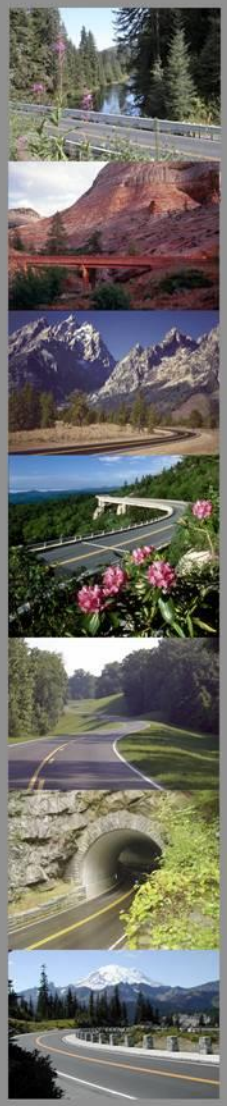


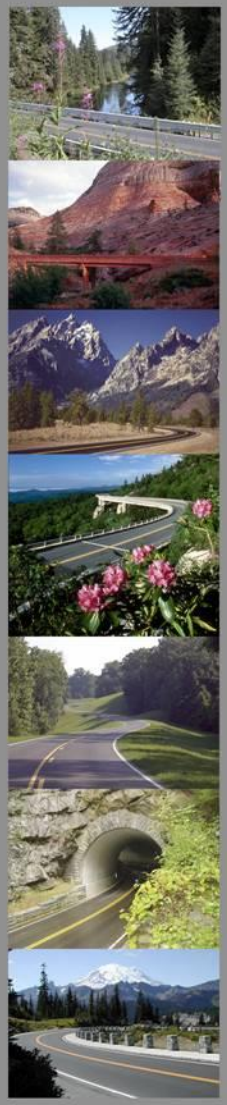
Geotechnical Engineering Applications

US Territorial Peer Exchange (USTPE)
August 2018

Central Federal Lands Highway Division
US Department of Transportation - Federal Highway Administration

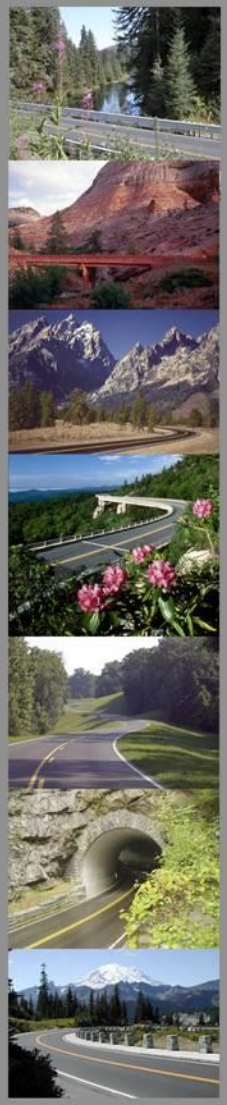
U.S. Department of Transportation
Federal Highway Administration
Federal Lands Highway

Engineering America's Scenic Highways



Outline

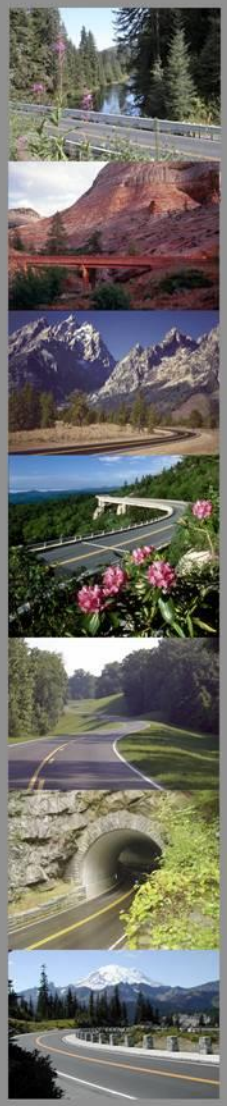
- FHWA Geotechnical Resources
  - Geotechnical Challenges for the Territories
  - FHWA/NHI Guidance Documents
  - Geotech Tools Website
- GRS-IBS Design and Construction
- Unstable Slope Management Program (USMP)
- Rockfall Mitigation



FHWA Geotechnical Resources

Territory Geotechnical Challenges

- May not have geotechnical experience within full-time staff
- Limited availability of geotechnical consultants
- Limited capabilities to perform site investigations
- No support for specifications
- No support during construction

