A Masonry Wall and Slide Repair Using Soil Nails and Rock Dowels

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1.0 Background

In the middle of August 2003, Vermont experienced several days of very heavy rains which precipitated a slide failure on Vermont Route 73 in Forest Dale at approximately mile marker 6.36. A blocked culvert on the south side of VT 73 caused an overflow of water across the road surface and over an asphalt and wood curb down an embankment. This resulted in a significant amount of erosion, undermining of the road surface (Figure 1) and a washout of a timber cribbing retaining structure located on the top of a mortared masonry wall (Figure 2).

Figure 1: Undermining of north side of VT 73 in Forest Dale.

In the project area, VT 73 is constructed on a retained embankment in steep terrain formed in sub-vertically dipping schistose meta-greywacke. The embankment along a valley sidewall was originally built by constructing masonry retaining structures to span between a series of rock knobs. Soils mantling the rock in the valley consist of dense glacial till. The natural terrain was incised by the Neshobe River, which occupies the valley floor approximately 80 feet below and 100 feet north of the project retaining walls.

Figure 2: Washout of timber cribbing above mortared masonry wall. (View from road level)

After site visits by Vermont Agency of Transportation (VTrans) staff, it was decided that the laid up masonry wall immediately west of the slide area was also in desperate need of repair. The laid up masonry wall (Figure 3) was observed to have broken and missing blocks. Also the top of the wall was leaning out past the bottom of the wall an estimated 12-18 inches. During the 1970's the west end of the laid up masonry wall was replaced with a cast in place concrete wall. As both walls could be remediated by the same contractor, it was decided to repair both locations at the same time.

Golder Associates Inc. (Golder) was retained to perform the engineering design for both walls under a current On-Call Geotechnical Engineering

Figure 3: Laid up masonry wall, immediately west of slide area.

Services Contract. This included performing a site survey, designing a remediation for the wash out area and a shoring system for the laid up masonry wall.

2.0 Design

After discussions between VTrans and Golder, it was agreed that the old timber grade separation structure would need to be replaced and the masonry walls repaired. An approach consisting of a gabion basket retaining structure and soil nail/rock reinforcement repairs to the masonry walls was selected. This would entail clearing brush around the sites, removing loose soil, placing a layer of shotcrete (A pneumatically sprayed concrete with steel fiber reinforcement) to the surface of the walls, drilling 2 and 4 inch holes and installing 1 inch diameter, 75 ksi threaded bars. After the bars had been grouted and reinforcing mats placed an additional 5 inch layer of shotcrete was applied. A gabion basket retaining wall would then be built on the top of the mortared masonry wall in the wash out area to provide a stable slope back up to the road surface. A Gabion basket structure was selected to minimize the need for specialty construction, and allow participation of VTrans maintenance personnel in the construction to expedite the project. To support design of the structures, VTrans completed 6 standard penetration borings in the roadway behind the two walls.

Design of the gabion wall for the washout area consisted of a conventional retaining wall design for a sloping backfill condition. Soil strength values used included a friction angle of 32 degrees and zero cohesion used for the analysis and input into the GAWACWIN 2003 program for gabion wall design developed by Maccaferri Gabions Inc. The program results for a 30-degree back slope and a height of nine feet yielded a three tiered configuration as shown in Figure 4a. The Gabion wall was designed with a 6-degree batter, a shotcrete pad was incorporated to facilitate installation of the first course of Gabion baskets, and rock anchors were installed in the first tier of baskets to pin the wall to the supporting bedrock.

Support of the Gabion wall was checked using the program SLIDE developed by Rocscience. The analysis assumed that the existing masonry wall did not contribute to overall stability, only narrow sliver-type joint failures would be kinematically feasible because of joint orientations, and rock mass failure would occur as a circular failure. The critical cross section was analyzed for rotational stability and initially no rock anchors were considered in the analyses, with shear strength of the rock mass varied to evaluate the need for support. Assuming rock mass cohesion of 1500 pounds per square foot (psf), and a design rock mass friction angle of 40 degrees (conservative), the minimum calculated factor of safety was 2.1. While the calculated minimum factor of safety was adequate to support the Gabion wall, a pattern bolting design and shotcrete facing (Figure 4a) were included to address potential variability in rock mass strength, seasonal groundwater fluctuations and long-term repair to the masonry wall that had started to ravel at the toe (Figure 7).

