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CASE STUDIES OF IN-PLACE REHABILITATION OF FAILING MSE AND H-PILE WALLS

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ABSTRACT

Mechanically Stabilized Earth (MSE) and steel pile walls are commonly used throughout the United States to both repair landslides and create favorable site/road prism geometries. When improperly designed and installed, those structures have an associated failure rate. Post-failure reconstruction and remediation often presents challenges beyond those encountered during original construction, including difficult site access, maintenance of critical infrastructure, and/or roadway traffic.

This presentation outlines some innovative methods available to designers that are robust enough for structural repair and specific enough to prevent unnecessary impact to roadway users and disruption to critical infrastructure. These examples are illustrated using case studies from five design/build MSE and pile wall repair projects in the United States. Relevant technologies include the following: traditional soil nailing, reinforced shotcrete, reticulated micropile arrays, and Shored Geosynthetically Confined Soil (GCS®) walls.

The five case studies for this presentation include a 20,000 square foot MSE wall repair below a housing development in Georgia using soil nails and a partial MSE rebuild; a 50-ft tall MSE wall repair below a shopping center in Nashville, Tennessee using hollow bar soil nails, a reticulated micropile array, and a Shored GCS wall; a failed H-pile wall repair in West Virginia; a failed H-pile wall repair in near Sparta, North Carolina using a Shored Geosynthetically Confined Soil (GCS®) wall founded on a reticulated micropile array; and a failed piling wall system in Lincoln County, Montana.

1. INTRODUCTION

MSE walls, steel pile walls, gabion baskets, and other traditional wall systems have become a common approach to repair landslides and make roadway improvements. Unfortunately, they are sometimes designed improperly or used in the wrong application and therefore fail during construction or a few years after. This report will address five case studies of wall failures throughout the United States and the innovative repair approach used to rehabilitate the existing structures to a safe service state. In the authors' experience, MSE walls that use wide (greater than twelve inches) reinforcement spacing and fine-grained backfill and H-Pile walls with pile lengths greater than forty feet are most prone to failure.

2. CASE HISTORIES

2.1. COBB COUNTY – GEORGIA

An existing MSE retaining wall constructed with geogrid on 30-in spacing using on-site fine-grained soils failed during a high rainfall event (Figure 1). Tension cracks formed approximately 24-ft behind the face of the fall for 114 linear feet and the central 80 linear feet of wall was experiencing facing failure. Figure 1 below demonstrates the inadequate wall drainage with the water flowing over the wall into the road way below and the vicinity of the wall to existing condominium units.