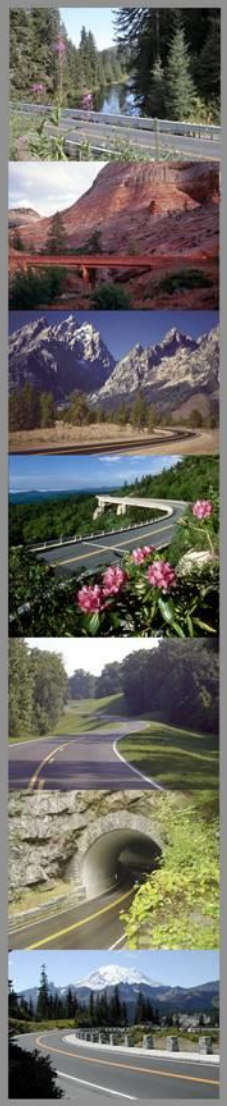


FHWA Geotechnical Resources
FHWA/NHI Guidance Documents

- **FHWA website with numerous guidance documents available for free download**

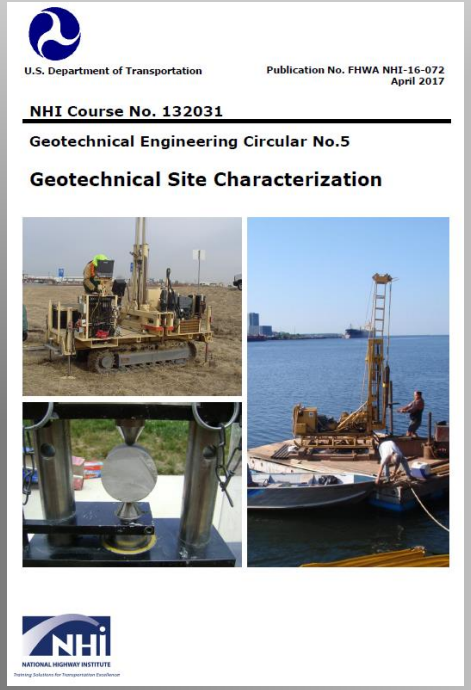
GEC	Geotechnical Engineering Circular No. 1 - Dynamic Compaction	1995	FHWA-SA-95-037	PB96-146105	(20 mb)
GEC	Geotechnical Engineering Circular No. 10 - Drilled Shafts: Construction Procedures and LRFD Design Methods	2010	FHWA-NHI-10-016		
GEC	Geotechnical Engineering Circular No. 11 - Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Vol. I GEC No. 11 - Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Vol II	2010	FHWA-NHI-10-024 FHWA-NHI-10-025		
GEC	Geotechnical Engineering Circular No. 12 - Design and Construction of Driven Pile Foundations - Volume I Geotechnical Engineering Circular No. 12 - Design and Construction of Driven Pile Foundations - Volume II Comprehensive Design Examples	2016	FHWA-NHI-16-009 FHWA-NHI-16-010 FHWA-NHI-16-064		
GEC	Geotechnical Engineering Circular No. 13 Ground Modification Methods Reference Manual - Volume I	2017	FHWA-NHI-16-027		(19 mb)
GEC	Geotechnical Engineering Circular No. 13 Ground Modification Methods Reference Manual - Volume II	2017	FHWA-NHI-16-028		(20 mb)
GEC	Geotechnical Engineering Circular No. 14 - Assuring Quality in Geotechnical Reporting Documents	2016	FHWA-HIF-17-016		(2 mb)
GEC	Geotechnical Engineering Circular No. 2 - Earth Retaining Systems	1996	FHWA-SA-96-038	PB97-173629	
GEC	Geotechnical Engineering Circular No. 3 - Earthquake Engineering for Highways, Design Principles	2011			(20 mb)
GEC	Geotechnical Engineering Circular No. 4 - Ground Anchors and Anchored Systems	1999	FHWA-IF-99-015	PB99-166191	(4 mb)
GEC	Geotechnical Engineering Circular No. 5 - Evaluation of Soil and Rock Properties	2002	FHWA-IF-02-034		
GEC	Geotechnical Engineering Circular No. 5 - Geotechnical Site Characterization	2016	FHWA-NHI-16-072		(32 mb)
GEC	Geotechnical Engineering Circular No. 6 - Shallow Foundations	2002	FHWA-IF-02-054		(8 mb)
GEC	Geotechnical Engineering Circular No. 7 - Soil Nail Walls	2015	FHWA-NHI-14-007		(17 mb)
GEC	Geotechnical Engineering Circular No. 8 - Design and Construction of Continuous Flight Auger Piles	2007	FHWA-HIF-07-039		(10 mb)
Geosynthetics	Geocomposite Drains	1986			
Geosynthetics	Geosynthetic Design and Construction Guidelines Participant Notebook	1995	FHWA-HI-95-038	PB95-270500	(50 mb)
Geosynthetics	Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide	2011	FHWA-HRT-11-026		(9 mb)
Geosynthetics	Geosynthetic Reinforced Soil Integrated Bridge System Synthesis Report	2011	FHWA-HRT-11-027		(2 mb)
Geosynthetics	Prefabricated Vertical Drains	1986			
Geotech Aspects of Pavements	Geotechnical Aspects of Pavements	2006	FHWA-NHI-05-037		(16 mb)
Geotechnical Notebook Issuances	GT-15 - Geotechnical Differing Site Conditions		FHWA-1996		(0.2 mb)
Geotechnical Notebook Issuances	GT-16 - "Determination of Unknown Subsurface Bridge Foundations," NCHRP 21-5 Interim Report Summary		FHWA-1998		(1 mb)

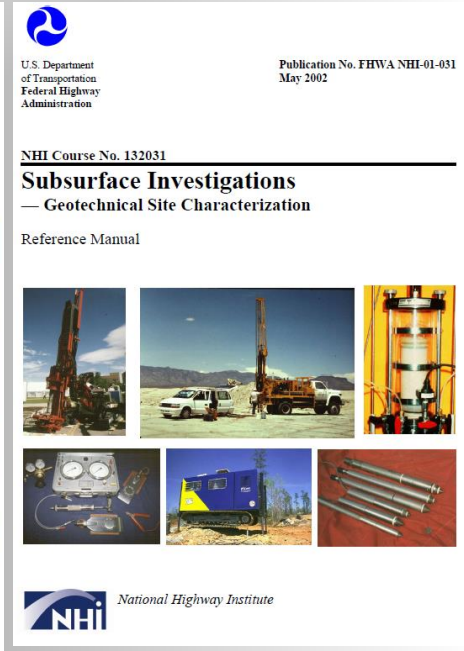
https://www.fhwa.dot.gov/engineering/geotech/library_listing.cfm



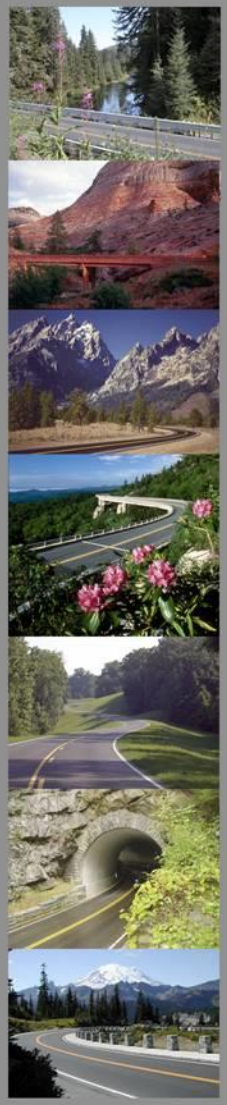
FHWA Geotechnical Resources
FHWA/NHI Guidance Documents