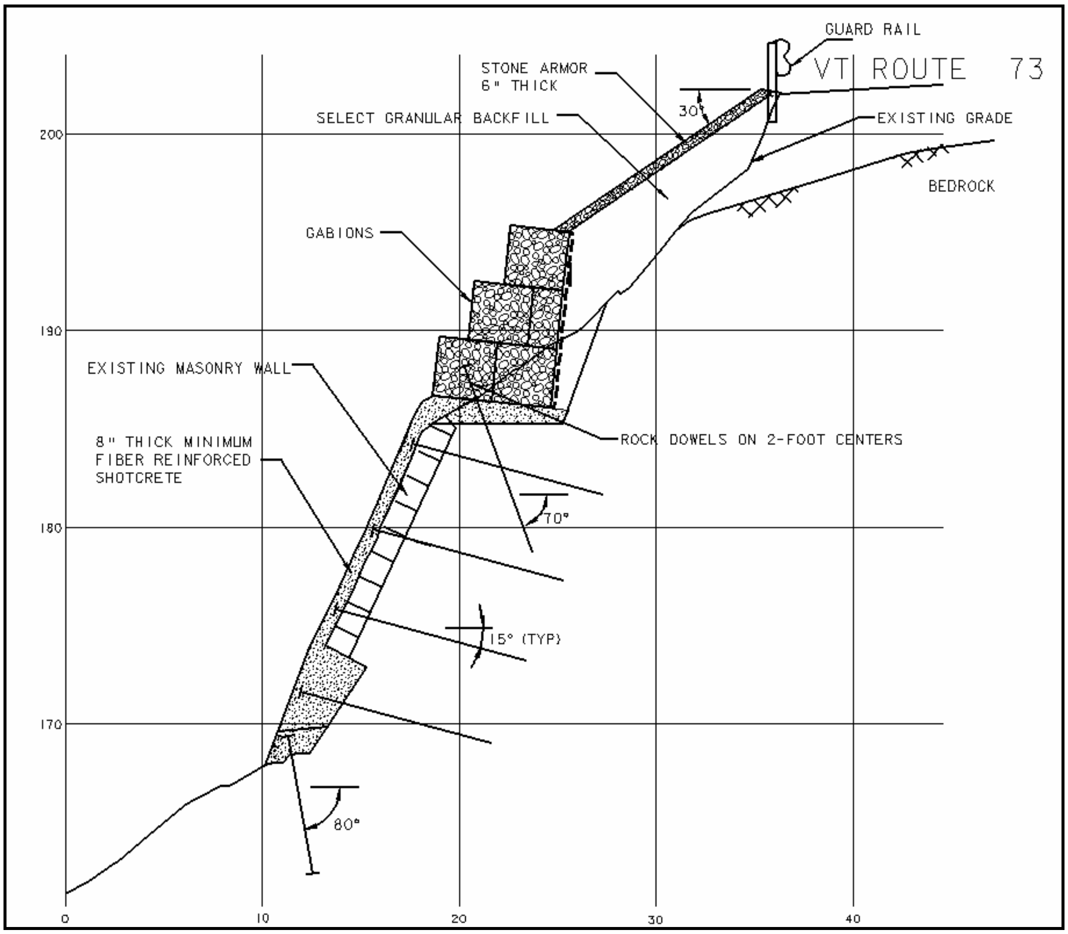

Figure 4a: Section view of mortared masonry wall.

