Innovative Slide Repair Techniques
Guidebook for Missouri

Prepared By

Shannon and Wilson, Inc

Report Prepared for Missouri Department of Transportation
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TRyy 1144 INNOVATIVE
SLIDE REPAIR TECHNIQUES FOR MISSOURI
GUIDEBOOK

September 14, 2011

Submitted to:
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41-1-37083-001

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1.0 INTRODUCTION

Shannon & Wilson, Inc. has completed the guidebook for this project. Our work was authorized on March 18, 2011 by the Missouri Highways and Transportation Commission.

This guidebook is not intended to be a comprehensive listing of slide repair options or to provide in-depth information on the analysis of landslides. Instead this guidebook is intended to provide general guidance on landslide repair/stabilization including “rules of thumb” for selected repair options.

The objective of and results expected from this project are as follow:

> *Soil slides often require immediate action to keep traffic moving safely. This study will focus on developing newer (innovative) approaches to evaluate slope failures and provide cost-effective repair and mitigation techniques. Typically slides are repaired by excavating the slide material and then backfilling with more stable material. However, MoDOT is looking for the researcher to review newer more innovative techniques that have been deployed nationally by other State Departments of Transportation, Geotechnical journals, Geotechnical contractors and any organization that is responsible for the repair of landslides. The goal is to find repairs that provide for long-term stabilization, but that are more cost effective than the typical excavation method. The research is to develop a listing and description of these innovative slope repair techniques. The study shall provide MoDOT with descriptions of when these innovative techniques could be deployed and what are the resources, materials, equipment and personnel needs required to accomplish such repairs.*

Each repair method is discussed on one page with a sketch of the repair on the opposing page for easy reference. Where photos of the repair method were available, they are included after the sketch.

2.0 REVIEW OF SLOPE INSTABILITY

Slope instabilities (landslides) come in many sizes and take many shapes. This short review is intended as a reference for those already familiar with the general concepts of slope stability and to standardize terms used later in the document.

Landslides occur in a variety of forms, such as falls, topples, flows, spreads, slides, and combinations. Falls and topples are common in rock slides, but rare in soil. Flows and spreads tend to be very shallow, potentially fast moving landslides. General slides can be shallow or deep, circular or wedge shaped or combinations of each of these. This general type of slide is the most common landslide type in Missouri and is the focus of this guidebook.

For discussion purposes, shallow slides will be those where all points along the failure plane, i.e. the dividing line between stable and unstable soil, is less than 10 feet below the ground surface measured vertically directly above the measured point. Deep slides are those where the failure plane is more than 10 feet below the ground surface. A typical slide is shown on Figure 1.

Circular slides are typified by an area of instability that looks like the side of a bowl. Wedge slides tend to be more elongated with a well defined active block located at the scarp. It is more difficult to estimate the depth of a circular slide than a wedge slide without explorations. Typical slides are shown on Figures 2 through 4.

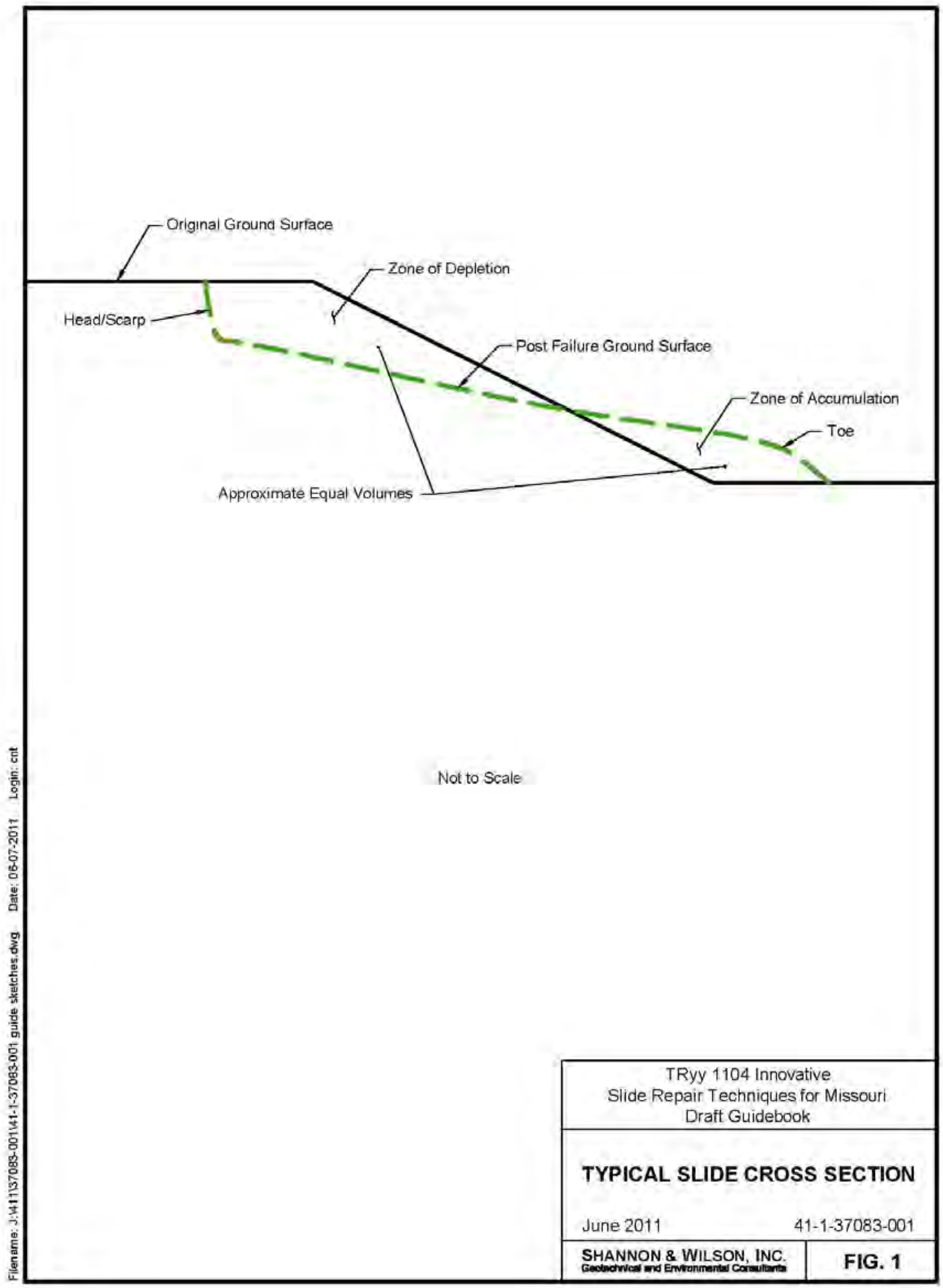
To stabilize a slide, the forces resisting the slide have to be greater than the forces driving the slide. This is generally accomplished by increasing the resisting forces, decreasing the driving forces, or a combination of both. Methods of increasing resisting forces include adding weight to the lower portion of the slide and increasing the strength of the material in the lower portion of the slide. Methods of decreasing driving forces include improved drainage of the upper portion of the slope and reducing the weight of the upper portion of the slope. Generally, the most cost effective solutions are ones that both reduce driving forces and increase resisting forces.

Certain activities should be avoided on steep slopes to reduce the risk of landslides. Likewise, care should be taken during slide repairs not to make conditions worse. The following is a list of things to avoid:

- Loading or stockpiling material along the upper portion of the slope,
- Unloading or excavating the lower portion of the slope,
- Directing water to the failure area, particularly in a concentrated manner,
- Denuding slope without a revegetation plan, and
- Installation of a permanent irrigation system.

As noted previously, poor drainage is often a contributing factor to slides. Poor drainage can be caused by intentionally or unintentionally directing water to a specific location without providing a controlled way for that water to reach the bottom of the slope, by blocked drainage ways (culverts and ditches) causing water to pond at the top of or on slopes, and by blocking natural drainage with fill during construction. These problems are best avoided by proper maintenance and design. Surface water drainage issues are best found by observing potential problem areas during or immediately following heavy or protracted rain events. Subsurface drainage problems are rarely visible and are not likely to be identified prior to formation of a slide. However, an indicator of subsurface drainage problems may be the presence of seepage, damp areas, or water-loving plants on the slope.

Slides are best avoided by considering the general principles discussed above when working on slopes. If weight (soil, rock, pavement, etc.) must be added to the upper portion of a slope, consideration should be given to adding weight to the lower portion of the slope to maintain the balance between driving and resisting forces. Likewise, if the lower portion of a slope must be cut, such as for a ditch, then consideration should be given to removing weight from the upper portion of the slope. If a natural drainage way is to be filled or an area of seepage is to be covered by fill, then consideration should be given to providing drainage in that existing drainage way or wet zone. This can often be accomplished by using free draining granular fill instead of clayey fill or by installation of an aggregate drain before any fill is placed.