- **We can provide documents not archived on the website upon request**





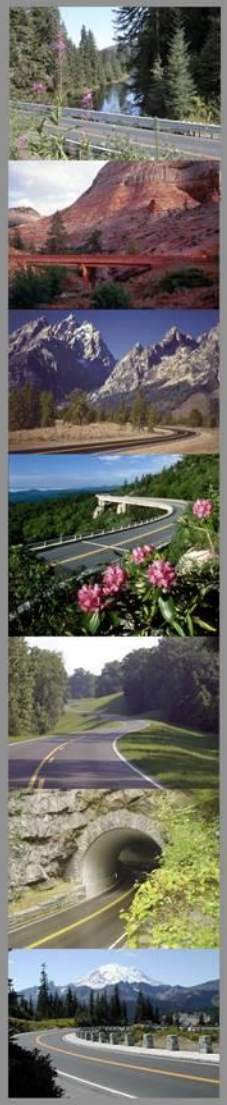
https://www.fhwa.dot.gov/engineering/geotech/library_listing.cfm



FHWA Geotechnical Resources
GeoTech Tools Web Application

U.S. Department of Transportation
Federal Highway Administration
Federal Lands Highway

Engineering America's Scenic Highways

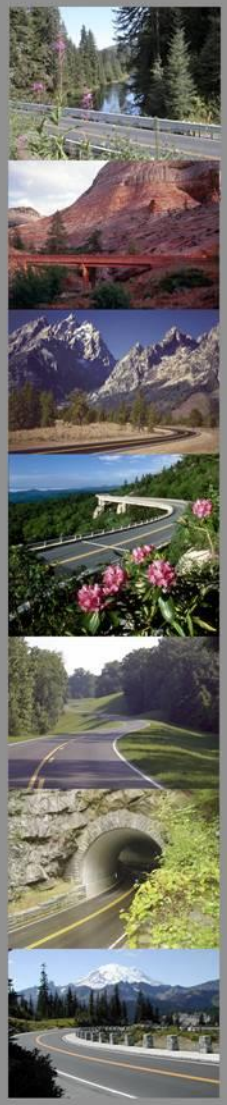


FHWA Geotechnical Resources
GeoTech Tools Web Application

www.GeoTechTools.org

A Comprehensive Web-Based Information & Guidance System for:

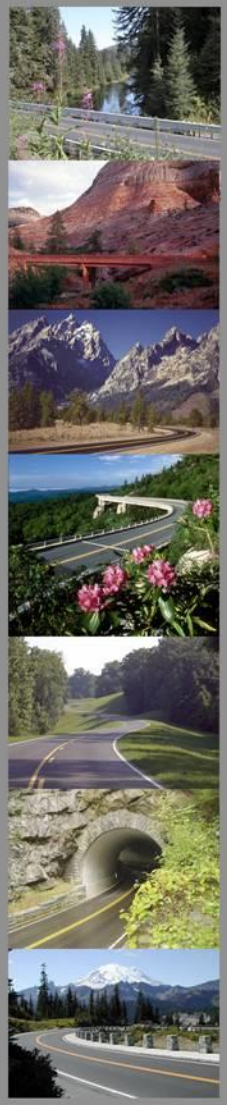
- **Embankment, Ground Improvement & Pavement Applications**
- **Project Development and Delivery Options**



FHWA Geotechnical Resources
GeoTech Tools Web Application

Goal of GeoTechTools Project

To make geotechnical solutions more accessible to public agencies in the U.S. for rapid renewal and improvement of the transportation infrastructure.

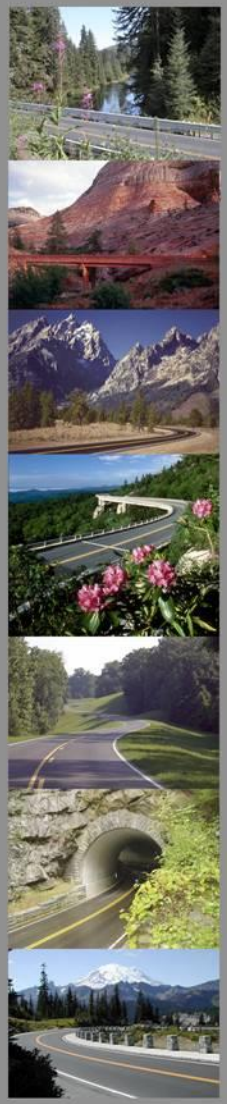


FHWA Geotechnical Resources
GeoTech Tools Web Application

Value of the System

The system collects, synthesizes, integrates, and organizes a vast amount of critically important information about geotechnical solutions on a readily accessible website

- Case Histories
- Photographs
- QA/QC Procedures
- Specifications
- Fact Sheets
- Design Procedures
- Cost Estimating Tools
- Bibliography



FHWA Geotechnical Resources
GeoTech Tools Web Application

Technology Selection Tool

Technology Selection

From this page, a user can narrow potential technologies by choosing to view a list of technologies by classification or by using the interactive selection system.

View technologies by classification

This option is designed for users who already know the general project geoconstruction methodology to be used (e.g., lateral earth support). Selecting this option will list applicable technologies according to classification.

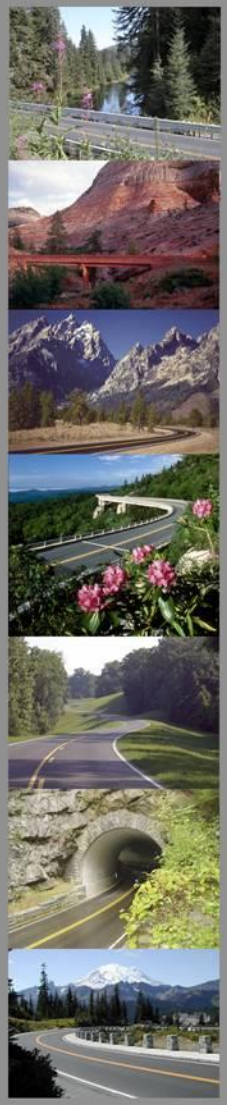
Access the interactive selection system

This option leads to an interactive selection system that has been developed to aid the user in identifying a candidate list of technologies for any application. By selecting this option, the user will enter a dynamic system that narrows the potential technologies though a series of questions. Initially, technologies are divided into four applications: Construction over Unstable Soils, Construction over Stable/Stabilized Soils, Geotechnical Pavement Components, and Working Platforms.