Design of soil nail reinforcement of the masonry wall west of the washout assumed a 16-foot wall height with no batter and a surcharge load of 640 psf consistent with HS20-44 loading. The service load design followed the procedures outlined in the Federal Highway Administration (FHWA) “Manual for Design and Construction Monitoring of Soil Nail Walls” revised October 1998 (FHWA-SA-96-069R). Soil internal friction was assumed at 34 degrees and the soils assumed to be cohesionless (conservative). Global stability of the nailed soil block was checked using the program SLIDE. To account for variations in rock surface elevation, the soil nails were extended a minimum of 8 feet into sound bedrock at each nail location (Figure 4b).

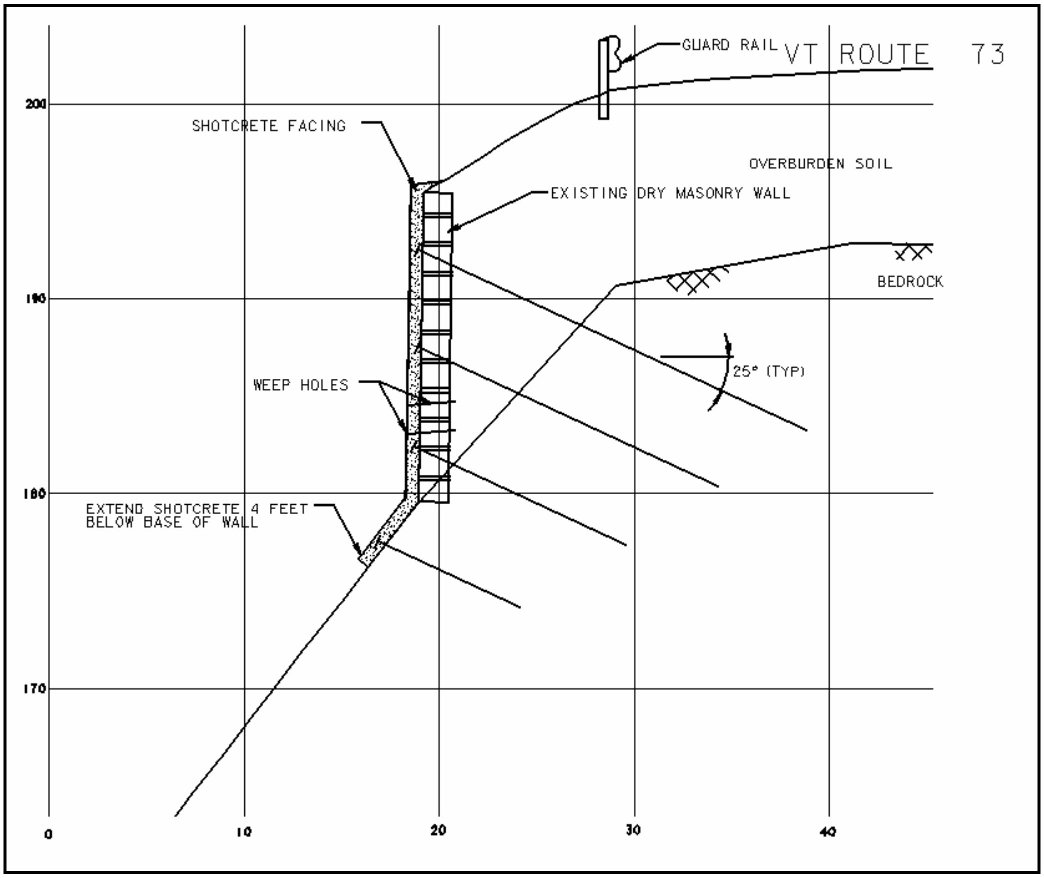

Figure 4b: Section view of laid up masonry wall repair

3.0 Construction

Due to the highly specialized nature of the rock reinforcement work and steep terrain at the two sites combined with the winter season quickly approaching, it was decided not to bid the project but to hire Janod Inc. (Janod) of Quebec, Canada under a force account contract. Janod specializes in rock scaling and drilling soil nails/rock dowels while on rappel and had completed a similar soil nail wall project on rappel for the New York State Thruway Authority two years earlier. Additionally, Janod has experience applying and protecting shotcrete in winter and inclement weather conditions (Figure 5).

