Slope Stabilization Guide

for Minnesota Local Government Engineers

LRRB
LOCAL ROAD RESEARCH BOARD

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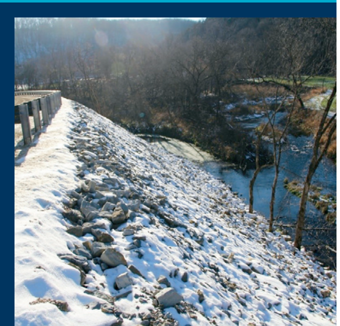

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16. Abstract (Limit: 250 words)

This user guide provides simple, cost-effective methods for stabilizing locally maintained slopes along roadways in Minnesota. Eight slope stabilization techniques are presented that local government engineers can undertake using locally available materials and equipment. These methods are the result of a research effort that analyzed recent slope failures in Minnesota. The recommendations are based on input from Minnesota county engineers; case studies from site investigations within the state; and slope stability analysis, including limit equilibrium methods. This guide is based on information provided in *Slope Stabilization and Repair Solutions for Local Government Engineers*, which presents the results of a Minnesota Local Road Research Board research project on slope stabilization methods. Detailed information about the research project along with complete descriptions of the field sites is available in the report. Local government engineers are encouraged to reference the report when using this guide.

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INTRODUCTION

PURPOSE

Roadside slope failures, often the result of weather events, can block roads, damage pavement and pose numerous safety hazards. While there is no single method to repair and stabilize all slopes, several methods have proven effective, including improving drainage, changing the geometry of the slope and reinforcing the soil.

This user guide provides simple, cost-effective methods for stabilizing locally maintained slopes along roadways in Minnesota. Eight slope stabilization techniques are presented that local government engineers can undertake using locally available materials and equipment. These methods are the result of a research effort that analyzed recent slope failures in Minnesota. The recommendations are based on input from Minnesota county engineers; case studies from site investigations within the state; and slope stability analysis, including limit equilibrium methods.

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SCOPE

This user guide describes common slope failures, the conditions that may contribute to the failures and stabilization techniques that can be used to repair damaged slopes. The guide is intended for county or local municipal engineers who do not have specialized geotechnical engineering experience.

The guide begins with an overview of the common causes of slope failure and methods of stabilizing slopes with respect to local site conditions, such as type of slope failure, type of soil and drainage. Next, scenarios representing eight different slope failures are presented that were developed using various combinations of the site conditions. Descriptions of these scenarios include a summary of site conditions at each slope failure and recommended solutions to repair the failure, such as removing and replacing in situ soil, regrading and recompacting soils, managing groundwater and drainage, and using surface covers to prevent erosion. Following these descriptions are recommended resources that provide more information about each of the stabilization methods presented in the guide.

OVERVIEW OF SLOPE FAILURE

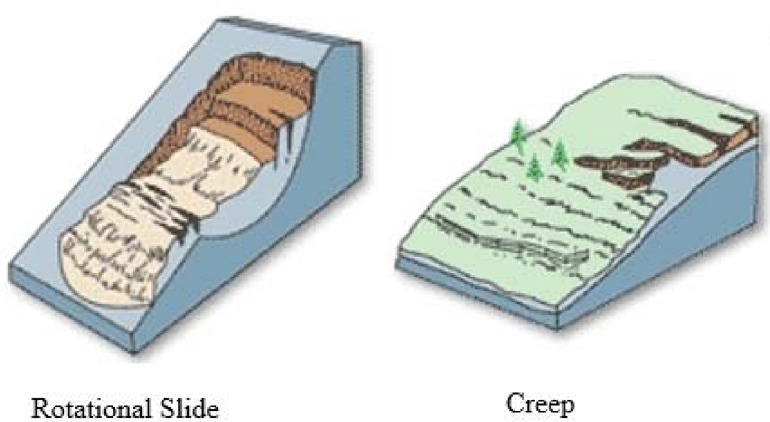
Slope stability is quantified by a factor of safety—the ratio of the soil's in situ shear strength to the shear strength required for equilibrium along a given potential failure surface. To stabilize a slope, the factor of safety must be increased, either by introducing stabilizing forces (increasing capacity) or limiting driving forces (decreasing demand).