*Refer to the document User's Guide to the Information and Guidance System for the constraints, intended uses, and limitations of the Technology Selection portion of this website.

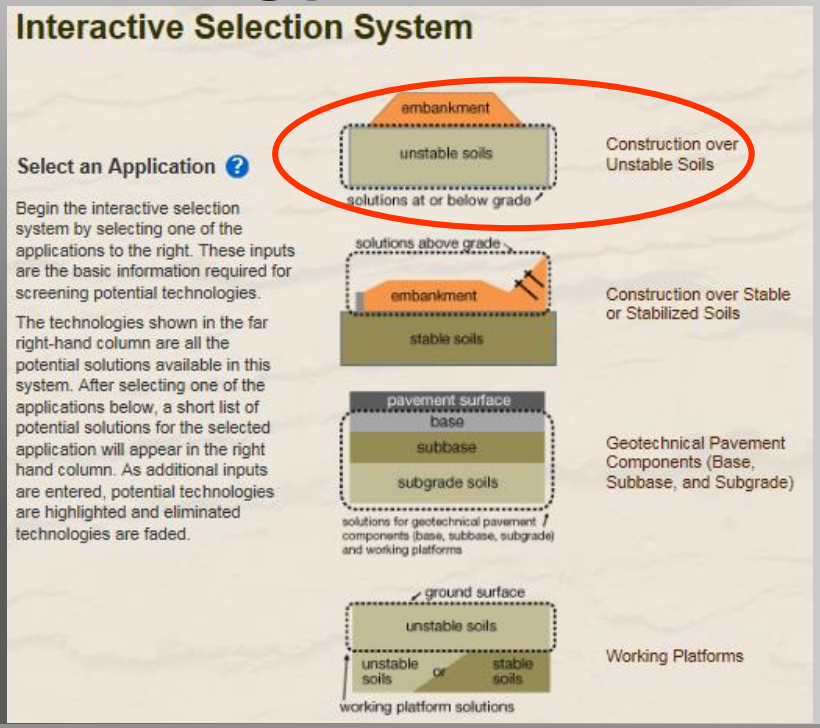
Access the liquifaction mitigation selection system

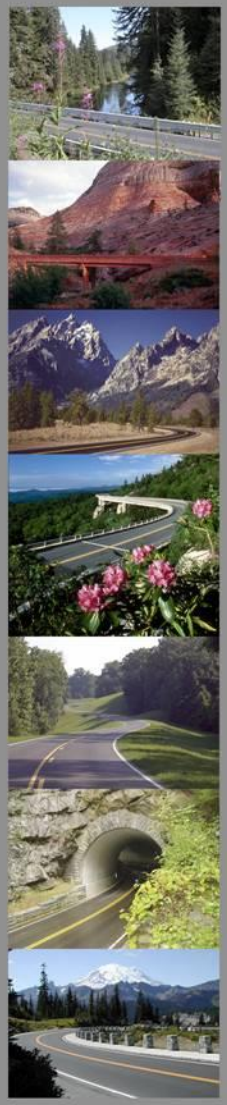
This option leads to an interactive selection system that focuses on liquefaction mitigation. This interactive selection system generates a list of unranked geoconstruction technology candidate(s) based on user's input addressing site and project-specific characteristics influencing on technology selection for liquefaction mitigation.