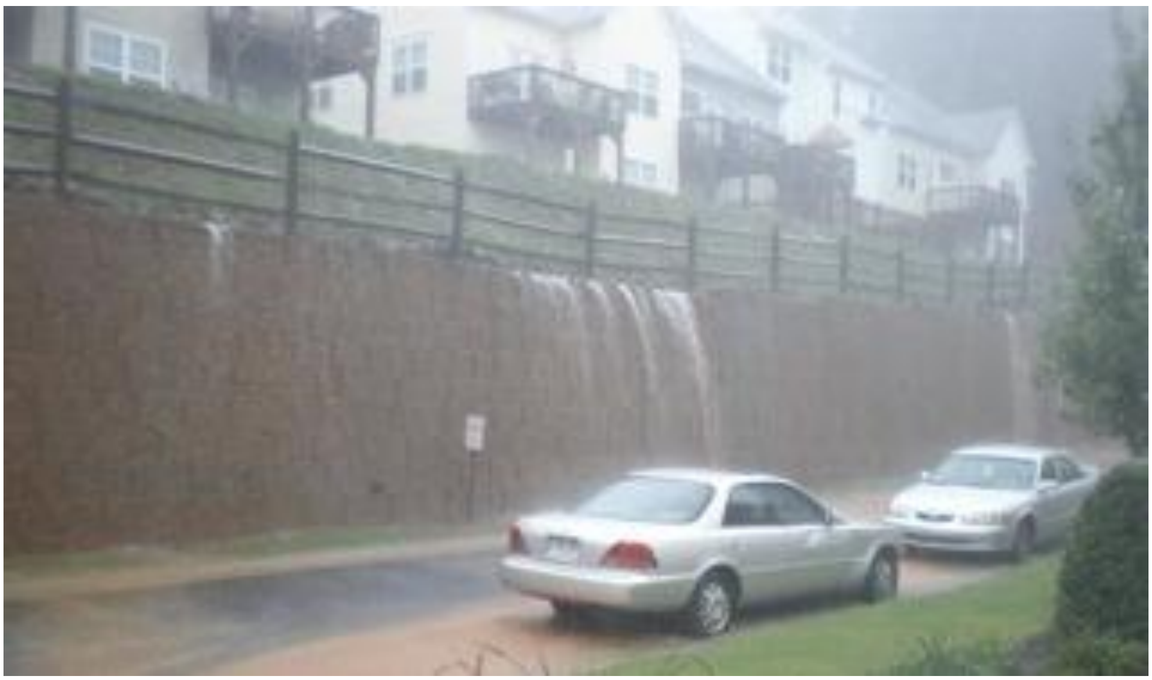

Figure 1: Inadequate Wall Drainage

Figure 2 shows a picture of the failing section of wall. The failure presented an immediate safety concern for the residents living in the condominiums above the wall and for traffic and pedestrians using the roadway directly below.

A remediation plan was quickly developed to stabilize the failing wall and to prevent damage to the existing property above and the existing road below. A limit equilibrium stability analysis on the existing wall showed that existing conditions had a factor of safety of 0.3 when the existing reinforcement was eliminated. Typical design requirements necessitate the existing MSE Wall to be designed at a 1.5 factor of safety but the failure indicated that the structure was likely around a 1.0 just before failure with the reinforcement. The repair consisted of installing up to 55-ft long soil nails throughout the existing wall with the nail heads sticking out enough to provide anchorage points to attach galvanized steel plates and epoxy coated hex nuts. The bearing plates, set in sanded mortar, were tensioned against the block face of the existing wall by tightening the nuts which prevented further wall movement and increased the factor of safety. In the sections where the wall had completely failed, the soil nails were anchored into a reinforced shotcrete back wall along the failure surface. Once the soil nails and shotcrete were installed, granular compacted backfill and blocks were installed on the original alignment allowing the repair to blend with the existing wall. The final repair brought the wall to a minimum factor of safety of 1.5. Drilling through the original wall proved to be difficult in places, as the fill contained everything from 18-inch diameter granite boulders to clay requiring a variety of drilling techniques to be used. Auger drilling produced ultimate bond strengths of around 3 psi; air rotary (open-hole) drilling produced bond strengths around 10 psi, and hollow-bar soil nails with continuous grout flushing produced bond strengths of around 19 psi.

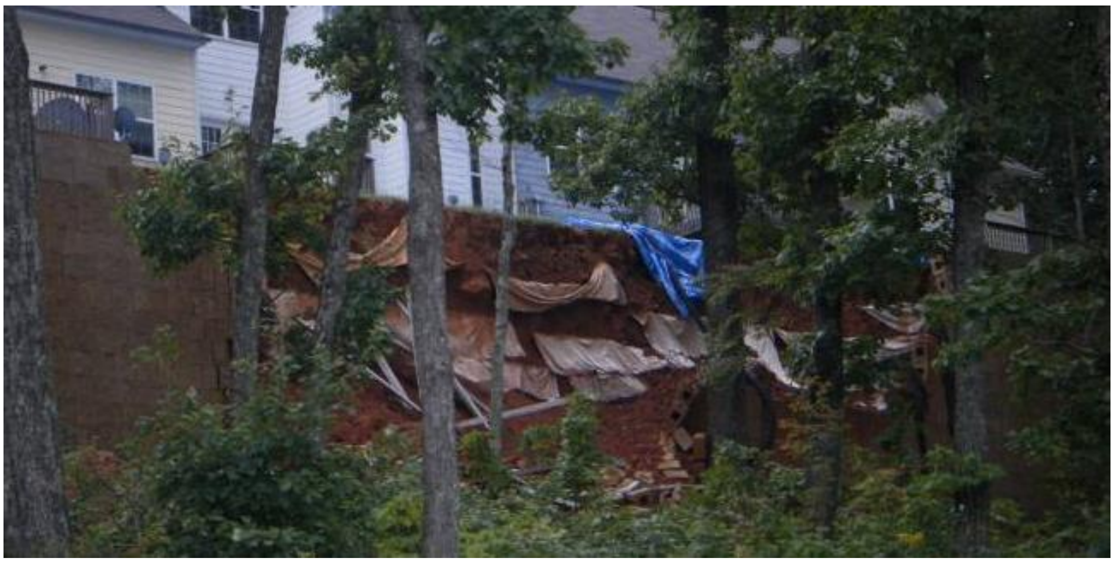

Figure 2: Failing Section of Wall

2.2. WV 20 MP 20.16 FENWICK MOUNTAIN ROAD – WEST VIRGINIA

A mountain highway was originally constructed on loose fill that was inadequately drained. Continued roadway movement had been occurring for over 20 years. Many different type of traditional repairs had been attempted to stop the slide from progressing. The final repair, an H-pile wall with lagging and a horizontal waler to hold the material in place, began moving a few years after initial construction.