Original Ground Surface
Zone of Depletion
Head/Scarp
Post Failure Ground Surface
Zone of Accumulation
Toe
Approximate Equal Volumes
Not to Scale
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Slide Repair Techniques for Missouri
Draft Guidebook
TYPICAL SLIDE CROSS SECTION
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FIG. 1
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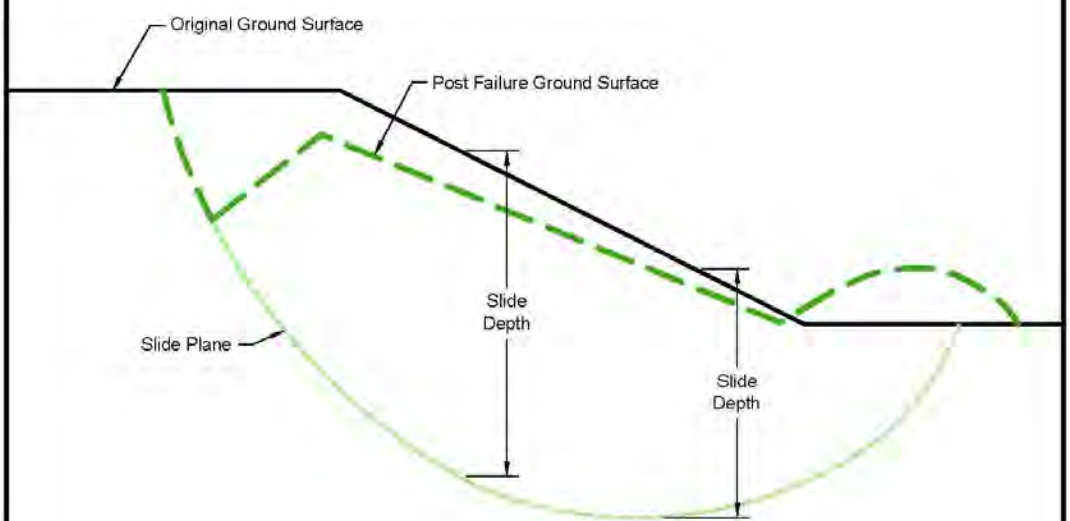

Not to Scale

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TYPICAL DEEP CIRCULAR SLIDE CROSS SECTION

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FIG. 2

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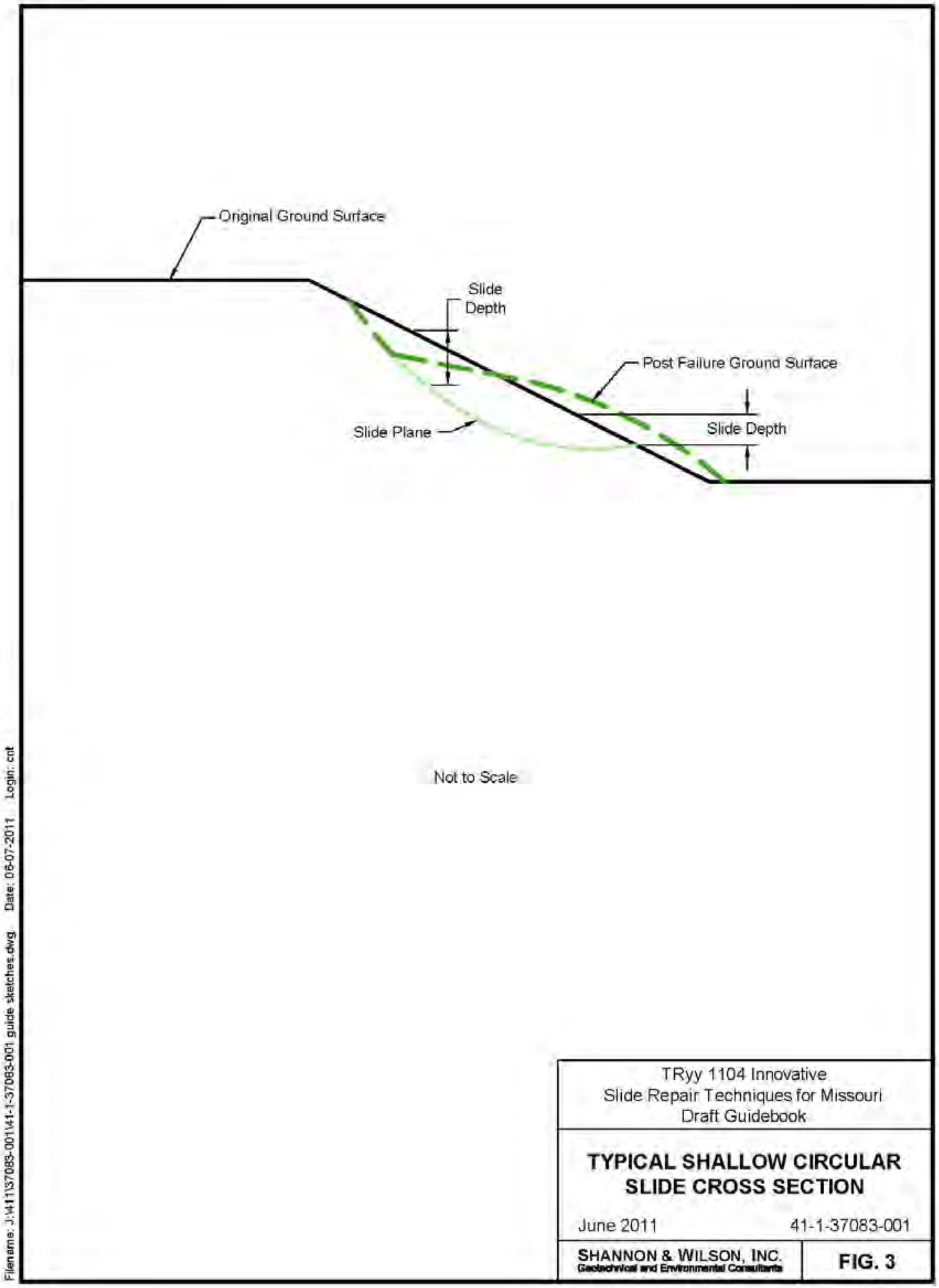
Original Ground Surface
Slide Depth
Post Failure Ground Surface
Slide Plane
Slide Depth
Not to Scale
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TYPICAL SHALLOW CIRCULAR
SLIDE CROSS SECTION
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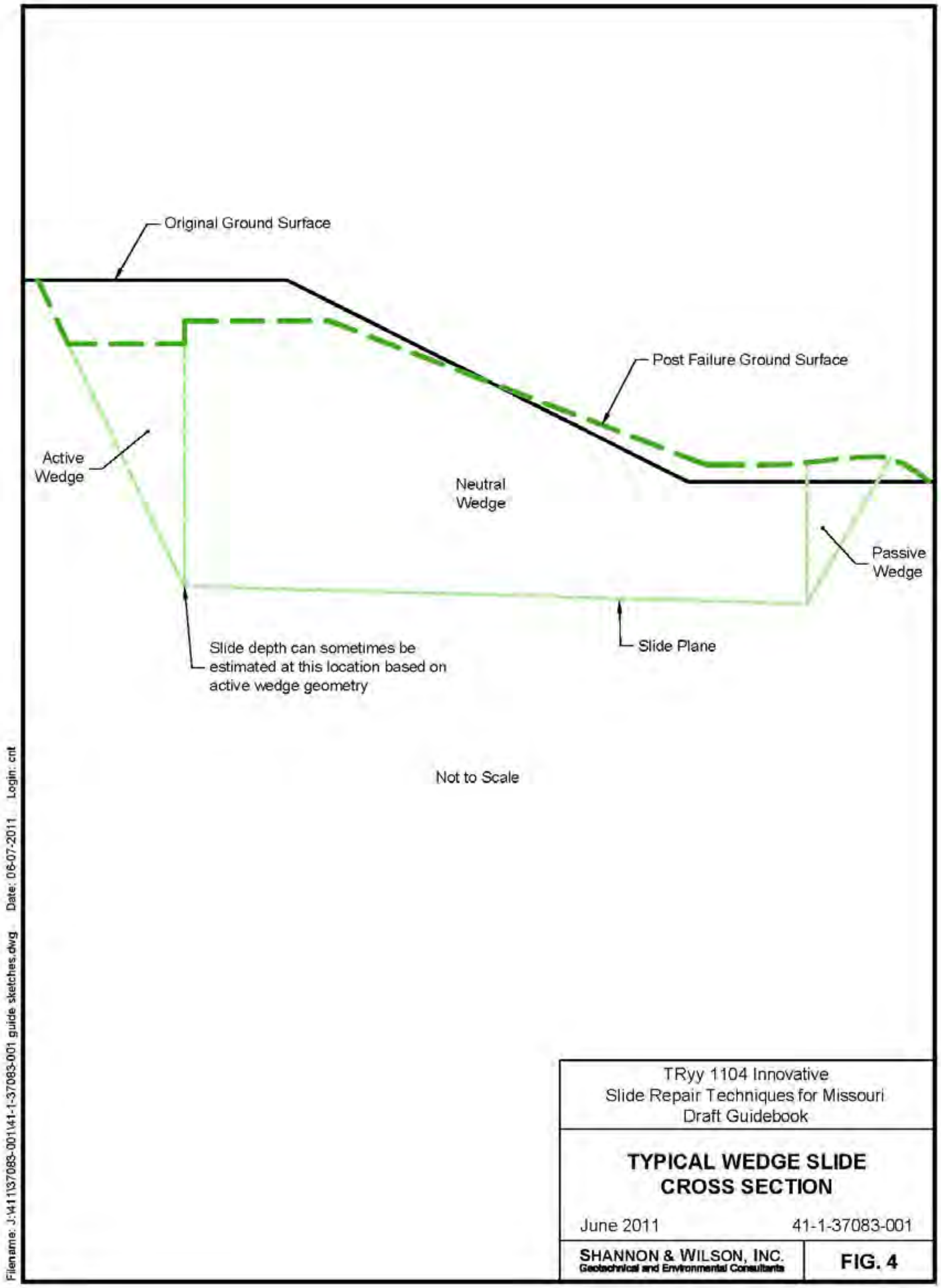
FIG. 3


Original Ground Surface
Post Failure Ground Surface
Active Wedge
Neutral Wedge
Passive Wedge
Slide Plane
Slide depth can sometimes be estimated at this location based on active wedge geometry
Not to Scale
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TYPICAL WEDGE SLIDE
CROSS SECTION
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Typical Slide

Typical Slide

3.0 ROCK/SOIL BUTTRESS REPAIRS

Buttresses can be constructed either with or without excavation. The method discussed herein is the no excavation option. This is a brute force solution that, when completed properly, has a high degree of success. The method consists of placing weight, rock and/or soil, in the lower portion of the slide to increase the resisting forces.

Applicability: This method can be applied to both shallow and deep slides; however, is generally more cost effective for deep slides than shallow ones.

Design Effort: Can be installed with no design effort using the rules of thumb included below under process. The expected factor of safety improvement is about 10 percent.

Advantages: Repairs can begin as soon as equipment and material are available at the site. No specialized equipment is required. Low quality material can be used in the buttress.