FHWA Geotechnical Resources
GeoTech Tools Web Application

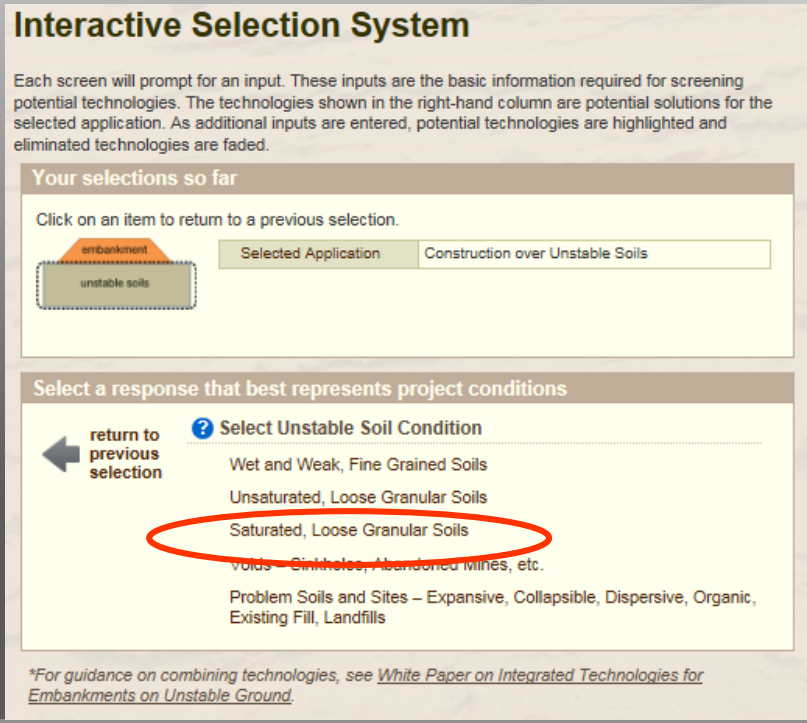
Technology Selection Tool

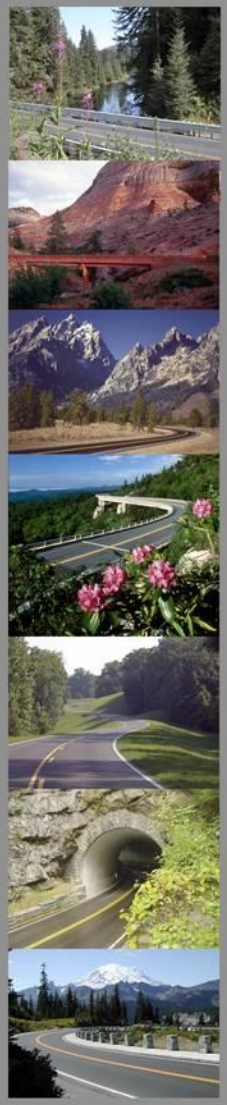




FHWA Geotechnical Resources
GeoTech Tools Web Application

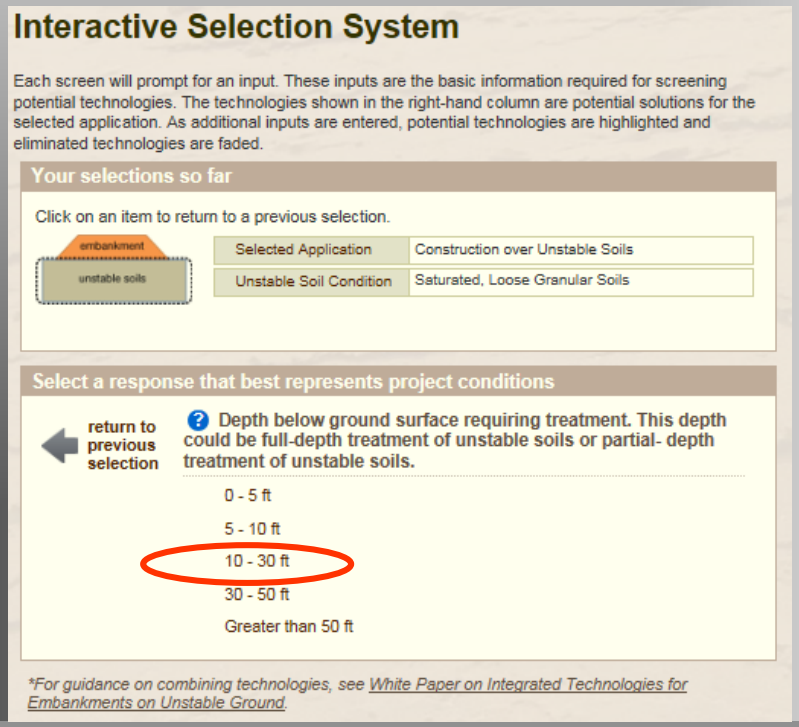
Technology Selection Tool

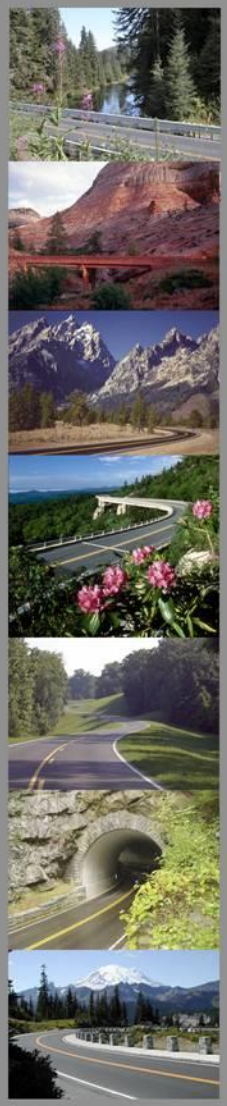




FHWA Geotechnical Resources
GeoTech Tools Web Application

Technology Selection Tool





FHWA Geotechnical Resources
GeoTech Tools Web Application

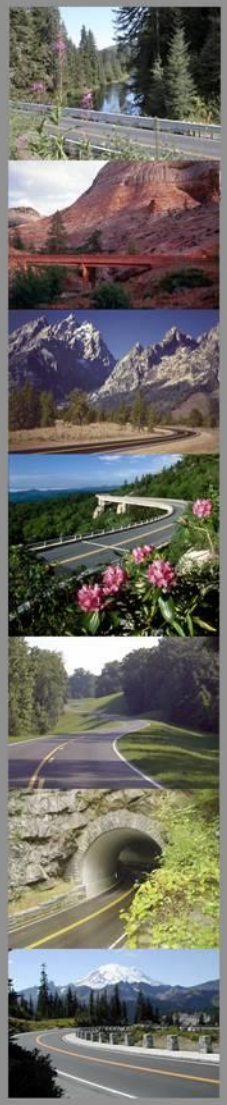
Technology Selection Tool

Potential Technologies

The potential technologies as a result of the project and site information are shown below.

Technology	Degree of Establishment*	Potential Contribution to SHRP 2 Renewal Objectives: Rapid Renewal*	Minimal Disruption*	Long-Lived Facilities*
Aggregate Columns	4	3	1	4
Blasting Densification	3	3	2	4
Chemical Grouting/Injection Systems	3	3	4	4
Column-Supported Embankments	3	5	1	4
Combined Soil Stabilization with Vertical Columns	2	3	1	4
Compaction Grouting	4	3	3	3
Continuous Flight Auger Piles	4	4	1	4
Deep Dynamic Compaction	5	4	1	4
Deep Mixing Methods	3	4	1	4
Jet Grouting	4	4	2	4
Micropiles	4	3	2	3
Rapid Impact Compaction	2	4	1	3
Sand Compaction Piles	2	4	1	3
Vibrocompaction	5	4	1	4
Vibro-Concrete Columns	3	4	1	4

*See the SHRP 2 R02 Technology Ratings Summary for a legend and description of rating development.



FHWA Geotechnical Resources
GeoTech Tools Web Application

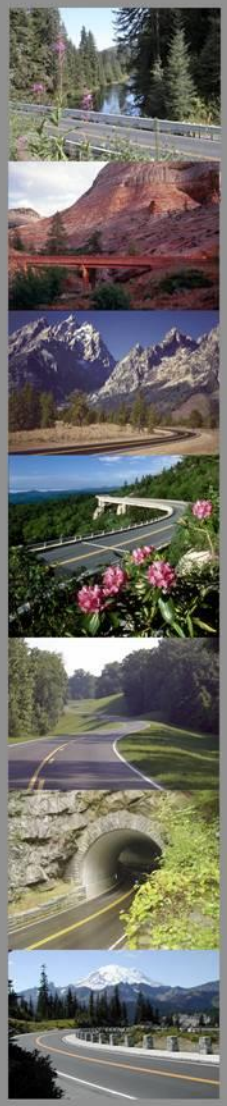
Example: Aggregate Columns

Aggregate Columns

Aggregate columns refer to both rammed aggregate piers and stone columns. Rammed aggregate piers are constructed by using a high-energy down-hole tamper to compact the aggregate and create individual stiff column elements. Stone columns are similar, but are constructed using a down-hole vibratory probe. Aggregate columns are applicable to new embankment construction over unstable soils and embankment widening.

