted to confirm the strength gains provided by the injected resin. However, post-injection core drilling conducted immediately behind the wall face did not distort the upper rock courses, suggesting the wall rock was behaving more as a consolidated mass – capable of resisting greater applied loads. This site will be visually monitored over the next few years to document wall stability and to determine how long it will take to fully weather the remaining evidence of unremoved face overruns.

Table 5. Injection rates for PUR on the South Fork project.

PUR South Fork Project							
Date	Injection Hole Number	Station (ft)	Offset Behind Top of Wall (ft)	Wall Height (ft)	Depth of PUR Injection Port (ft)	Time Interval (min)	PUR per hole est. (lb)
9/24/07	1	0+15	5.5	9.5	5	30	300
	2	0+28	3	9.5	8	49	450
	3	0+17.5	4.5	9.5	8	35	200
	4	0+18	4.5	9.5	9	28	250
	5	0+58	2.5	9	6	27	300
	6	0+07	5	7.5	6	5	20
	7	0+10	3.5	7	3	5	20
	8	0+15	4	7	3	7.5	75
	9	0+19	4	7	3	10	25
9/25/07	10	0+35	4	9.5	8	17	250
	11	0+42	3.5	11	7	6	100
	12	0+51	3.5	10.5	7	28	200
	13*	0+00 to 0+40	na	10	na	75	250
	14	0+24	4	9	4	4	25
	15	0+36	5.5	10.5	3	2	25
	16	0+40	5	11	3	4	50
	17*	0+40 to 0+60	na	10	na	75	350
	18	1+44	3	7	5	19	150
9/26/07	19	1+49	1.5	7	3	25	150
	20	1+39	2	7	3.5	51	300
	21	1+33	2	8.5	3	37	200
	22*	1+30 to 1+50	na	10	na	75	310

(Application of PUR to facing of wall, stationing, offsets, and quantities are approximate).