Disadvantages: Generally requires a lot of material be hauled to the site. Access to the toe of the slide is required and significant land is required past the toe of the slide. Sufficient right-of-way may not be available. Soil fill can reduce drainage from the slope.

Personnel/Equipment: This repair can be completed by one to two operators working with one to two laborers. Required equipment consists of trucks to deliver the buttress material and a machine to move the buttress material, usually a track-hoe or small dozer.

Process: Care should be taken in delivering material to the area so that weight is not, even temporarily, added to the top of the slide. Rock is the preferred material.

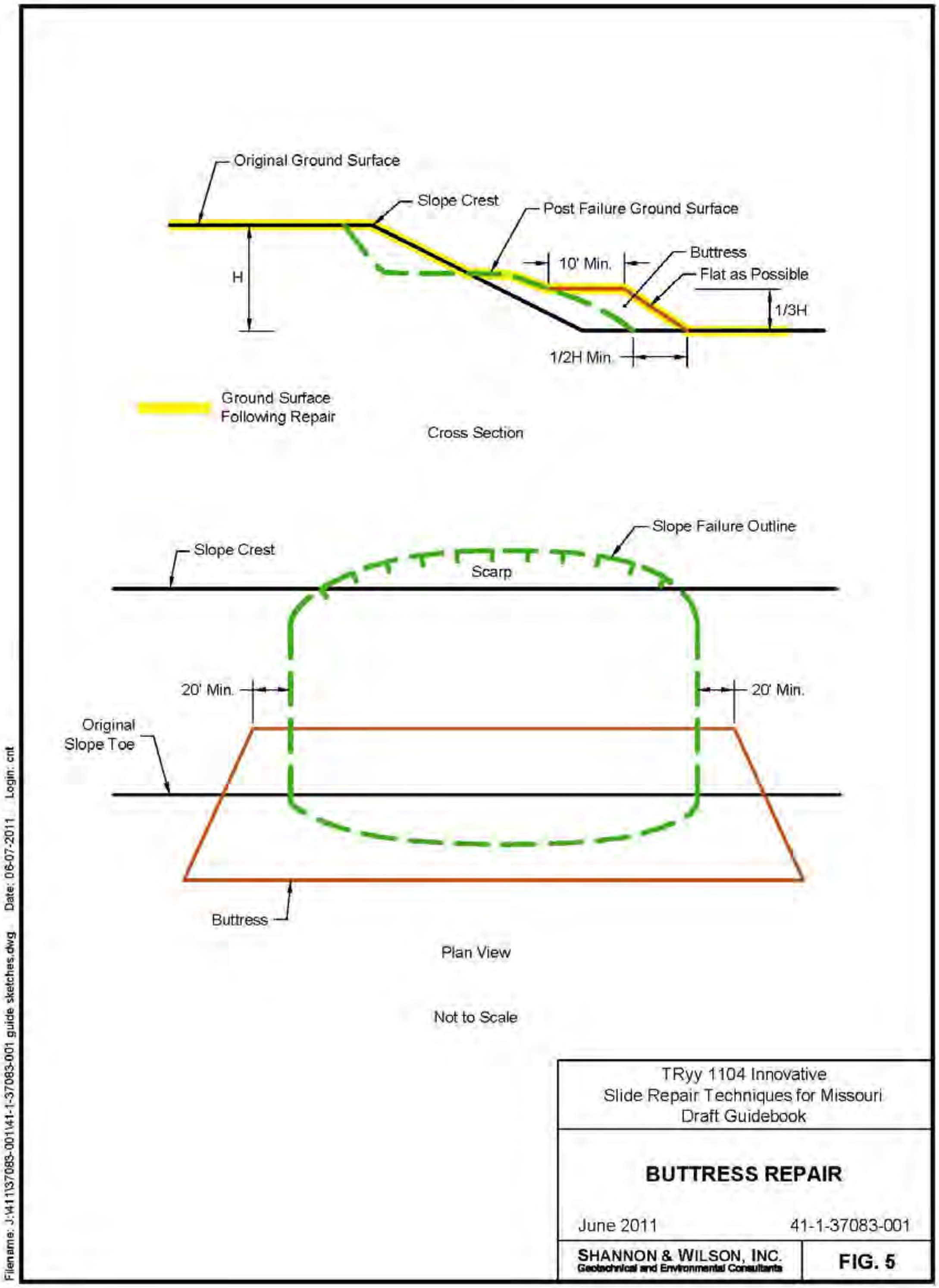
Fill material is placed on the lower 1/3 of the slope to add weight and resisting forces, as shown in Figure 5. The bottom width of the buttress should be a minimum of ½ the height (½ H) of the slope. The top width of the buttress should be a minimum of 10 feet. The free face of the buttress should have as flat a slope as possible, but a maximum slope of 2(H):1(V) for soil and 1.5(H):1(V) for rock is recommended. The buttress should extend a minimum of 20 feet past each end of the slide.

Rock fill consisting of any free draining rock, such as shot rock, is generally acceptable. A well graded material provides more weight per cubic foot and is usually easier to handle/place at the site. The rock should be placed in lifts not greater than 3 feet and compacted by multiple passes of tracked equipment. Compaction is not critical but does provide a higher unit weight and therefore more resisting force than uncompacted fill.

Soil fill can consist of any non-organic material. For clayey soils, compaction with sheep's foot rollers is recommended, but not always practical. At a minimum, multiple passes with tracked equipment should be used. Lift thicknesses should be determined based on the soil and the type of equipment being used for compaction.

Since this repair does not rely on the strength of the buttress material, only the weight, compaction is important to increase the density (weight) of the material. Moisture conditioning will make placement easier and allow achieving higher densities, but is not required. Likewise, pumping material in the buttress is not a concern other than its negative effect on the placement of additional material. Compaction testing is not generally justifiable or performed.

Any cracks in the ground surface above the slide should be sealed to reduce the likelihood of surface water entering the slide. Sealing can be accomplished by blading and tracking over cracks with a small dozer. Once the buttress is installed, the slope should be generally regraded as shown on Figure 5.


Original Ground Surface
Slope Crest
Post Failure Ground Surface
10' Min.
Buttress
Flat as Possible
H
1/3H
1/2H Min.
Ground Surface Following Repair
Cross Section
Slope Failure Outline
Slope Crest
Scarp
20' Min.
20' Min.
Original Slope Toe
Buttress
Plan View
Not to Scale
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BUTTRESS REPAIR
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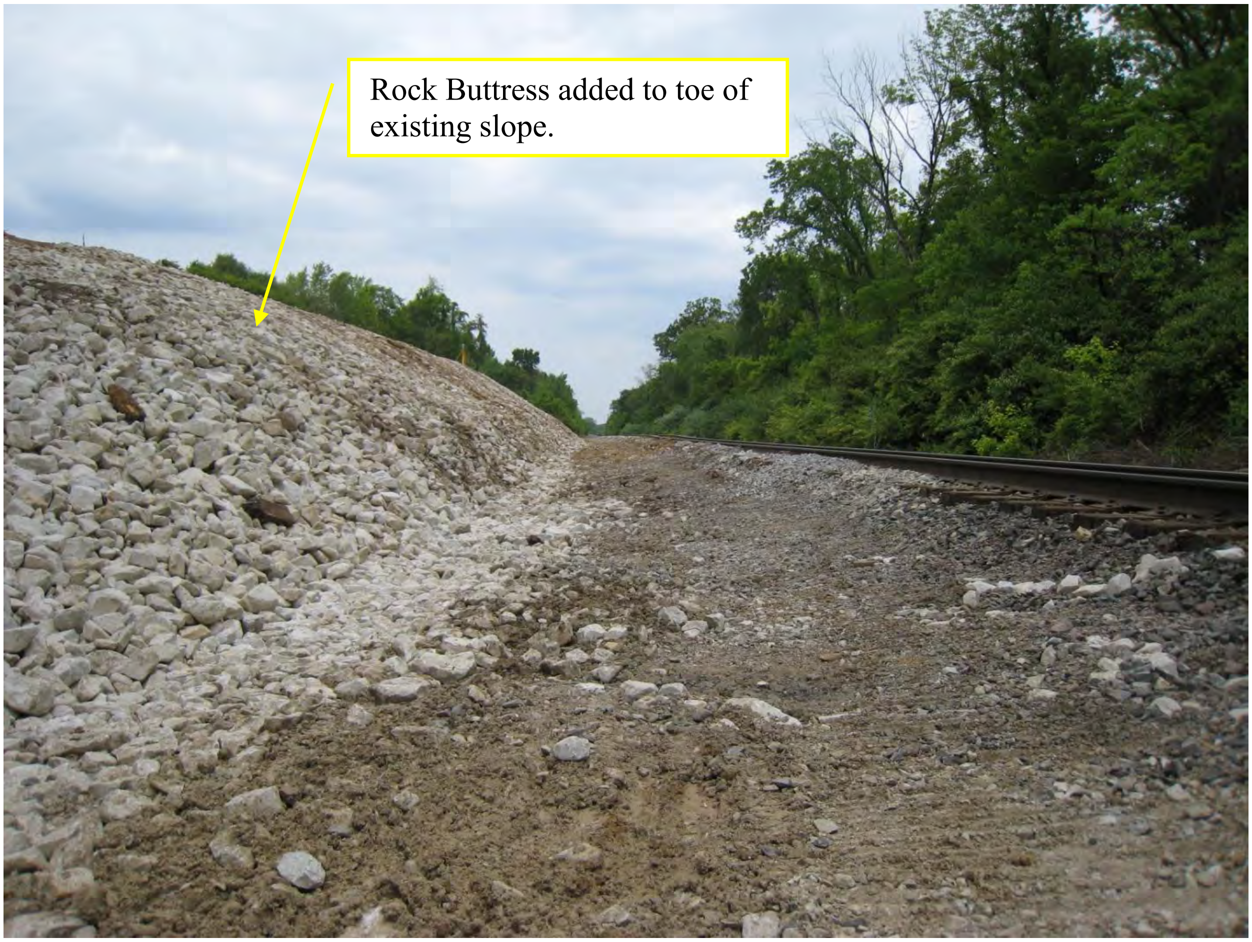


Rock Buttress Repair

Soil Buttress and Crest Unloaded Repair

4.0 AGGREGATE DRAIN REPAIRS

Aggregate drains improve the stability of slopes by removing water from the slope. Water is often, but not always, a trigger to the start of sliding. Water in the slope increases the weight of soil materials while decreasing the effective stress on potential slide planes. This solution is aimed at removing water weight from the upper portions of the slide. This also results in a slight increase in the strength of the soil along much of the slide plane.