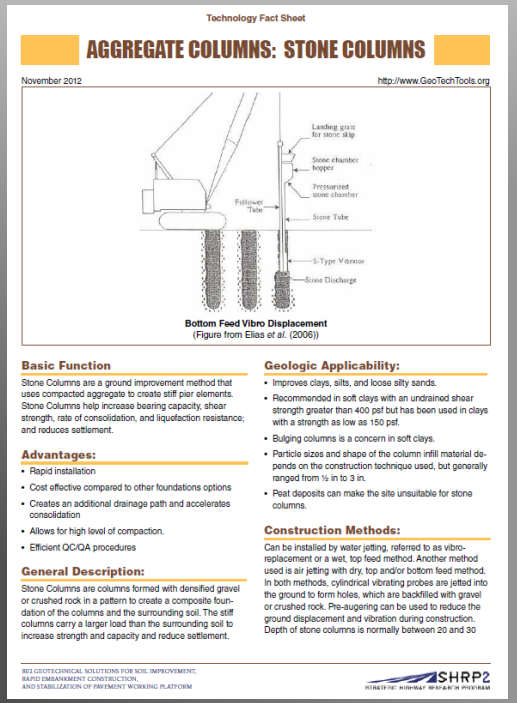
- ☐ Technology Fact Sheets
- ☐ Photos
- Case Histories
  - ☐ MSE Wall Support, VA
  - ☐ Slope Stabilization, New York
  - ☐ Liquefaction Potential Reduction, Missouri
  - ☐ Slope Rehabilitation, Washington, DC
- ☐ Design Guidance
- ☐ Quality Control/Quality Assurance
- ☐ Cost Information
- ☐ Specifications
- ☐ Bibliography

Check All | Clear



FHWA Geotechnical Resources
GeoTech Tools Web Application

Technology Fact Sheet



Technology Fact Sheet

AGGREGATE COLUMNS: STONE COLUMNS

November 2012 http://www.GeoTechTools.org

Bottom Feed Vibro Displacement
(Figure from Elias *et al.* (2006))

Basic Function
Stone Columns are a ground improvement method that uses compacted aggregate to create stiff pier elements. Stone Columns help increase bearing capacity, shear strength, rate of consolidation, and liquefaction resistance; and reduces settlement.

Advantages:
- Rapid installation
- Cost effective compared to other foundations options
- Creates an additional drainage path and accelerates consolidation
- Allows for high level of compaction.
- Efficient QC/QA procedures

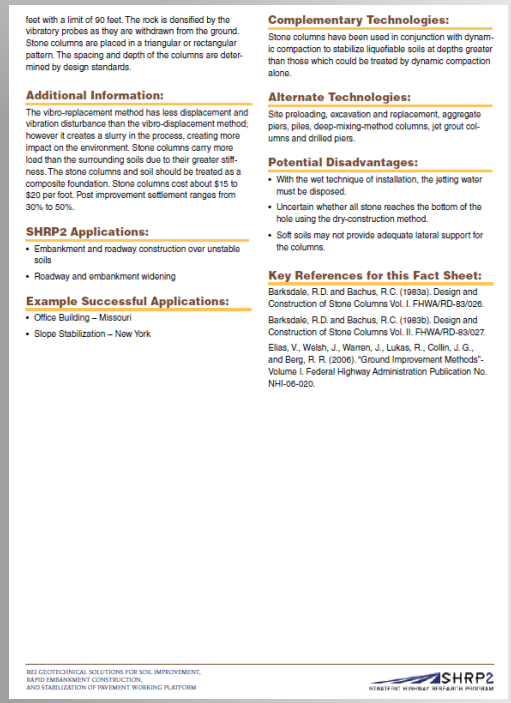
General Description:
Stone Columns are columns formed with densified gravel or crushed rock in a pattern to create a composite foundation of the columns and the surrounding soil. The stiff columns carry a larger load than the surrounding soil to increase strength and capacity and reduce settlement.

Geologic Applicability:
- Improves clays, silts, and loose silty sands.
- Recommended in soft clays with an undrained shear strength greater than 400 psf but has been used in clays with a strength as low as 150 psf.
- Bulging columns is a concern in soft clays.
- Particle sizes and shape of the column infill material depends on the construction technique used, but generally ranged from ½ in to 3 in.
- Peat deposits can make the site unsuitable for stone columns.

Construction Methods:
Can be installed by water jetting, referred to as vibro-replacement or a wet, top feed method. Another method used is air jetting with dry, top and/or bottom feed method. In both methods, cylindrical vibrating probes are jetted into the ground to form holes, which are backfilled with gravel or crushed rock. Pre-augering can be used to reduce the ground displacement and vibration during construction. Depth of stone columns is normally between 20 and 30

R02 GEOTECHNICAL SOLUTIONS FOR SOIL IMPROVEMENT, RAPID EMBANKMENT CONSTRUCTION, AND STABILIZATION OF PAVEMENT WORKING PLATFORM

SHRP2 STRATEGIC HIGHWAY RESEARCH PROGRAM



feet with a limit of 90 feet. The rock is densified by the vibratory probes as they are withdrawn from the ground. Stone columns are placed in a triangular or rectangular pattern. The spacing and depth of the columns are determined by design standards.

Additional Information:
The vibro-replacement method has less displacement and vibration disturbance than the vibro-displacement method; however it creates a slurry in the process, creating more impact on the environment. Stone columns carry more load than the surrounding soils due to their greater stiffness. The stone columns and soil should be treated as a composite foundation. Stone columns cost about $15 to $20 per foot. Post improvement settlement ranges from 30% to 50%.