Slopes can be stabilized by adding a surface cover to the slope, excavating and changing (or regrading) the slope geometry, adding support structures to reinforce the slope or using drainage to control the groundwater in slope material.

Three site conditions should be considered when choosing an appropriate method for stabilizing a slope:

- Type of slope failure
- Type of soil
- Presence of groundwater (poor drainage)

Slope failure is generally classified as either a rotational slide or a surficial soil creep failure. Rotational slide failures generally occur in a circular pattern and typically leave behind exposed soil. In some soil types, cracking at the surface can indicate the slope is nearing a rotational slide failure. Creep failures are slow-moving, soil surface failures where slope material gradually moves downhill. Common causes of creep failure are seasonal freeze-thaw cycles and inadequate shear strength properties in soil. Bent trees or signs can indicate creep failure.



Examples of common slope failure types

(Source: Varnes, D.J. (1978). Slope movement types and processes. *Special Report 176: Landslides: Analysis and Control.* Washington, D.C.: National Research Council)

Two soil types were considered in this study: cohesive (such as silt and clay) and granular (sand) soils. These soil types can usually be distinguished by a visual inspection, but sometimes laboratory testing is required. In general, slopes made of granular or sandy soil are less likely to experience deep rotational slides. Slopes made of cohesive soils like clay and silt usually have more drainage concerns and are more susceptible to seasonal frost heave.

The third major site condition that affects a slope is poor drainage. Drainage is considered poor if groundwater lowers soil shear strength and leads to failure. Water negatively affects soil's ability to resist shearing, leading to slope instability. An increase in soil's pore pressure (due to the presence of water) leads to a decrease in effective stress. Because effective stress governs soil strength and deformation characteristics, the presence of water leads to decreased soil shear strength. Groundwater has a significant effect on shear strength. In the research study, removing groundwater provided the greatest difference in the output factor of safety.