Applicability: This method can be applied to both shallow and deep slides; however, when installed alone it is most effective on shallow slides. Can be installed in conjunction with most other stabilization options, which is where the most benefit is gained.

Design Effort: Can be installed with no design effort using the rules of thumb included below under process. The expected factor of safety improvement is about 10 to 20 percent.

Advantages: Repairs can begin as soon as equipment and material are available at the site. No specialized equipment is required.

Disadvantages: Improvement to stability will be minimal if water is not a significant factor in triggering the slide.

Personnel/Equipment: This repair can be completed by one operator working with one laborer. Required equipment consists of trucks to deliver the drain material and a track-hoe to excavate and backfill the drain. A small dozer is convenient for shaping the final slope but not required.

Process: Care should be taken in delivering material to the area so that weight is not, temporarily, added to the top of the slide.

The drains should extend a minimum of 10 feet below existing grade, unless the total slope height is less than 10 feet in which case the drain should extend the full height of the slope (Figure 6). The bottom of the drain should be sloped to drain unless the slope is less than 10 feet high in which case a flat bottom is acceptable. If possible, the drains should be extended to intersect the failure surface as this will generally decrease the buildup of water along the failure surface.

The drains should be constructed approximately 30-inches wide.

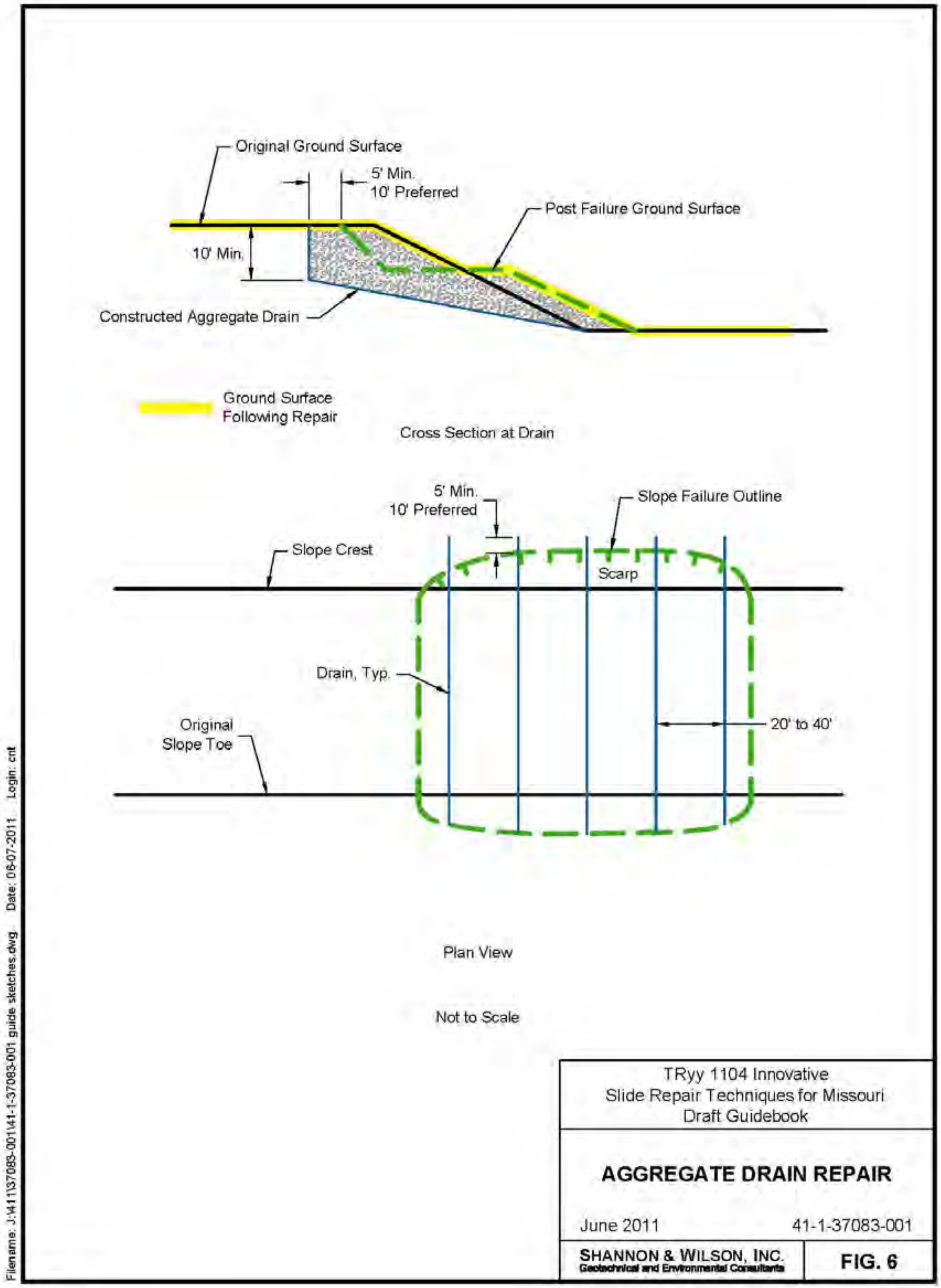
The top of the drain should extend a minimum of 5 feet past the slide scarp, 10 feet past is preferable. The drain should be extended to the bottom of the slope, regardless of where the slide ends.

Drains should generally be installed on 20 to 40-foot centers within the slide area. A minimum of two drains is recommended.

Drain material should consist of MoDOT Aggregate for Drainage in accordance with 1009.3.5 Grade 5. Alternately material meeting 1009.3.2, or 1009.3.4 can be used. Pipes and separation fabric are not required in the drains.

It is beneficial to place material excavated from the drains on the lower 1/3 of the slope to form a buttress. In this case, drains must be extended through the buttress.

Any cracks in the ground surface above the slide should be sealed to mitigate surface water from entering the slide. Sealing can be accomplished by blading and tracking over cracks with a small dozer. Once the drains are installed, the slope should be generally regraded as shown on Figure 6.


Original Ground Surface
5' Min.
10' Preferred
Post Failure Ground Surface
10' Min.
Constructed Aggregate Drain
Ground Surface
Following Repair
Cross Section at Drain
5' Min.
10' Preferred
Slope Failure Outline
Slope Crest
Scarp
Drain, Typ.
Original
Slope Toe
20' to 40'
Plan View
Not to Scale
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AGGREGATE DRAIN REPAIR
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FIG. 6
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Aggregate Drain Repair

Aggregate Drain Repair

5.0 HORIZONTAL DRAIN REPAIRS

Horizontal drains improve the stability of slopes by removing water from the slope. Water is often, but not always, a trigger to the start of sliding. Water in the slope increases the weight of soil materials while decreasing the effective stress on potential slide planes. This solution is aimed at removing water weight from the upper portions of the slide. This also results in a slight increase in the strength of the soil along portions of the slide plane. Standard horizontal drains are typically installed by drilling, requiring extensive subsurface investigations and specialized equipment. Herein, an alternate horizontal drain system using wick drains is discussed.

Applicability: This method can be applied to both shallow and deep slides; however, for shallow slides aggregate drains are expected to be more cost effective. Can be installed in conjunction with most other stabilization options.

Design Effort: Can be installed with no design effort using the rules of thumb included below under process. The expected factor of safety improvement is about 10 to 30 percent. With a site specific investigation and design, the likelihood of success can be evaluated and the number and length of drains can be optimized.

Advantages: Less of the slope is disturbed when compared to aggregate drains and much less material is required to be delivered to the site. Longer and deeper drains are possible than with aggregate drains. Amount of water being produced by the drains can be monitored over time.

Disadvantages: Improvement to stability will be minimal if water is not a significant factor in triggering the slide. Specialized equipment and materials required. Horizontal drains are more prone to clogging than aggregate drains due to their smaller size. Drains can also be severed by ongoing or renewed movement of the landslide mass.

Personnel/Equipment: We understand that this repair can be completed by one to two operators working with two or three laborers. Required equipment is a machine to move push the wick drain into the slope, either a small dozer or track-hoe, a mandrel, an excavator to extend the drains to the toe of slope and a small dozer to shape the final slope.