Figure 5: Shotcrete being applied while on rappel.

Construction commenced on Wednesday October 15, 2003. Janod operated primarily with a five man crew. It took approximately one day to clear out the brush around the two job sites. Weep pipe locations were chosen based upon visual inspection of the wall surfaces. If an area had visible moisture coming through the rock face a 3” PVC pipe was placed to provide drainage after the shotcrete was placed. A minimum three inch initial layer of shotcrete was applied to both retaining walls after they were cleaned to provide a secure working surface for personnel. The shotcrete was applied using a dry mix pumped through a hose and then mixed with high pressure water at the nozzle, just prior to exiting the hose.

Figure 6: Shotcrete pump with a bag of shotcrete suspended over it.

The shotcrete was delivered in 2200 pound bags and suspended by a crane over the pump (Figure 6). The flow of the shotcrete was under constant supervision during the application. In some areas of the masonry walls the initial thickness of shotcrete was much greater than three inches due to inconsistencies in the rock face and void spaces between the rocks (Figure 3). The initial layer of shotcrete not only provided reinforcement of the masonry walls during drilling operations, but also provided an even surface for soil nail bearing plates and other reinforcing elements. The raveled void below the mortared masonry wall at the washout area was also backfilled with shotcrete (Figure 7). With the start of winter weather and daily low temperatures of 30-40 degrees, thermal blankets were placed over the shotcrete at night, for a minimum of 2 days to prevent the concrete from freezing during the curing process.

Figure 7: Masonry wall below washout.

Following application of the initial layer of shotcrete, the next step was to drill the holes for the soil nails and rock dowels. For design purposes, all of the 4-inch diameter holes with grouted bars were deemed to be soil nails, even when drilled for a minimum of 8 feet into competent rock. Two-inch diameter holes were drilled for rock dowels, which were installed where bedrock was exposed at the slope surface. Rock dowels were also drilled a minimum of 8 feet into competent rock. Two sacrificial test soil nails were drilled, one located near each retaining wall. It was decided not to perform tests on nails installed through the existing masonry walls to avoid causing any further damage to the walls during the testing process. After the site was cleared of loose soil and vegetation, the edge of the laid up masonry wall and rock outcrops became more distinct. To accommodate the encountered field conditions, several soil nails were relocated or eliminated.

There were 20 holes drilled in each wall, for a total of 40 holes. All 20 of the holes drilled in the mortared masonry wall in the washout area were rock dowels, while in the laid up masonry wall 12 of the holes were soil nails and 8 were rock dowels. If a soil nail hole was found to have fracturing during the drilling process, the hole was drilled deeper in order to achieve a minimum 8 foot embedment depth into competent rock. If fracturing was encountered, a woven fiberglass "sock" was used on the outside of the 1 inch diameter threaded steel bar to prevent excess grout loss into the void spaces. The fiberglass socks (Figure 8) were used on 8 of the 12 soil nail holes. In the soil nail holes, centralizers, spaced no more than 5 feet apart, were placed on the threaded bars prior to placement.

Prior to the grouting of the production soil nails and rock dowels, soil nail bond verification tests were performed. Both test nails were tested to 1.5 times the design load of 4 kips per linear foot for pullout and creep. The test nails at both locations performed satisfactorily.

Figure 8: Fiberglass socks shown protruding from the top of soil nail holes.

The production nails were grouted in place using Sika 212 grout. The grout was tremmie pumped into the holes using grout tubes to ensure that the grout reached the bottom of the holes. Pumping continued until the grout flowed from the collar of the holes. If the level of the grout receded, additional grout was placed to bring the grout level up to the surface of the shotcrete wall face.

After the soil nails and rock dowels were grouted, welded wire fabric was placed over both walls. Reinforcing bar whalers were placed above and below each row of soil nails and rock dowels. A 3 foot piece of reinforcing bar was placed vertically on each side of each soil nail and rock dowel (Figure 9).

The final layer of shotcrete was then applied with a minimum thickness of 5 inches to encapsulate the reinforcing fabric and whalers.