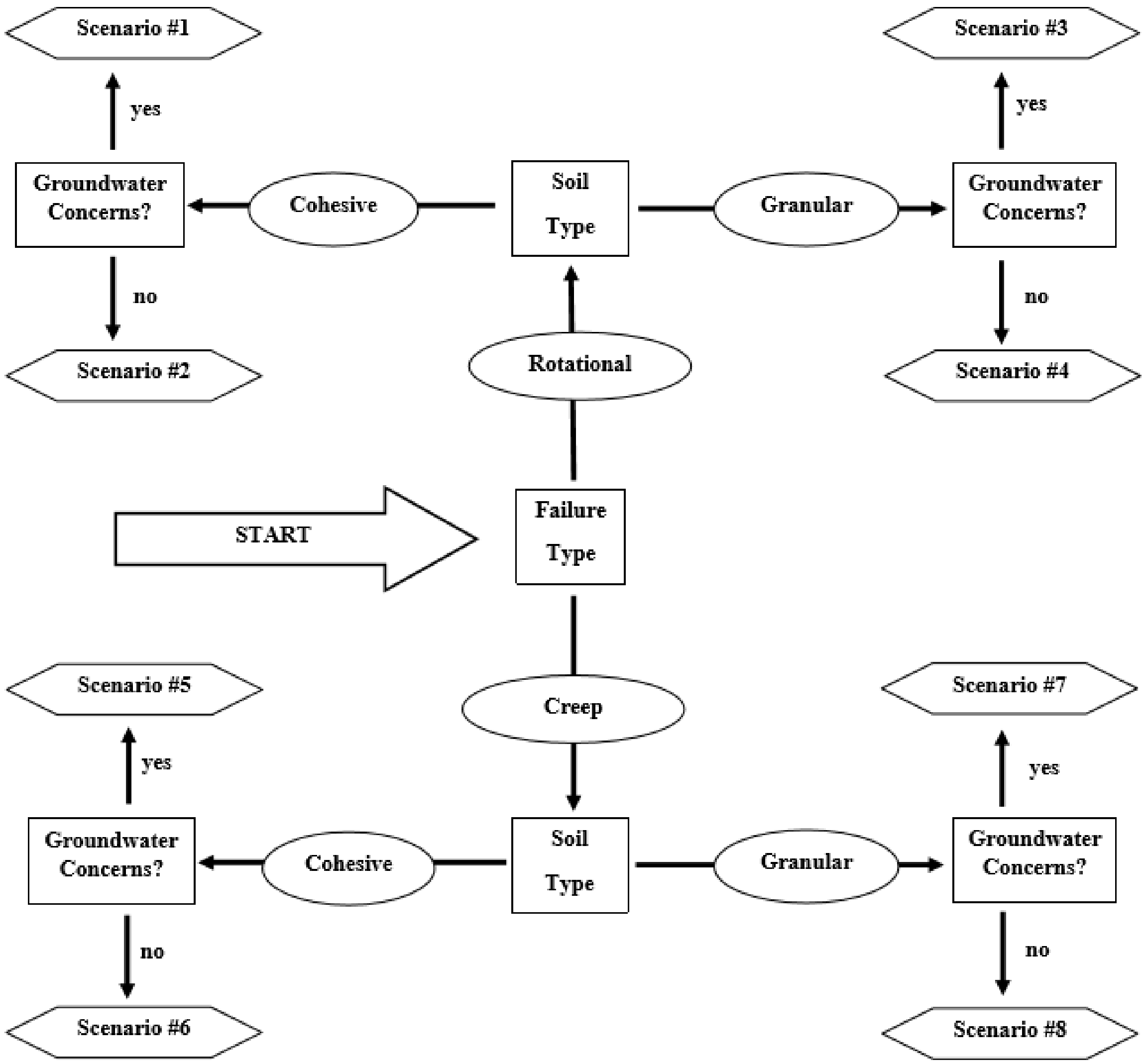
SLOPE FAILURE SCENARIOS

Eight possible scenarios have been developed for slope failure in Minnesota. These scenarios are based on a combination of the three site characteristics: slope failure type, soil type and presence of groundwater. The scenarios and their corresponding site conditions are presented in Table 3.1.

Summary of slope failure scenarios

	Failure Type	Soil Type	Groundwater Concerns?
Scenario 1	Rotational Slide	Cohesive	Yes
Scenario 2	Rotational Slide	Cohesive	No
Scenario 3	Rotational Slide	Granular	Yes
Scenario 4	Rotational Slide	Granular	No
Scenario 5	Surficial Creep	Cohesive	Yes
Scenario 6	Surficial Creep	Cohesive	No
Scenario 7	Surficial Creep	Granular	Yes
Scenario 8	Surficial Creep	Granular	No

The flowchart below illustrates the process for selecting the appropriate scenario. By choosing the site conditions that most closely match the slope failure, users can quickly determine the stabilization method needed to repair the failed slope.



Flowchart for slope failure scenarios

To use the flowchart to determine the appropriate scenario, users:

- First, determine the failure type (rotational or creep).
- Next, choose the soil type of the slope material (cohesive or granular).
- Finally, determine whether groundwater is present at the site. (Note: "Poor drainage" is interchangeable with "groundwater concerns.")

Descriptions about each of the scenarios, including site conditions and recommended repair techniques to stabilize the slope, are provided in this guide.

SLOPE STABILIZATION RECOMMENDATIONS

The following eight scenarios represent site characteristics commonly found in slope failure situations. Each scenario includes the main identifying features of the slope, a recommended stabilization approach and next steps for making the repair.

To determine the scenario that best describes a failed slope, use the flowchart above to identify the set of conditions that most closely match the observed slope stabilization site. Then locate the appropriate scenario in the following descriptions to find the recommended stabilization techniques.

SCENARIO 1: ROTATIONAL FAILURE, COHESIVE SOIL, POOR DRAINAGE

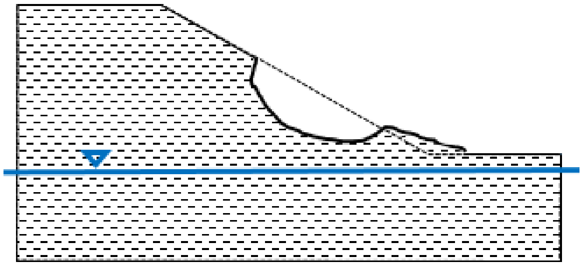
Scenario 1: Pennington County, Minnesota, site

Site Conditions

- Rotational failure
- Cohesive soil
- Groundwater concerns

Recommended Stabilization Approach:

Remove and replace. Add drainage features and vegetative cover.