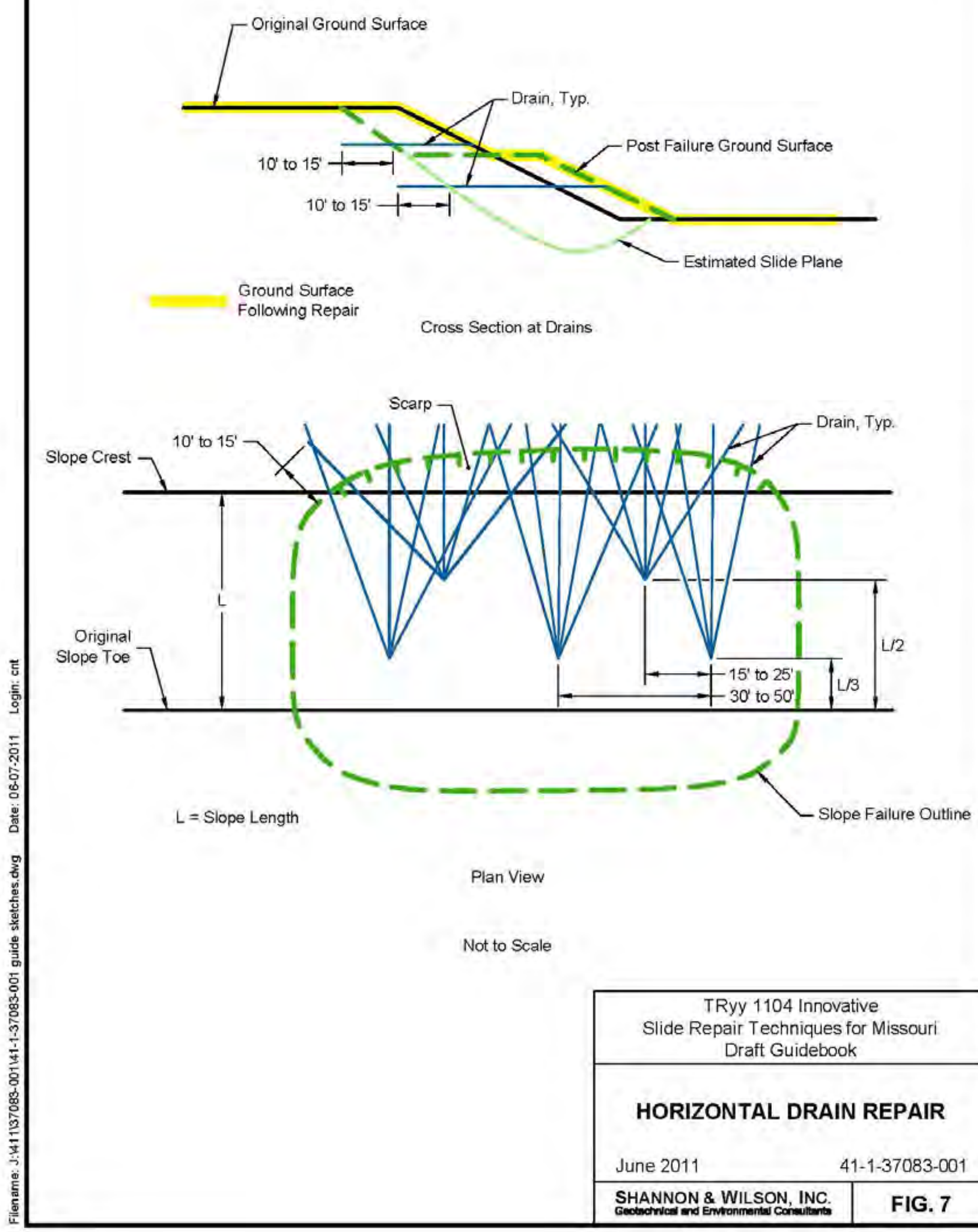
Process: Drains are installed using wick drains normally manufactured for vertical installation. Installation has been accomplished using custom built drive and retrieval heads and AW drill rods as the mandrel. The mandrel is pushed into the soil using a dozer, track hoe or other large equipment. Wick filter fabric with a #100 mesh should be used in silt/clay soils and #70 mesh in sandy soils.

Drains should be installed at multiple levels on the slope and horizontally or slightly up angled in groups (not exceeding 10 percent), in a fan arrangement with between four and eight drains per group, as shown in Figure 7. Larger numbers of drains per group are used with longer drains. A target drain spacing of 25 feet center to center at the location of the slide plane should be used.

The end of the drain should extend between 10 and 15 feet past the slide scarp.

Drain groups should be terminated in shallow aggregate drains that convey the water to the toe of the slope. Alternately, each drain can be terminated in a section of PVC pipe that is then connected to a header pipe and extended to the toe of the slope. This will allow for monitoring of flow volumes from the drains, individually or in the aggregate.

Any cracks in the ground surface should be sealed to reduce the likelihood of surface water entering the slide. Sealing can be accomplished by blading and tracking over cracks with a small dozer.



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HORIZONTAL DRAIN REPAIR

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FIG. 7

6.0 PIN PILE AND MICROPILE REPAIRS

Pin piles or micropiles can be driven or drilled into a slope to increase the resistance to sliding. This increase in resistance is created by the comparatively high strength of these piles crossing the failure plane. The piles can be constructed of plastic, steel or grout.

Applicability: This method can only be applied to shallow slides. Plastic and unreinforced grout piles are limited to slide depths of approximately 5 feet and steel and reinforced grout piles to about 10 feet. Unreinforced grout piles are not generally recommended.

Design Effort: Can be installed with no design effort using the rules of thumb included below under process. However, if the slide depth is underestimated, then no improvement may result. The expected factor of safety improvement is about 10 percent assuming that the slide depth is accurately estimated using no design and the rules of thumb below. With a full design effort, the factor of safety can be improved significantly.

Advantages: Repairs can begin as soon as equipment and material are available at the site. Limited site disturbance and quick installation for small slides. Limited materials required. No excavation required.

Disadvantages: Some specialized equipment required to install the piles. Materials can be expensive and may have significant lead times.

Personnel/Equipment: We understand that this repair can be completed by one to two operators working with two to three laborers. Required equipment is a machine to drive the piles. A small dozer is convenient for shaping the final slope but not required.

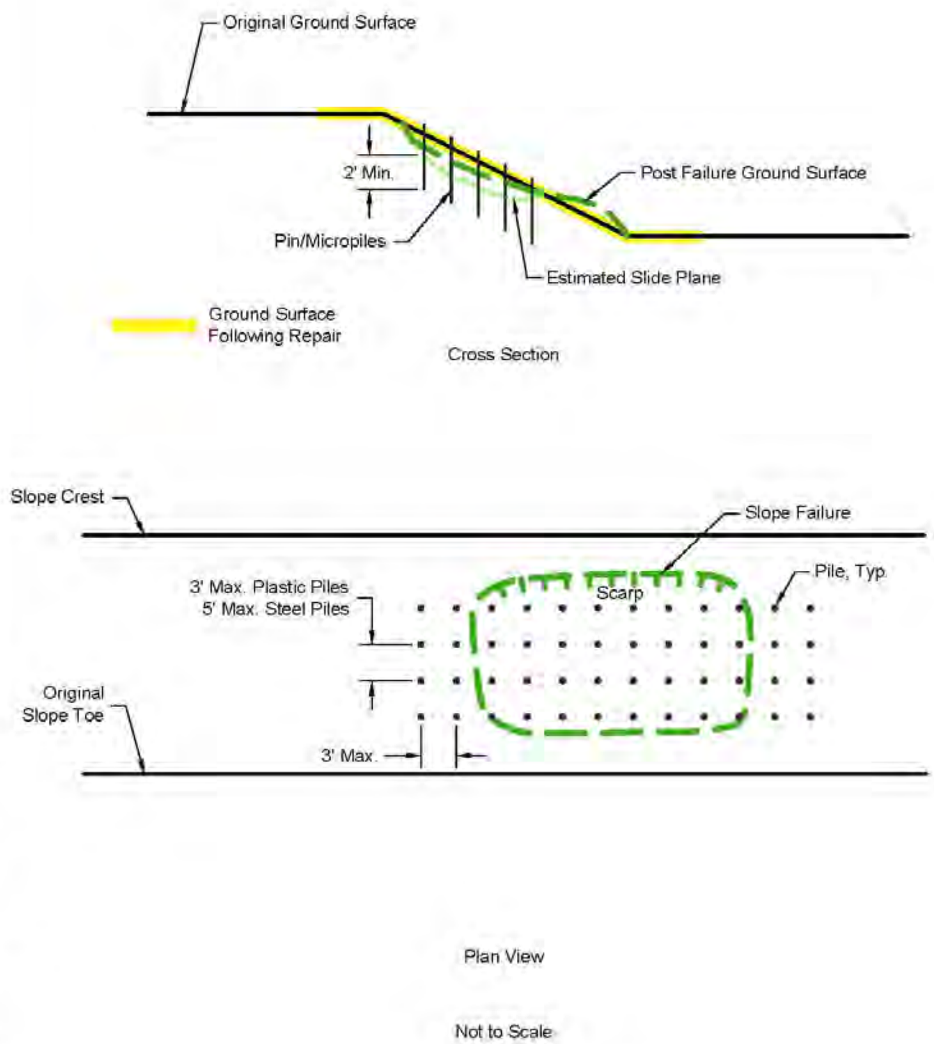
Process: Piles are placed in the slope to a depth at least 2 feet greater than the actual depth of the slide so as to extend beyond the slide plane, as shown in Figure 8. Piles should be as long as can be practically installed and may be installed vertically or perpendicular to the slope.

Best performance and cost effectiveness are achieved by designing the installation pattern based on a site specific investigation and analysis. Otherwise a 3 foot by 3 foot staggered grid of plastic piles has reportedly been successful.

Due to the relatively high material costs, spacing of steel piles, grouted or ungrouted, should generally be based on site specific designs. Without a site specific design, a lateral spacing of 3 feet and a transverse spacing of 5 feet could be used.

The piles should be installed throughout the slide area and a minimum of 2 piles on both sides of the slide.

Any cracks in the ground surface should be sealed to reduce the likelihood of surface water entering the slide. Sealing can be accomplished by blading and tracking over cracks with a small dozer.



NOTE

Piles may be installed vertically or perpendicular to the slope.