Because the piles had not moved significantly and were embedded into bedrock, the remediation plan included leaving the piles in place to retain their existing capacity and to limit the impact and time of construction. A 12-ft tall soil nail wall consisting of up to 70-ft long soil nails was installed between the existing piling to achieve 10-ft minimum embedment into bedrock on the inboard side of the roadway. Existing slope material in front of the piles was removed including material below the piles as necessary to achieve the necessary working face to install subsequent rows of soil nails. Reinforced shotcrete was installed in lifts to cover the existing piles and to secure the soil nails. Shotrock and vegetation were installed at the base of the shotcrete to prevent potential erosion issues below the repair. Finally, drilled horizontal drains were installed to remove groundwater behind the wall as seen in Figure 4.

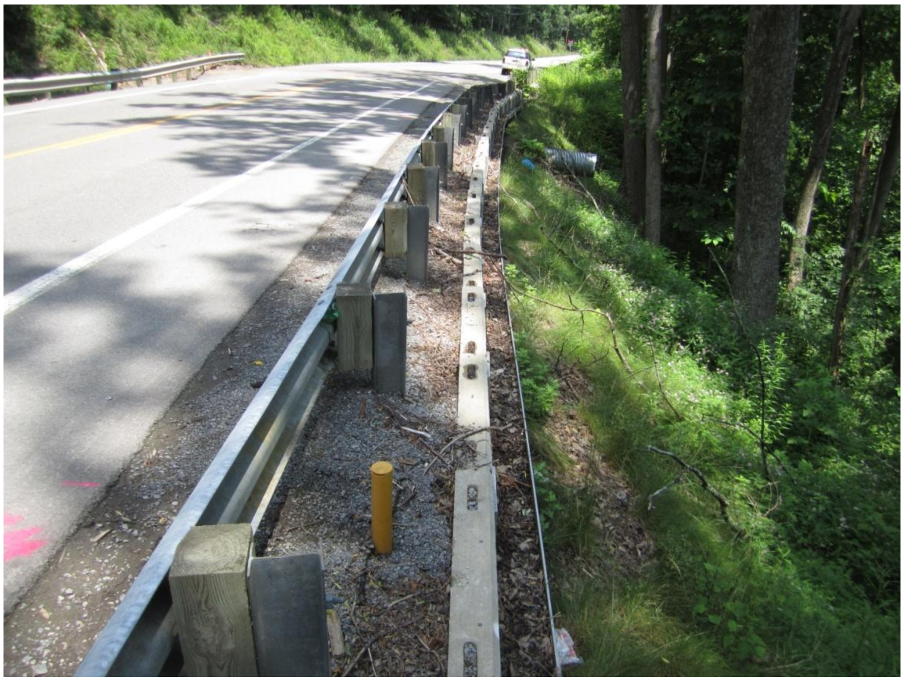

Figure 3: Failing Piling Wall

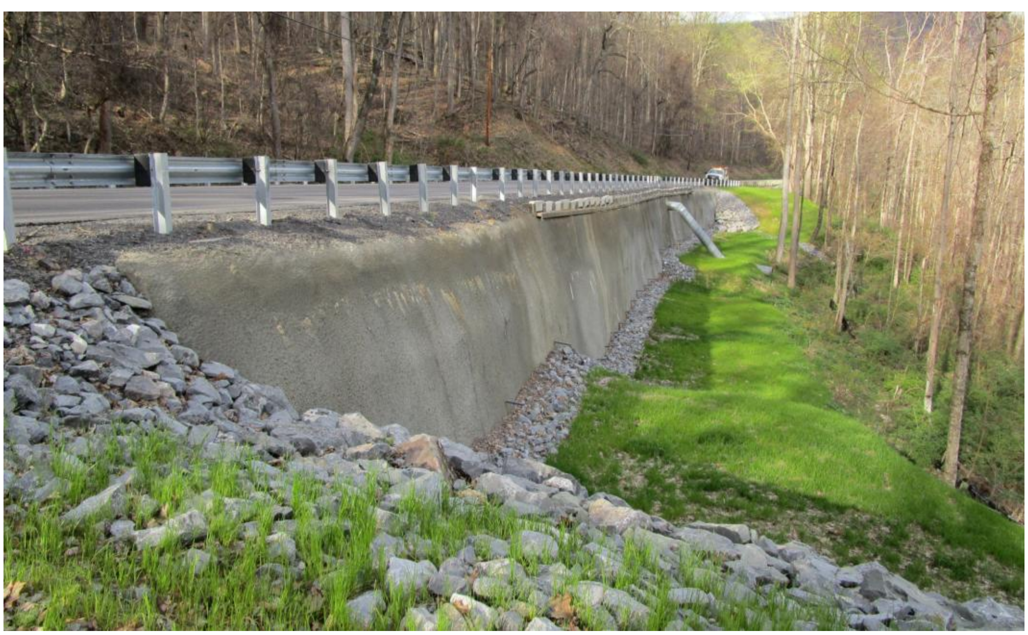

Figure 4: Soil Nail Wall Repair

All repairs were constructed using the outboard traffic lane and the inboard lane remained open which allowed vehicles to pass with minimal interruption. Both traffic lanes were open in the evenings when workers were not active.