Rotational failure is visible at these sites. Consider either removing and replacing soil or regrading with in situ soil, and adding drainage features and vegetative cover. Drainage features remove groundwater, and fill-and-regrade work adds stability. Place drains near the toe of the slope. If significant rotational failure has already occurred, rebuild the slope with as low of a slope angle as possible.

SCENARIO 2: ROTATIONAL FAILURE, COHESIVE SOIL

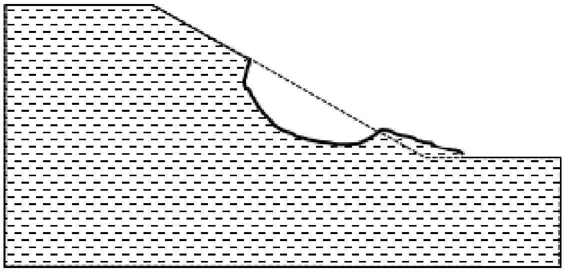
Scenario 2: Olmsted County, Minnesota, site

Site Conditions

- Rotational failure
- Cohesive soil
- No groundwater concerns

Recommended Stabilization Approach:

Remove and replace, or regrade and recompact. Add vegetative cover.



Rotational failure is visible at these sites. Many factors other than the effects of groundwater can cause soil to lose strength, such as poor compaction. Regrading and recompacting the slope properly will increase soil strength and slope stability. Evaluate the in situ soil properties and either reuse the material or use common borrow if native material has poor properties.

SCENARIO 3: ROTATIONAL FAILURE, GRANULAR SOIL, POOR DRAINAGE

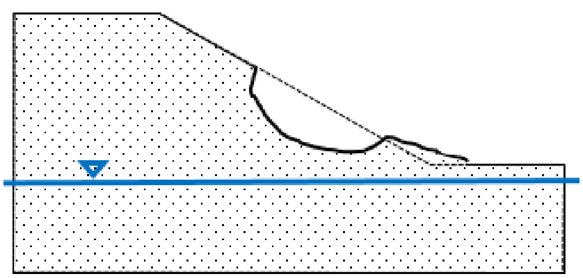
Rotational failure in sand, similar to Scenario 3

Soil Conditions

- Rotational failure
- Granular soil
- Groundwater concerns

Recommended Stabilization Approach:

Remove and replace, or regrade and recompact. Add drainage features and adequate surface cover.



As with other rotational failures, excavation and reconstruction is necessary. Surface cover is very important for slopes with granular soil because erosion is a concern. Surface erosion can cause geometric inconsistencies that lead to failure. Erosion can often cause washout failure. Regrade or, if necessary, replace with sand fill. Add drainage features to remove groundwater in the slope.

SCENARIO 4: ROTATIONAL FAILURE, GRANULAR SOIL

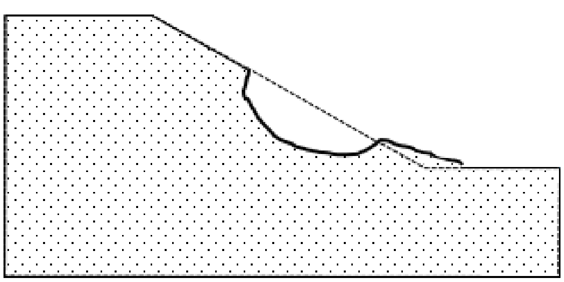
Scenario 4: Lac Qui Parle County, Minnesota, site

Site Conditions

- Rotational failure
- Granular soil
- No groundwater concerns

Recommended Stabilization Approach:

Regrade and recompact. Add vegetative cover or more involved surface cover.