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PIN PILE AND MICROPILE REPAIR

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FIG. 8

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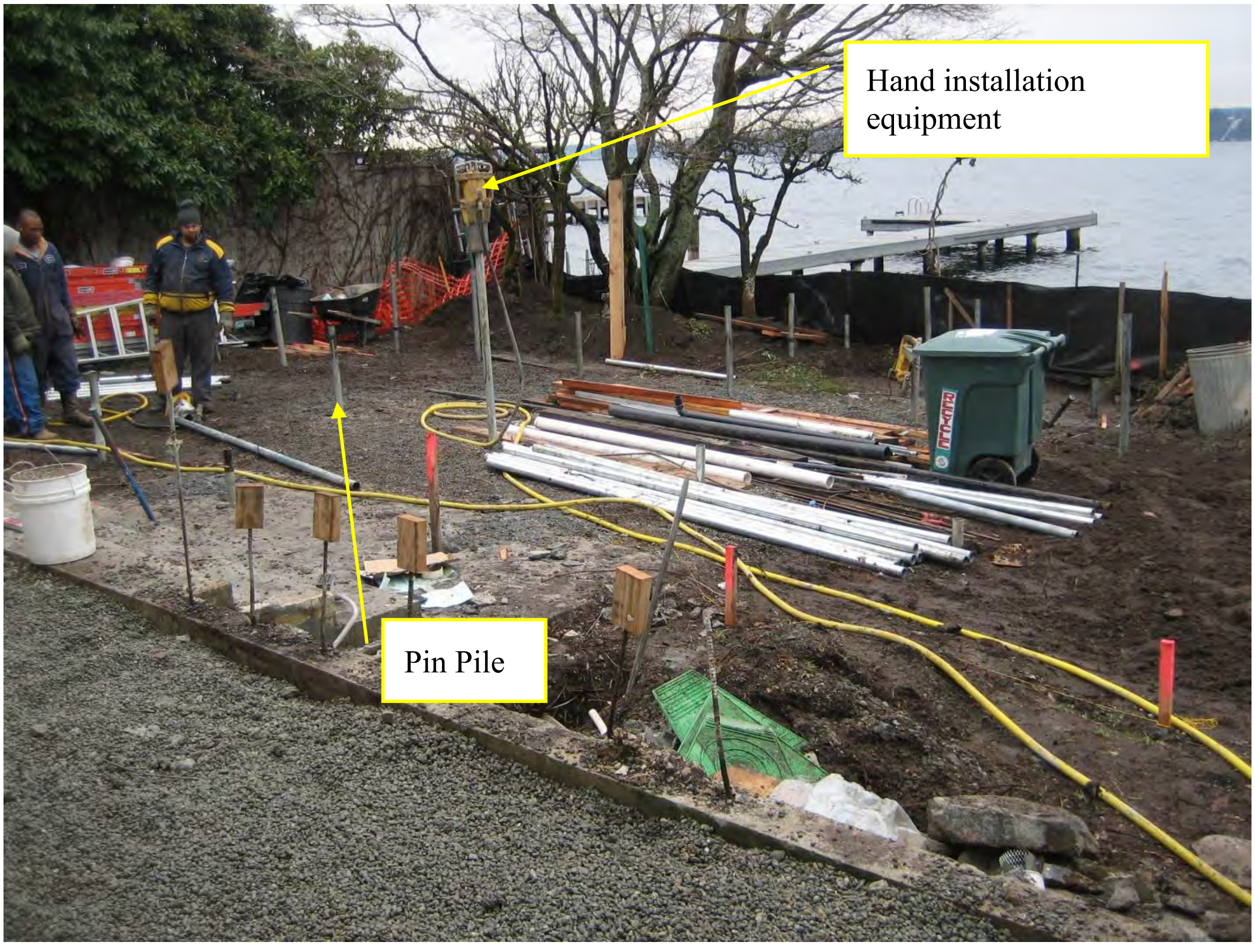


Pin Piles being installed using hand equipment.

Micropile installation.

7.0 TIRE BALE AND SHREDDED TIRE REPAIRS

Tire bales and shredded tires can be used as a light weight fill placed at the top of a slide to reduce the weight of material driving the slide. Tire bales have the added benefit of potentially increasing drainage from the slope and increasing the shear strength of material in the slide. While similar, there are some differences between these repair methods as discussed below.

Applicability: This method can be applied to both shallow and deep slides.

Design Effort: Can be installed with no design effort using the rules of thumb included below under process. The expected factor of safety improvement is about 15 to 20 percent. For larger slides, a site specific investigation and design is recommended.

Advantages: Repairs can begin as soon as equipment and material are available at the site. No specialized equipment is required.

Disadvantages: Materials may not be readily available. Unfamiliarity with material and bale manufacturing may hamper productivity. Small chance of internal combustion with shredded tires.

Bales vs. Shredded: Bales are expected to yield a higher strength, better drainage, and provide a stiffer subgrade than shredded material, if pavement is to be placed on top of the fill. Shredded tires may be more available.

Personnel/Equipment: We understand that this repair can be completed by one or more operators working with two to three laborers. Required equipment is a track-hoe or hi-lift to excavate the slide, handle the tire bales and backfill. It is expected that if a hi-lift is used, that an all-terrain forklift would also be helpful to handle the bales. A small dozer would be convenient for shaping the final slope but not required.

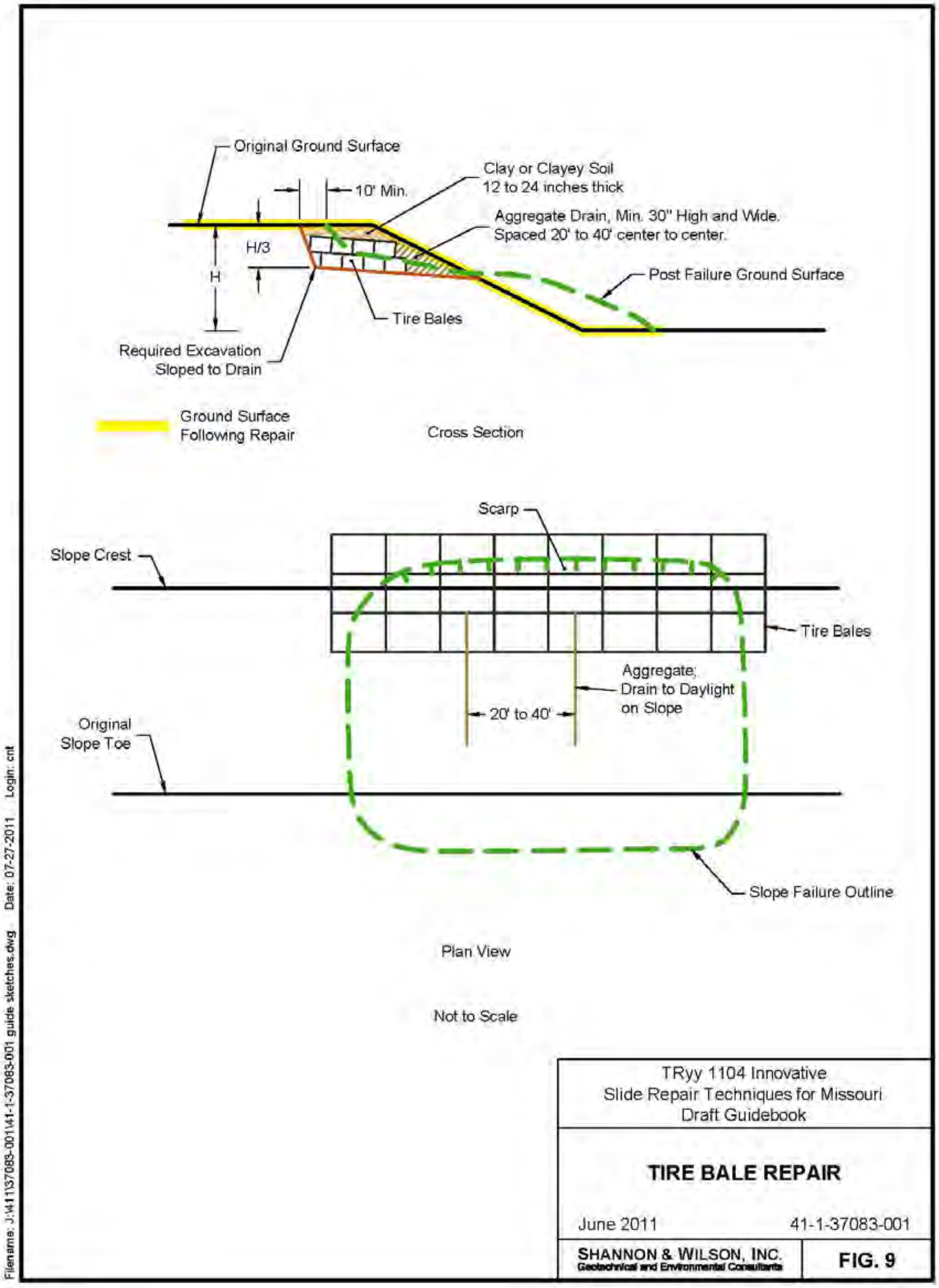
Process: The upper third of the slide should be excavated, as shown in Figure 9. The bottom of the excavation should be sloped to drain. The excavation should extend at least 10 feet past, uphill, of the slide scarp.

Care should be taken in delivering material to the area so that weight is not, even temporarily, added to the top of the slide.

Tire bales or shredded tire material should be placed in the excavation area as lightweight fill. Shredded tires should be placed in lifts not greater than 12-inches thick and compacted with several passes of tracked equipment. A 12-inch thick layer of lean clay or sand should be placed every 36 vertical inches when using shredded tires. If clay is used, the clay should be sloped to drain.

Between 12- and 24-inches of clay or clayey soils should be placed on top of the tire bales or shredded tires. The slope face of the bales or shredded tires can be covered with soil; however, aggregate drains should be installed through the clayey soil cover to provide drainage and prevent water from building up in the tire fill. These aggregate drains should be installed on 20- to 40-foot centers and the water should be carried to the toe of the slope by pipes or in a rock-lined ditch.

Any cracks in the ground surface should be sealed to reduce the likelihood of surface water entering the slide. Sealing can be accomplished by blading and tracking over cracks with a small dozer.


Original Ground Surface
10' Min.
Clay or Clayey Soil
12 to 24 inches thick
Aggregate Drain, Min. 30" High and Wide.
Spaced 20' to 40' center to center.
H/3
H
Post Failure Ground Surface
Tire Bales
Required Excavation
Sloped to Drain
Ground Surface
Following Repair
Cross Section
Scarp
Slope Crest
Tire Bales
Aggregate;
Drain to Daylight
on Slope
20' to 40'
Original
Slope Toe
Slope Failure Outline
Plan View
Not to Scale
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TIRE BALE REPAIR
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FIG. 9
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8.0 POLYSTYRENE BLOCK GEOFOAM REPAIRS

Polystyrene block geofoam (EPS) can be used as a light weight fill placed at the top of a slide to reduce the weight of material driving the slide. The blocks should be underlain by a drainage layer and a drain material should be placed on the uphill side of the blocks.

Applicability: This method can be applied to both shallow and deep slides.

Design Effort: Due to material costs, a site specific investigation and design are recommended. However, the method can be installed with no design effort using the rules of thumb included below under process. The expected factor of safety improvement is about 15 to 20 percent.