2.3. NASHVILLE – TENNESSEE

An MSE wall (constructed using uniaxial geogrid on 36-in spacing and on-site fine-grained soil) which supported the rear parking lot of a shopping center in Nashville, Tennessee failed catastrophically due to a bearing failure at the base of the wall. When the wall failed, the facing and soil translated to the slope below posing an immediate threat to the road surface located partially on the MSE wall for approximately 434 linear feet. An immediate repair was needed to ensure the stability of the slope and to protect nearby structures. Figure 5 below shows the failure of the MSE wall taken from the parking lot surface above. Note the separated pipe in the center of the picture.

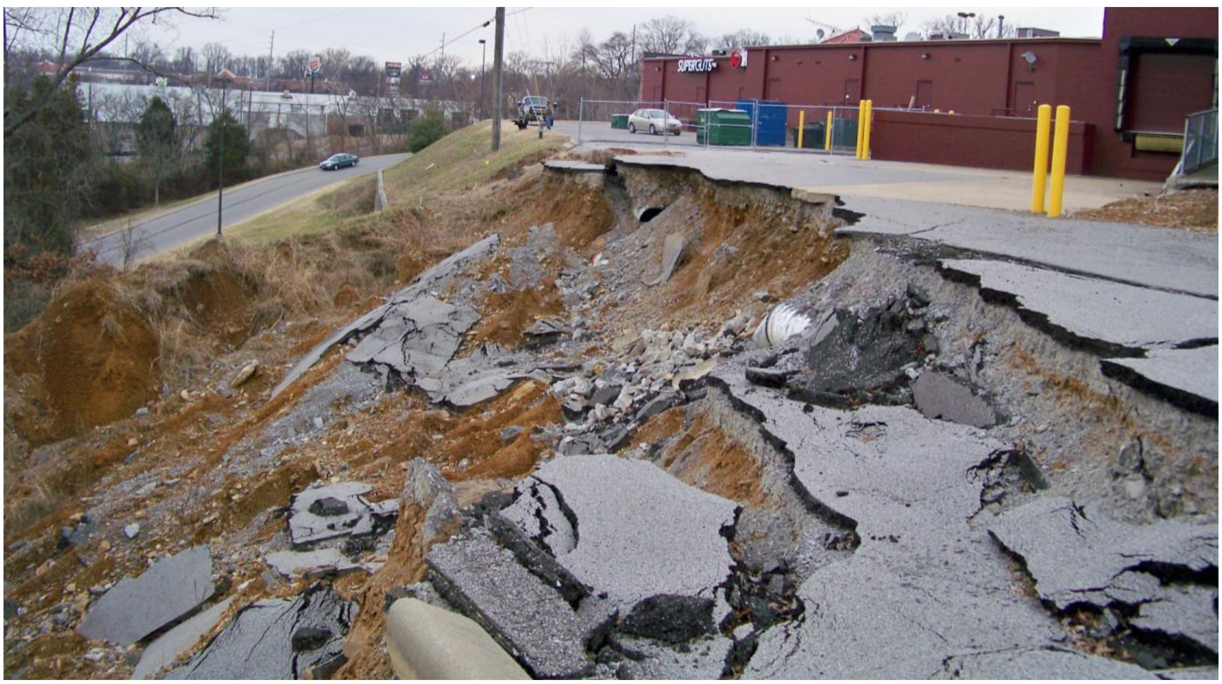

Figure 5: MSE Failure

The repair required a new wall to be constructed in place of the existing one and would require two phases of construction. The first phase consisted of removing much of the failed wall system and constructing a temporary shoring system with up to 30-ft long soil nails and reinforced shotcrete, constructed in lifts. In areas where the existing MSE wall block face remained, nails were drilled into the existing block face. The 20,000 square foot temporary soil nail wall varied in height up to approximately 50-ft with a design factor of safety of 1.3.