Because groundwater is not the primary reason for failure, identify and mitigate the main cause of the soil losing strength. If erosion is evident, consider using a more involved cover, such as riprap or gravel. If slope steepness is a concern, regrade and compact with in situ material. Also, consider using adequate groundcover to protect the slope from erosion damage.

SCENARIO 5: CREEP FAILURE, COHESIVE SOIL, POOR DRAINAGE

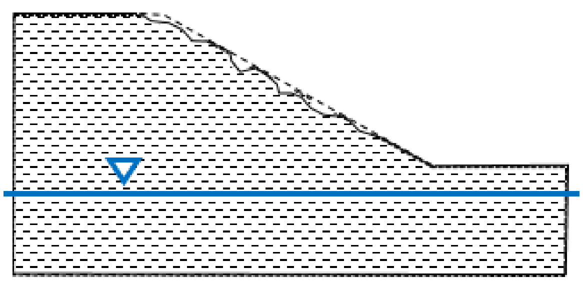
Scenario 5: Koochiching County, Minnesota, site

Site Conditions

- Creep failure
- Cohesive soil
- Groundwater concerns

Recommended Stabilization Approach:

Regrade and recompact. Add drainage features. If one area of failure, remove and replace.



Sites with cohesive soils are more likely to have drainage concerns. Surficial creep failure can be identified by bent signs or trees that lead to pavement damage. With the presence of groundwater and frost-susceptible cohesive soil, frost heave is a possible cause of soil movement. Add drainage features. If creep is at the top of the slope, also consider replacing that portion of the slope with free-draining sand. If the failure is near the bottom of the slope, use a buttress to stabilize the slope.

SCENARIO 6: CREEP FAILURE, COHESIVE SOIL

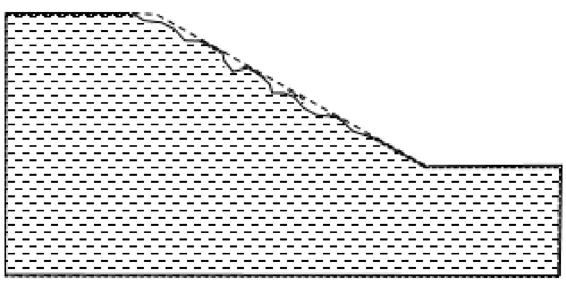
Scenario 6: Murray County, Minnesota, site

Soil Conditions

- Creep failure
- Cohesive soil
- No groundwater concerns

Recommended Stabilization Approach:

Remove, replace and recompact.



Surficial creep failure can be identified by bent signs or trees that lead to pavement damage. The image above clearly shows how soil creep at the top of a slope can lead to pavement damage. Replace the failed portion of the slope with sand fill to increase sliding resistance. In the absence of groundwater, poor compaction decreases the soil's shear strength. If in situ soil has adequate strength properties, consider regrading and recompacting, but keep in mind that creep failure indicates concerns about the strength of native material.

SCENARIO 7: CREEP FAILURE, GRANULAR SOIL, POOR DRAINAGE

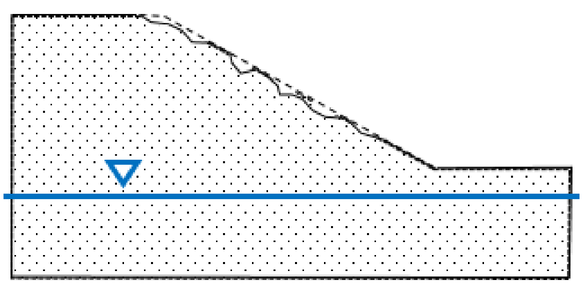
Scenario 7: Carver County, Minnesota, site

Soil Conditions

- Creep failure
- Granular soil
- Groundwater concerns

Recommended Stabilization Approach:

Remove and replace, or regrade and recompact. Add drainage features and adequate surface cover.



Bent guardrails are evidence of soil creep, which typically causes pavement damage. Proper drainage can remove groundwater from the area, increasing resistance to soil creep. Install drainage features, and replace failed soil with properly compacted fill or recompact in situ material. Use adequate groundcover to prevent erosion in slopes with sand.