SHRP2 Applications:
- Embankment and roadway construction over unstable soils
- Roadway and embankment widening

Example Successful Applications:
- Office Building – Missouri
- Slope Stabilization – New York

Complementary Technologies:
Stone columns have been used in conjunction with dynamic compaction to stabilize liquefiable soils at depths greater than those which could be treated by dynamic compaction alone.

Alternate Technologies:
Site preloading, excavation and replacement, aggregate piers, piles, deep-mixing-method columns, jet grout columns and drilled piers.

Potential Disadvantages:
- With the wet technique of installation, the jetting water must be disposed.
- Uncertain whether all stone reaches the bottom of the hole using the dry-construction method.
- Soft soils may not provide adequate lateral support for the columns.

Key References for this Fact Sheet:
Barksdale, R.D. and Bachus, R.C. (1983a). Design and Construction of Stone Columns Vol. I. FHWA/RD-83/026.

Barksdale, R.D. and Bachus, R.C. (1983b). Design and Construction of Stone Columns Vol. II. FHWA/RD-83/027.

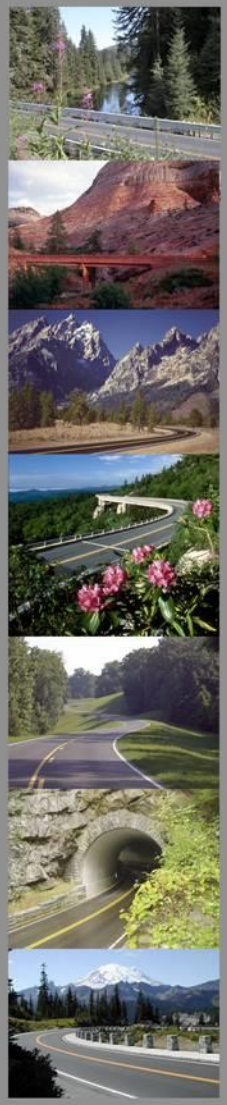
Elias, V., Welsh, J., Warren, J., Lukas, R., Collin, J. G., and Berg, R. R. (2006). "Ground Improvement Methods"- Volume I. Federal Highway Administration Publication No. NHI-06-020.

R02 GEOTECHNICAL SOLUTIONS FOR SOIL IMPROVEMENT, RAPID EMBANKMENT CONSTRUCTION, AND STABILIZATION OF PAVEMENT WORKING PLATFORM

SHRP2 STRATEGIC HIGHWAY RESEARCH PROGRAM

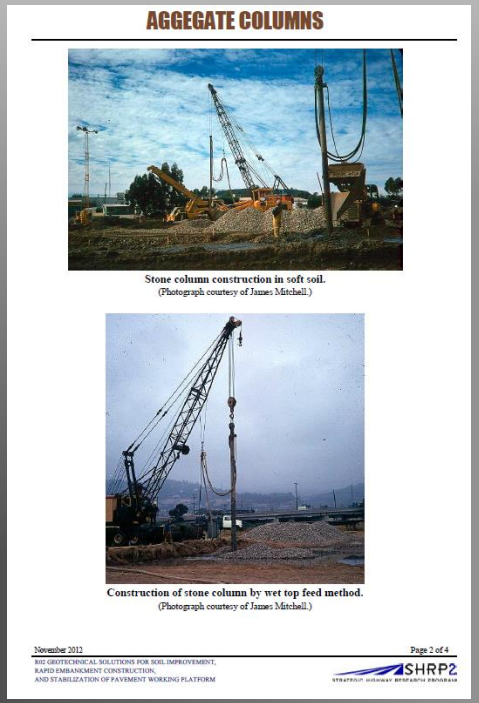
U.S. Department of Transportation
Federal Highway Administration
Federal Lands Highway