Once Phase I was completed, crews could safely begin working on Phase II at the base of where the previous MSE wall was located. Phase II was a rebuild of the failed wall. Before wall construction began, however, karst areas were identified in the base of the new wall. A foundation system was installed to provide sufficient bearing capacity for the new wall, which consisted of an array of, 2-in diameter micropiles on 5-ft centers with a minimum 2-ft embedment into the underlying limestone bedrock. Actual installation depths varied between 5 and 30 feet, and the piles were then integrated into a reinforced shotcrete raft foundation.

Other foundation improvement systems were considered during the design phase, including rammed aggregate piers and caissons, but the small-diameter micropile array was chosen for the redundancy it provided – if any single pile were to fail in the varying karst formation, the surrounding piles would be able to take up the load. Figure 6 shows the temporary shoring system with horizontal drains, and Figure 7 shows the micropile foundation during installation. A shored Geosynthetically Confined Soil wall (using lightweight woven polypropylene geosynthetic on 8-in centers in a well-compacted granular backfill) was constructed on top of the micropile raft foundation and the overall global stability was increased to a factor of safety greater than 1.5.

Figure 6: Temporary Shoring during Phase I

Figure 7: Micropile foundation during Phase 1

2.4. US 21 – WILKES COUNTY, NORTH CAROLINA

An unstable section US 21 near Sparta, North Carolina was stabilized previously using H-piles and timber lagging on the outboard shoulder of roadway for 237 linear feet. The piles were not embedded into bedrock, and had begun to both tip and translate. The roadway was showing signs of distress with tension cracks near the centerline and significant overall sagging. The piling wall was bulging in the center and a large scarp had formed at the base of the lagging wall. Large amounts of material had washed out below the slide. Figure 8a shows the scarp forming below the piling wall and the bulge in the lagging and Figure 8b shows the roadway distress occurring above the piling wall.

Two repair options were proposed to stabilize this large slide. The first option was to install up to 50-ft long soil nails through the piling lagging wall to stabilize the roadway in the upper portion of the slide and prevent further movement. Next a reinforced shotcrete facing would be applied over the soil nails and wall face. Finally, an array of micropiles and tieback would be installed in a grade beam outside the piling wall to support the lower section of the wall.

The second, more economical, repair option was selected. The site was excavated along the scarp line running through the existing road surface for the length of the slide. Up to 30-ft long soil nails with reinforced shotcrete facing were then installed in lifts to protect the existing road platform and to prevent the slide from regressing into the remaining travel lane. Next, an up to 40-ft high Shored Geosynthetically Confined Soil (GCS) Wall was installed on an array of micropiles. The wall provided additional road width and replaced section of roadway lost in the landslide.

Upon completion, the final repair brought the existing slope to a global stability of 1.5. Figure 9 below shows the GCS Wall being constructed in front of the permanent soil nail wall.