SCENARIO 8: CREEP FAILURE, GRANULAR SOIL

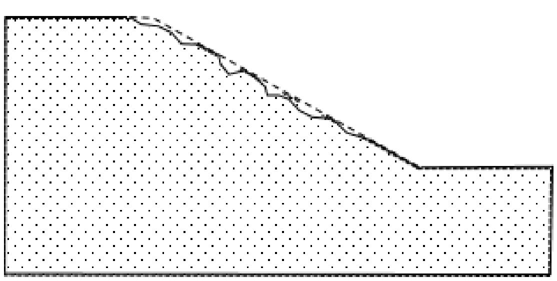
Soil creep in sand, similar to Scenario 8

Soil Conditions

- Creep failure
- Granular soil
- No groundwater concerns

Recommended Stabilization Approach:

Remove and replace, or regrade and recompact. Add adequate surface cover.



Erosion is a concern with granular soils. Surficial damage caused by erosion is not always soil creep, but the movement type and stabilization methods are similar. Surface washout can undermine roadways and cause pavement damage. Ensure adequate groundcover on slopes with granular fill. Repair damage at the top of a slope by regrading.

RECOMMENDED RESOURCES

The resources listed below provide more information about the stabilization methods presented in this guide. Users are encouraged to consult these resources before selecting a stabilization method.

Drainage Features

Cornforth, D. (2005). "Dewatering Systems," chapter 17 in *Landslides in Practice: Investigations, Analysis, and Remedial/Preventative Options in Soils*. Hoboken, N.J.: John Wiley & Sons.

Dewatering

Coduto, D., Yeung, M., Kitch, W. (2011). "Rate of Consolidation," chapter 11 in *Geotechnical Engineering: Principles and Practices* (2nd ed.). Upper Saddle River, N.J.: Pearson Education, Inc.

Vegetative Cover

Abramson, L. W., Lee, T., Sharma, S., Boyce, G. (2002). "Slope Stabilization Methods," chapter 7 in *Slope Stability and Stabilization Methods* (2nd ed.). New York: Wiley.

Buttressing/Riprap Cover

Abramson, L. W., Lee, T., Sharma, S., Boyce, G. (2002). "Slope Stabilization Methods," chapter 7 in *Slope Stability and Stabilization Methods* (2nd ed.). New York: Wiley.

Geosynthetics

Gee, B. (2015). Geosynthetic materials help build optimized infrastructure. *Geostrata, 19*(2), 50.

Lightweight Fill

Abramson, L. W., Lee, T., Sharma, S., Boyce, G. (2002). "Slope Stabilization Methods," chapter 7 in *Slope Stability and Stabilization Methods* (2nd ed.). New York: Wiley.

Remove and Replace

Duncan, J. M., Wright, S. (2005). "Slope Stabilization and Repair," chapter 16 in *Soil Strength and Slope Stability*. Hoboken, N.J.: John Wiley & Sons.

Regrading and Benching

Cornforth, D. (2005). "Earthworks," chapter 15 in *Landslides in Practice: Investigations, Analysis, and Remedial/Preventative Options in Soils*. Hoboken, N.J.: John Wiley & Sons.

Retaining Walls

Cornforth, D. (2005). "Retaining Walls," chapter 19 in *Landslides in Practice: Investigations, Analysis, and Remedial/Preventative Options in Soils*. Hoboken, N.J.: John Wiley & Sons.

Soil Nailing

Abramson, L. W., Lee, T., Sharma, S., Boyce, G. (2002). "Slope Stabilization Methods," chapter 7 in *Slope Stability and Stabilization Methods* (2nd ed.). New York: Wiley.

Mechanically Stabilized Earth Embankments

Abramson, L. W., Lee, T., Sharma, S., Boyce, G. (2002). "Slope Stabilization Methods," chapter 7 in *Slope Stability and Stabilization Methods* (2nd ed.). New York: Wiley.

Research Study Final Report

Saftner, D., Carranza-Torres, C., Nelson, M. (2017). *Slope Stabilization and Repair Solutions for Local Government Engineers*. Minnesota Department of Transportation. http://www.cts.umn.edu/Publications/ResearchReports/reportdetail.html?id=2590