Figure 9: Welded wire fabric and rebar on mortared masonry wall.

At the location of each soil nail/rock dowel several inches of shotcrete was built up, and then a 5 inch square bearing plate was wet set into the shotcrete followed by a hand tightened nut. The soil nails and rock dowels were *not* post-tensioned. Additional shotcrete was then applied to encapsulate the bearing plate and nut to achieve 5 inches of cover to prevent corrosion.

Six of the rock dowels installed in the top of the mortared masonry wall were designed to provide a support system for a gabion wall which was constructed to replace the failed timber crib wall. The six rock dowels were equally spaced at approximately 2 feet on center and installed with a 70^{o} rake from horizontal.

The gabion baskets were assembled and constructed by VTrans personnel from the District 3 Brandon garage. The bottom row of 2 baskets was placed over the six rock dowels. They were filled 2/3 of the basket height with stone prior to a 5 inch bearing plate and nut being installed on the threaded rod. The remainder of the baskets were then filled with stone. Additional layers of gabion baskets were installed. Each layer of baskets was laced to one another and to the row of baskets below them. A granular backfill was compacted behind the gabion wall in 1 foot lifts. A Geotextile was placed behind the gabion wall and brought over the top of the granular backfill. Stone fill was then placed on the geotextile to form the slope back up to the road surface. The final gabion wall can be seen in Figure 10.

Figure 10: Completed Gabion wall

The construction for both walls was completed in 13 working days. There were 714 yd^3 of shotcrete applied, 446 yd^3 to the laid up masonry wall and 268 yd^3 to the mortared masonry wall. A total of 251 feet of 1 inch diameter threaded bar was installed in the mortared masonry wall and 233 feet in the laid up masonry wall.

Materials Testing

The specifications required that the test procedures outlined in Table 1 be performed. Reinforced and un-reinforced pre-production test panels were fabricated prior to the start of shotcreting operations. Strength testing was conducted on shotcrete cores taken from the un-reinforced panels. Tests for absorption were conducted on cores taken from both reinforced and un-reinforced panels. The Sika 212 grout was only tested for compressive strength. Additionally, the VTrans Materials and Research Lab checked the thickness of the galvanization on a hex nut and a 5 inch square bearing plate even though there was no specific requirement for the galvanizing thickness. The average galvanization on the hex nut was 2.05 mil and 12.0 mil on the bearing plate. The galvanization measurements were performed using an Elcometer magnetic coating thickness gauge.

Material	Test Method	Minimum Requirement	Actual
Sika 212 Grout – Test Nails	AASHTO T106 – 3 days	1500 psi	2170 psi
Sika 212 Grout – Test Nails	AASHTO T106 – 28 days	3000 psi	5630 psi
Sika 212 Grout – Production Nails	AASHTO T106 – 3 days	1500 psi	3340 psi
Sika 212 Grout – Production Nails	AASHTO T106 – 28 days	3000 psi	5770 psi
Shotcrete – Compressive Strength	AASHTO T22 – 7 days	2000 psi	5350 psi
Shotcrete – Compressive Strength	AASHTO T22 – 28 days	4000 psi	8303 psi
Shotcrete – Absorption	ASTM C642	Less than 8%	8.70%
Shotcrete – Boiled Absorption	ASTM C642	Less than 8%	8.92%
1” Diameter Threaded Bar - Yield	AASHTO T244	75000 psi	81329 psi
1” Diameter Threaded Bar - Ultimate	AASHTO T244	100000 psi	115038 psi
1” Diameter Threaded Bar Elongation in 8 inches	AASHTO T244	7%	13.4%

Table 1, Laboratory Test Results

Conclusions

As a result of the collaborative effort between the VTrans, Golder and Janod, a repair concept and design were quickly implemented and project construction progressed very smoothly. The project was completed in less time than estimated and under budget. The finished walls can be seen in Figures 11 and 12.

Figure 11: Completed repairs to mortared masonry wall below slide area.

Figure 12: Completed repairs to laid up masonry wall.