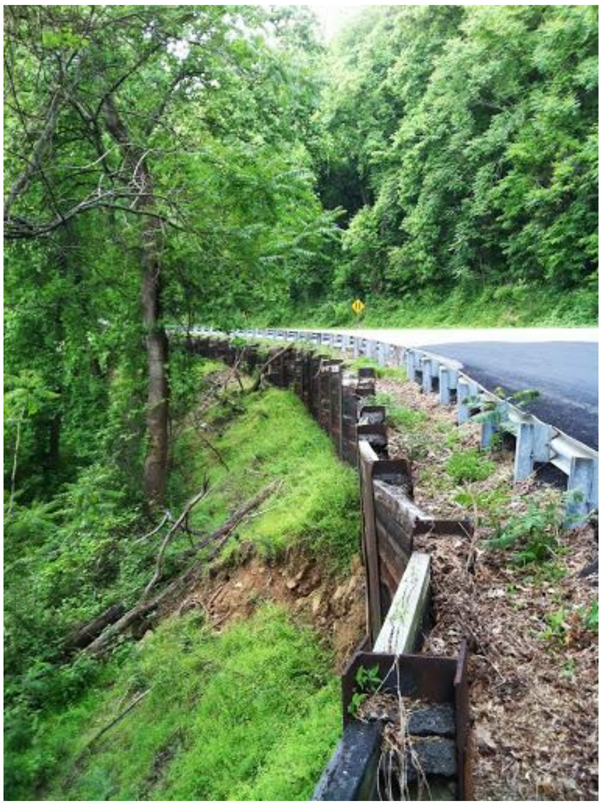

Figure 8a: Scarp formation

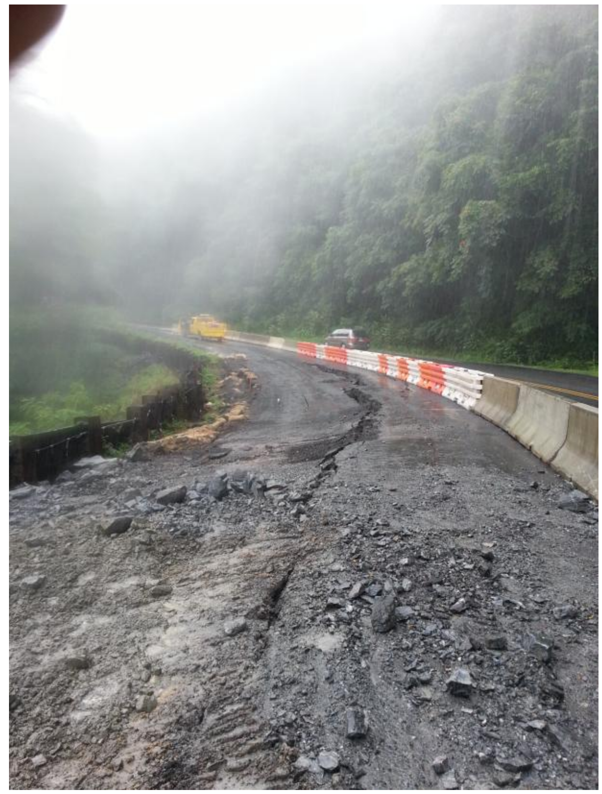

Figure 8: Failing Roadway Above Lagging Wall

Figure 9: GCS® Wall Construction

2.5. US 2 MP 5.23 – LINCOLN COUNTY, MONTANA

A section of US Highway 2 had been repaired two separate times using piling lagging walls in an attempt to stop continued roadway landslides. The first attempt to repair the road consisted of installing a piling lagging wall approximately 6-ft from the outboard shoulder of the roadway.