Advantages: Repairs can begin as soon as equipment and material are available at the site. No specialized equipment is required.

Disadvantages: Materials may not be readily available. Unfamiliarity with material may hamper productivity. Material cost is high. Should not be used where fill can be flooded, as EPS blocks will float.

Personnel/Equipment: We understand that this repair can be completed by one or more operators working with two to three laborers. Required equipment is a track-hoe or hi-lift to excavate the slide, potentially handle the geofoam blocks and backfill. It is expected that if a hi-lift is used, that an all-terrain forklift would also be helpful to handle the blocks. A small dozer would be convenient for shaping the final slope but not required.

Process: The upper 20 to 40 percent of the landslide should be excavated, as shown on Figure 10. The bottom of the excavation should be sloped to drain. The excavation should extend at least 10 feet past, uphill, of the slide scarp.

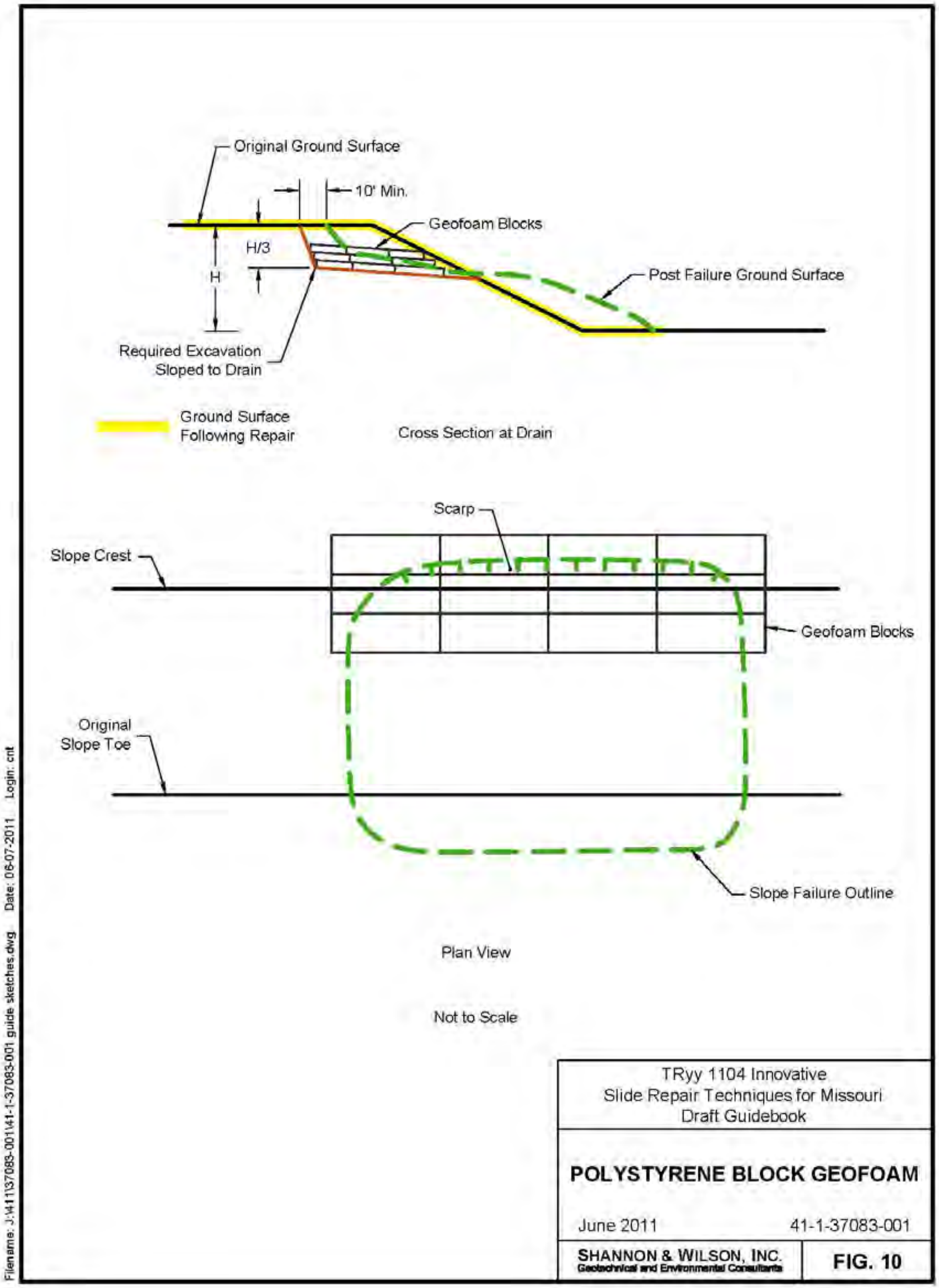
18-inches of drain material consisting of MoDOT Aggregate for Drainage in accordance with 1009.3.5 Grade 5 (Alternately material meeting 1009.3.2, or 1009.3.4 can be used) should be placed on the prepared surface. This drainage layer must extend to the final slope face.

Care should be taken in delivering and stockpiling drain material to the area so that weight is not, even temporarily, added to the top of the slide.

EPS blocks should be placed on the drain material. 12-inches of drain material should be placed between the rear blocks and the uphill side of the slope/excavation.

The EPS blocks should be covered with a minimum of 24-inches of clay or clayey soil. The slope face of the blocks should be covered with soil; however, care should be taken to avoid blocking the installed drainage layer.

Any cracks in the ground surface should be sealed to reduce the likelihood of surface water entering the slide. Sealing can be accomplished by blading and tracking over cracks with a small dozer.



Original Ground Surface
10' Min.
Geofoam Blocks
H/3
H
Post Failure Ground Surface
Required Excavation
Sloped to Drain
Ground Surface
Following Repair
Cross Section at Drain
Scarp
Slope Crest
Geofoam Blocks
Original
Slope Toe
Slope Failure Outline
Plan View
Not to Scale
Filename: J:\411\37083-001\41-1-37083-001 guide sketches.dwg Date: 06-07-2011 Login: cnt
TRyy 1104 Innovative
Slide Repair Techniques for Missouri
Draft Guidebook
POLYSTYRENE BLOCK GEOFOAM
June 2011
41-1-37083-001
SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. 10

Geofoam (EPS) Block installation.

Geofoam (EPS) Block installation.

9.0 RAMMED AGGREGATE PIERS AND STONE COLUMN REPAIRS

Rammed aggregate piers and stone columns function to stabilize slides by intersecting the slide plane and increasing the strength and effective stress and friction along the slide plane. They accomplish this by replacing relatively weak soil with highly compacted crushed stone. In addition, drainage from the slope can be improved by the installed repair if groundwater is intercepted by the piers or columns.

For slide repairs, both methods are essentially identical. The only difference is the equipment used for installation.

Applicability: This method can be applied to shallow or deep slides. We anticipate that this method will not be cost effective on slides greater than 20 to 30 feet in height.

Design Effort: Can be installed with no design effort using the rules of thumb included below under process. However, if the slide depth is underestimated, then <u>no</u> improvement may result. The expected factor of safety of improvement is about 10 to 20 percent. With a site specific investigation, the factor of safety can be improved significantly.

Advantages: Repairs can begin as soon as equipment and material are available at the site. Limited site disturbance and quick installation for small slides.

Disadvantages: Specialized equipment and personnel required to install either method.

Personnel/Equipment: This repair can be completed by two or more operators working with one to two laborers. Required equipment consists of trucks to deliver material and two specially modified track-hoes and a skid steer. If a bench is required to install the piers, then a dozer or standard track-hoe will be required. A small dozer would be convenient for shaping the final slope but not required.

Process: Care should be taken in delivering material to the area so that weight is not, even temporarily, added to the top of the slide.

Holes are created on a grid pattern to a depth at least 5 feet below the bottom of the slide plane or to a hard stratum, such as bedrock.

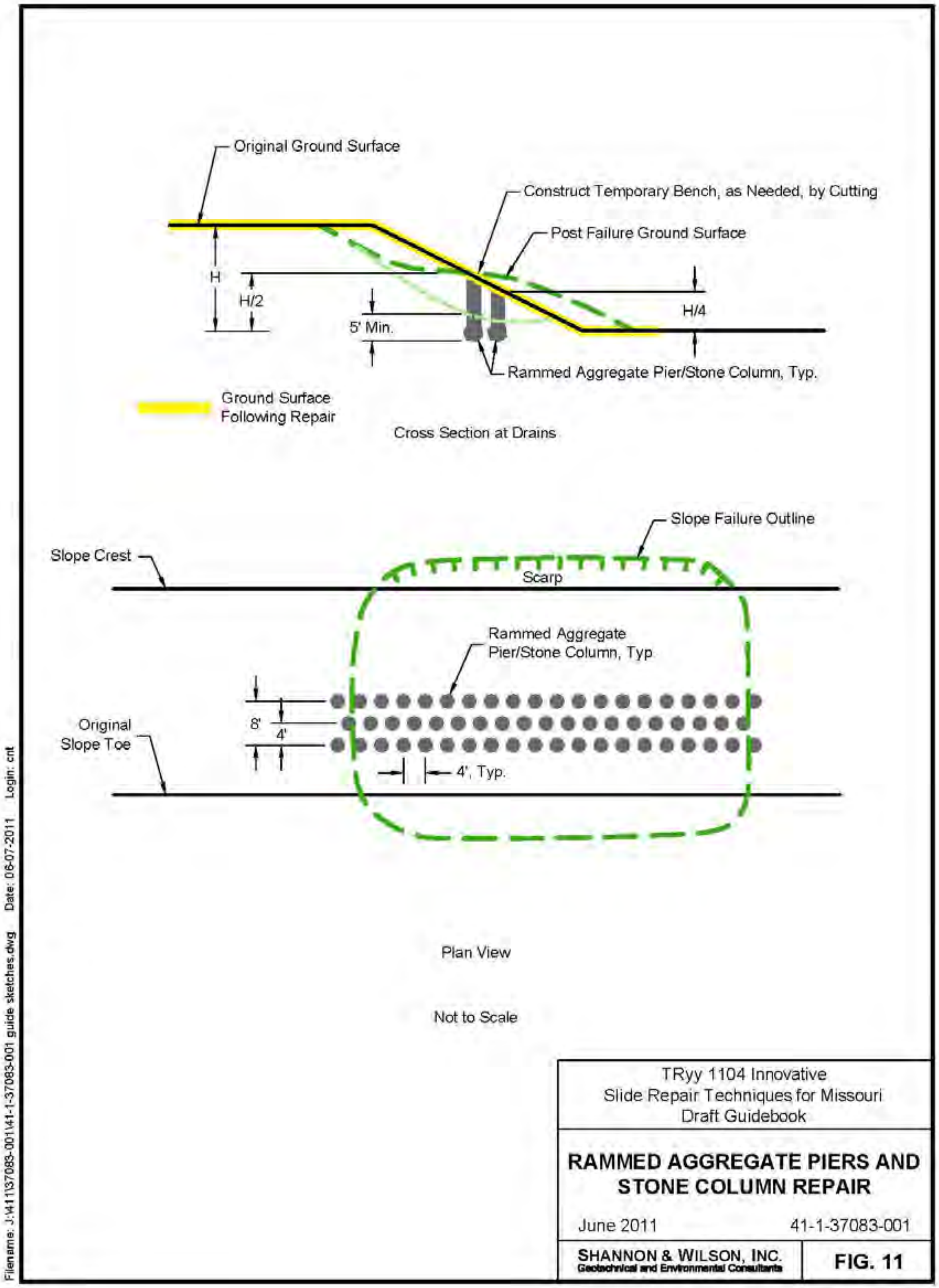
Best performance and cost effectiveness is achieved by designing of the installation pattern based on a site specific investigation and analysis. Otherwise a 4 foot by 4 foot staggered grid of 30-inch-diameter holes can be used, as shown in Figure 11.