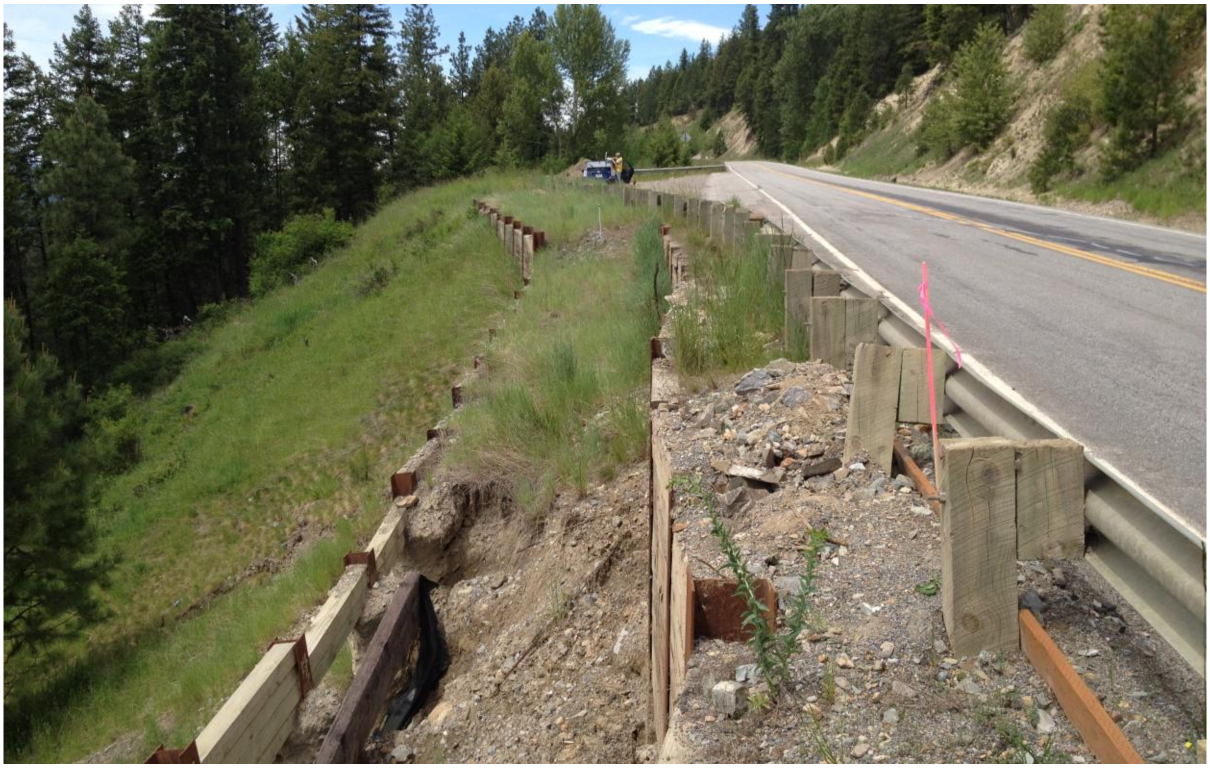

Figure 10: Failing Piling Walls

When the road continued to move, an additional piling wall was installed approximately 15-ft from the outboard edge of pavement with the piles embedded even deeper than the first wall. The lower piling wall had failed completely, the upper piling wall was showing signs of bulging, and soils were eroding from below the timber lagging. An additional piling wall was installed just Northwest of the two failing walls and it was observed that the landslide scarp was encroaching on that wall. The total repair area was measured to 185 linear feet.

Based on a site reconnaissance, boring logs, and a limit-equilibrium analysis, engineers determined that the slope was failing through the silt layer in the upper 20 feet of the formation. The failure was estimated to be just below the embedment depth of the lower piling wall. Further subsurface investigations showed that the bottom of the pilings were installed approximately 8-ft above competent bedrock.

The repair consisted of installing an array of up to 50-ft long soil nails at various angles to optimize the minimum nail lengths and ensure sufficient embedment into bedrock. The upper rows of nails were installed from the existing roadway platform while maintaining an open inboard lane for traffic. The piling walls were torched and trimmed down during each excavation lift so that crews could install the soil nails and reinforced shotcrete facing. The lower rows of nails were then installed using a bench wide enough for equipment. The pilings were removed from the hillside once crews could access the final construction bench. The height of the soil nail wall varied up to approximately 26-ft in height and extended to the bedrock layer below to prevent soils from undermining the shotcrete facing. The final design provided a 1.5 factor of safety and was constructed in approximately 6 weeks.