The holes should be installed in the lower middle quarter of the slide area and result in the replacement of 40 to 50 percent of the soil in that area.

A bench will likely be required along the slope to create a working pad for the equipment. The stone fill should be placed to the ground surface and not covered with soil to allow for drainage from the slope. At the conclusion of the installation, a drainage blanket of free-draining material should be installed prior to the soil slope being restored.

The holes should be installed throughout the slide area and a minimum of 10 feet on both sides of the slide.

Any cracks in the ground surface should be sealed to reduce the likelihood of surface water entering the slide. Sealing can be accomplished by blading and tracking over cracks with a small dozer.


Original Ground Surface
Construct Temporary Bench, as Needed, by Cutting
Post Failure Ground Surface
H
H/2
5' Min.
H/4
Rammed Aggregate Pier/Stone Column, Typ.
Ground Surface Following Repair
Cross Section at Drains
Slope Failure Outline
Slope Crest
Scarp
Rammed Aggregate Pier/Stone Column, Typ
8'
4'
Original Slope Toe
4', Typ.
Plan View
Not to Scale
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Draft Guidebook
RAMMED AGGREGATE PIERS AND STONE COLUMN REPAIR
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FIG. 11
Filename: J:\411\37083-001\41-1-37083-001 guide sketches.dwg Date: 06-07-2011 Login: cnt

Stone Column installation.

Typical Rammed Aggregate Pier installation, photo courtesy of Geopier ®

10.0 MECHANICALLY STABILIZED EARTH (WALL) REPAIRS

This method consists of excavating the lower portion of the slide material in short sections (slots) and placing a geogrid-reinforced mass to stabilize the slide. This results in a zone of increased strength, and possibly increased weight, in the lower portion of the slide to increase the resisting forces. A wall facing can optionally be placed on the reinforced mass to create a steeper front slope and for erosion protection.

Applicability: This method can be applied to both shallow and deep slides.

Design Effort: Site specific investigation and analysis are required to determine the size and shape of the reinforced mass. This analysis will also determine the allowable slot size.

Advantages: A high degree of success can be achieved with this method. Materials are generally readily available.

Disadvantages: Requires a site specific investigation and analysis. Requires that much of the slide mass be excavated and road closure. Slot excavation is time-consuming and may result in additional movement of the slide, if the size of the slot/excavation is too aggressive.

Personnel/Equipment: This repair can be completed by two or more operators working with two to three laborers. Required equipment consists of trucks to deliver material and a track-hoe or hi-lift to excavate and backfill the slot. A dozer can also be used during backfilling and would be convenient for shaping the final slope.

Process: Care should be taken in delivering material to the area so that weight is not, even temporarily, added to the top of the slide.

Specifics will be determined by the site specific analysis and design.

Slots, generally less than 25 feet wide, are excavated in the lower third to half of the slope, as shown in Figure 12. All of the disturbed soil and some undisturbed soil are removed. Thereafter, either new fill (generally rock) or the excavated soil along with geogrid is installed and compacted in layers. Once the slot has been backfilled to sufficient height, the next slot is excavated, and the process repeated across the face of the slide.

The front face of the reinforced mass can generally be constructed at about 1(H):1(V) using soil/rock or nearly vertical if using a wall facing.

Drainage should be included in the design of the reinforced mass to decrease the static water level in the slope.

Any cracks in the ground surface should be sealed to reduce the likelihood of surface water entering the slide. Sealing can be accomplished by blading and tracking over cracks with a small dozer.

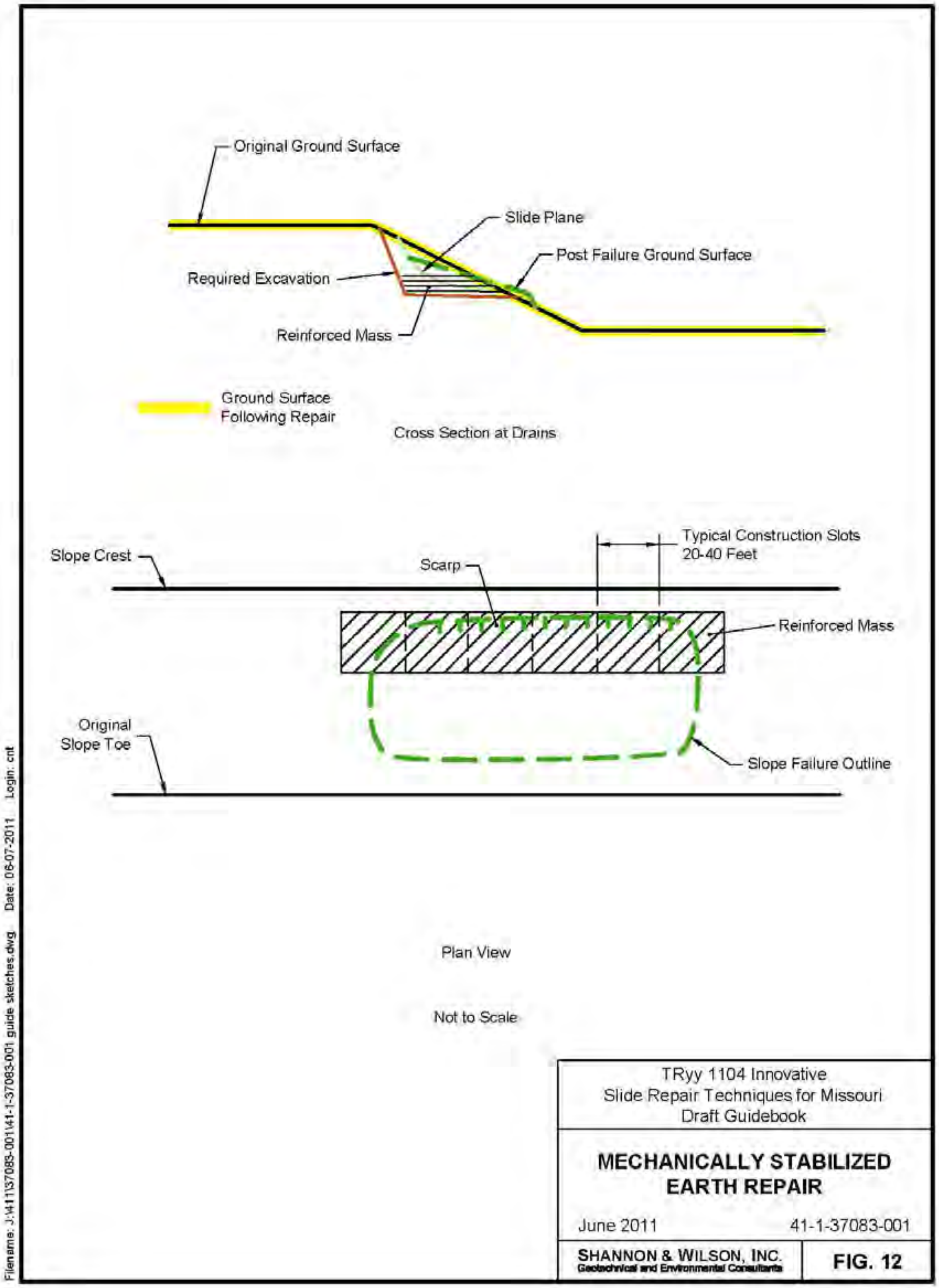
Original Ground Surface
Slide Plane
Post Failure Ground Surface
Required Excavation
Reinforced Mass
Ground Surface Following Repair
Cross Section at Drains
Typical Construction Slots 20-40 Feet
Slope Crest
Scarp
Reinforced Mass
Original Slope Toe
Slope Failure Outline
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FIG. 12
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MSE Wall under construction.

MSE Wall repair complete and ready for pavement.

11.0 SUMMARY

The rules of thumb presented herein can be used as a starting point for design and repair of landslides. The likelihood of success of any repair is greater with site specific investigations and design; however, those activities take time. Many of the methods discussed herein can be installed quickly and at relatively low cost with the goal of quickly limiting additional movement and damage. Many of these methods can be combined, in particular, drainage can be used in conjunction with many of the other methods.

SHANNON & WILSON, INC.

Michael Lambert, P.E.
Associate

MTL:TJA:WTL/ml