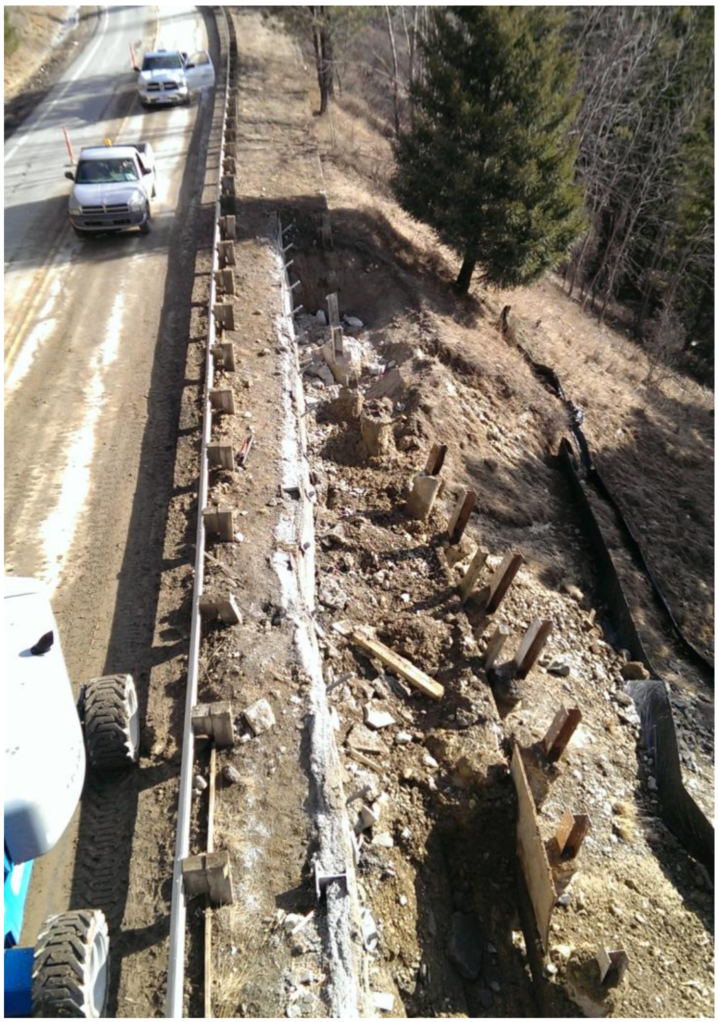

Figure 11: Existing Piling during Construction

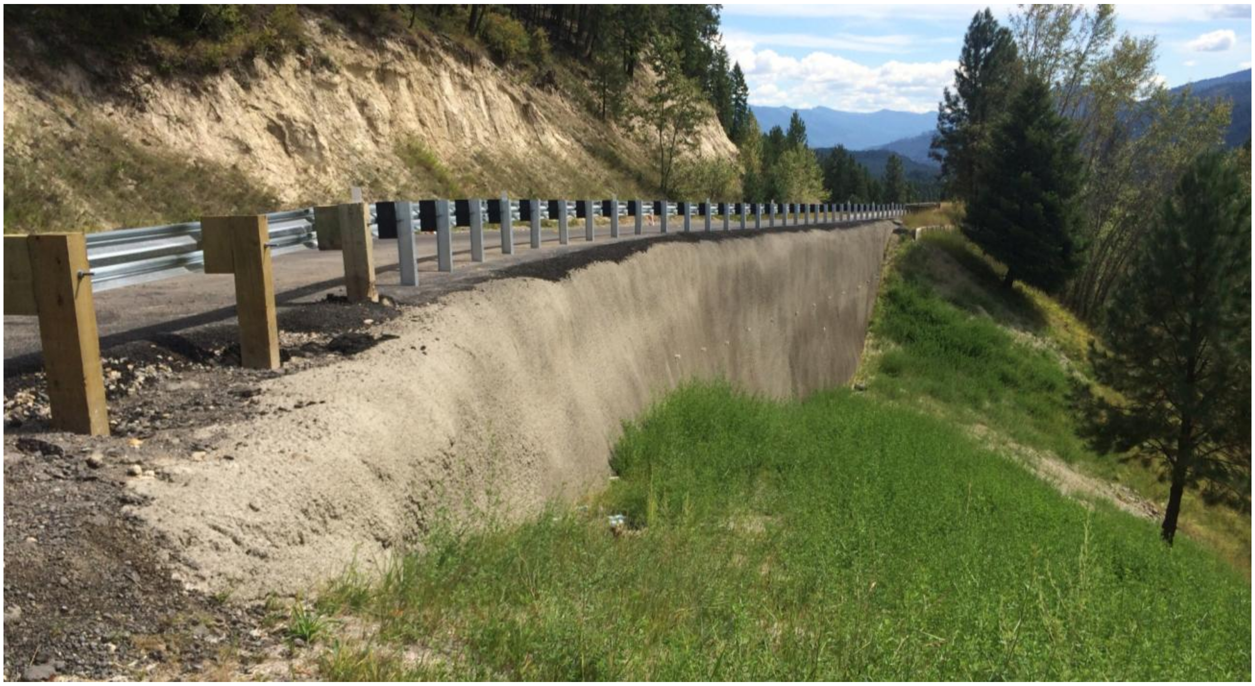

Figure 12: Completed Wall

2.6. CONCLUSIONS

Piling walls and MSE walls are commonly used for repairs and to create favorable site conditions and roadway platforms throughout the United States. Unfortunately, many are designed and/or installed incorrectly and have an associated failure rate. Repairs can be difficult as conditions and access have often changed from the time of construction. This paper outlined five case histories where existing MSE and piling walls in various locations failed and the innovative approaches used to repair them using technologies including traditional soil nailing, reinforced shotcrete, reticulated micropile arrays, and Geosynthetically Confined Soil (GCS) walls. In these cases, the use of innovative technologies allowed for minimal impact on roadway traffic and minimal disruption to critical infrastructure, and often allowed for the failed or failing structures to be stabilized without complete removal.