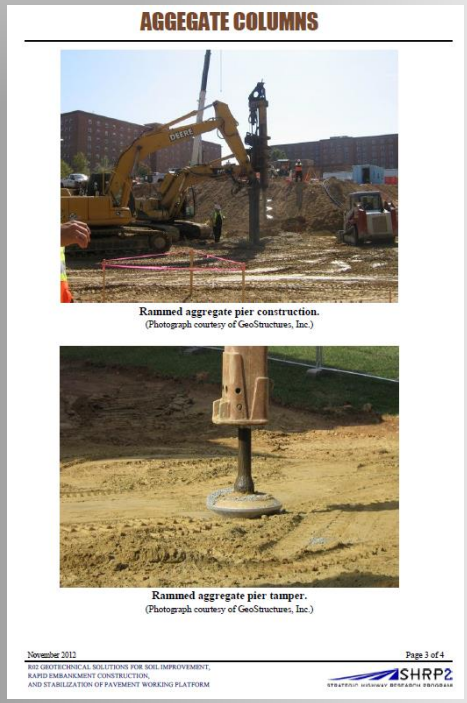
Engineering America's Scenic Highways

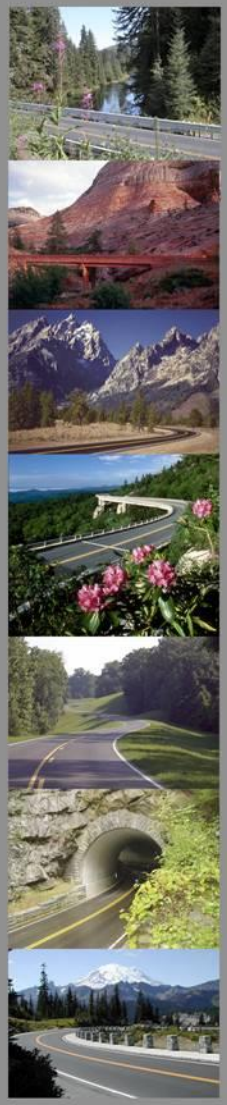


FHWA Geotechnical Resources
GeoTech Tools Web Application

Technology Photographs



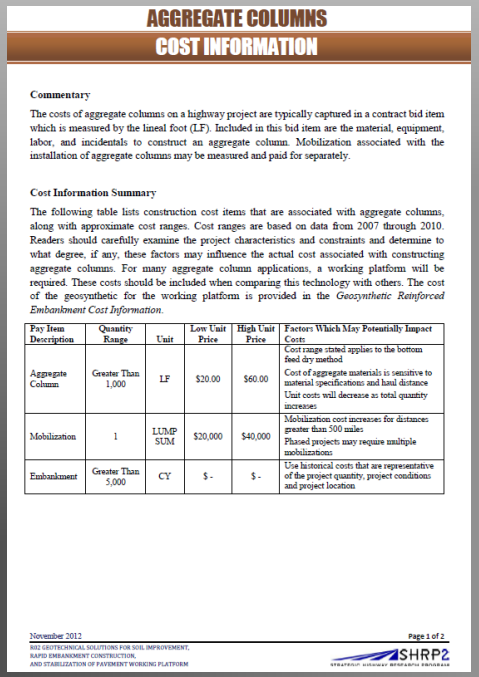




FHWA Geotechnical Resources

GeoTech Tools Web Application

Cost Data and Specifications



AGGREGATE COLUMNS

COST INFORMATION

Commentary

The costs of aggregate columns on a highway project are typically captured in a contract bid item which is measured by the lineal foot (LF). Included in this bid item are the material, equipment, labor, and incidentals to construct an aggregate column. Mobilization associated with the installation of aggregate columns may be measured and paid for separately.

Cost Information Summary

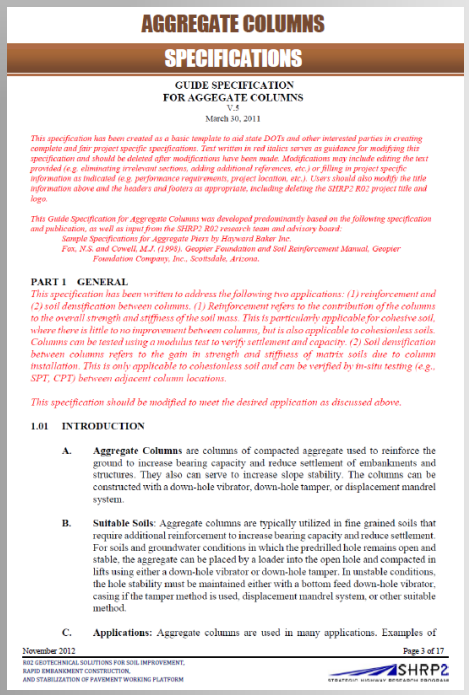
The following table lists construction cost items that are associated with aggregate columns, along with approximate cost ranges. Cost ranges are based on data from 2007 through 2010. Readers should carefully examine the project characteristics and constraints and determine to what degree, if any, these factors may influence the actual cost associated with constructing aggregate columns. For many aggregate column applications, a working platform will be required. These costs should be included when comparing this technology with others. The cost of the geosynthetic for the working platform is provided in the *Geosynthetic Reinforced Embankment Cost Information*.

Pay Item Description	Quantity Range	Unit	Low Unit Price	High Unit Price	Factors Which May Potentially Impact Costs
Aggregate Column	Greater Than 1,000	LF	$20.00	$60.00	Cost range stated applies to the bottom feed dry method Cost of aggregate materials is sensitive to material specifications and haul distance Unit costs will decrease as total quantity increases
Mobilization	1	LUMP SUM	$20,000	$40,000	Mobilization cost increases for distances greater than 500 miles Phased projects may require multiple mobilizations
Embankment	Greater Than 5,000	CY	$ -	$ -	Use historical costs that are representative of the project quantity, project conditions and project location

November 2012 Page 1 of 2

R02 GEOTECHNICAL SOLUTIONS FOR SOIL IMPROVEMENT, RAPID EMBANKMENT CONSTRUCTION, AND STABILIZATION OF PAVEMENT WORKING PLATFORM

SHRP2



AGGREGATE COLUMNS

SPECIFICATIONS

GUIDE SPECIFICATION FOR AGGEGATE COLUMNS

V.5

March 30, 2011

This specification has been created as a basic template to aid state DOTs and other interested parties in creating complete and fair project specific specifications. Text written in red italics serves as guidance for modifying this specification and should be deleted after modifications have been made. Modifications may include editing the text provided (e.g. eliminating irrelevant sections, adding additional references, etc.) or filling in project specific information as indicated (e.g. performance requirements, project location, etc.). Users should also modify the title information above and the headers and footers as appropriate, including deleting the SHRP2 R02 project title and logo.

This Guide Specification for Aggregate Columns was developed predominantly based on the following specification and publication, as well as input from the SHRP2 R02 research team and advisory board:

Sample Specifications for Aggregate Piers by Hayward Baker Inc.

Fox, N.S. and Cowell, M.J. (1998). Geopier Foundation and Soil Reinforcement Manual. Geopier Foundation Company, Inc., Scottsdale, Arizona.

PART 1 GENERAL

This specification has been written to address the following two applications: (1) reinforcement and (2) soil densification between columns. (1) Reinforcement refers to the contribution of the columns to the overall strength and stiffness of the soil mass. This is particularly applicable for cohesive soil, where there is little to no improvement between columns, but is also applicable to cohesionless soils. Columns can be tested using a modulus test to verify settlement and capacity. (2) Soil densification between columns refers to the gain in strength and stiffness of matrix soils due to column installation. This is only applicable to cohesionless soil and can be verified by in-situ testing (e.g., SPT, CPT) between adjacent column locations.

This specification should be modified to meet the desired application as discussed above.

1.01 INTRODUCTION

A. Aggregate Columns are columns of compacted aggregate used to reinforce the ground to increase bearing capacity and reduce settlement of embankments and structures. They also can serve to increase slope stability. The columns can be constructed with a down-hole vibrator, down-hole tamper, or displacement mandrel system.

B. Suitable Soils: Aggregate columns are typically utilized in fine grained soils that require additional reinforcement to increase bearing capacity and reduce settlement. For soils and groundwater conditions in which the predrilled hole remains open and stable, the aggregate can be placed by a loader into the open hole and compacted in lifts using either a down-hole vibrator or down-hole tamper. In unstable conditions, the hole stability must be maintained either with a bottom feed down-hole vibrator, casing if the tamper method is used, displacement mandrel system, or other suitable method.

C. Applications: Aggregate columns are used in many applications. Examples of

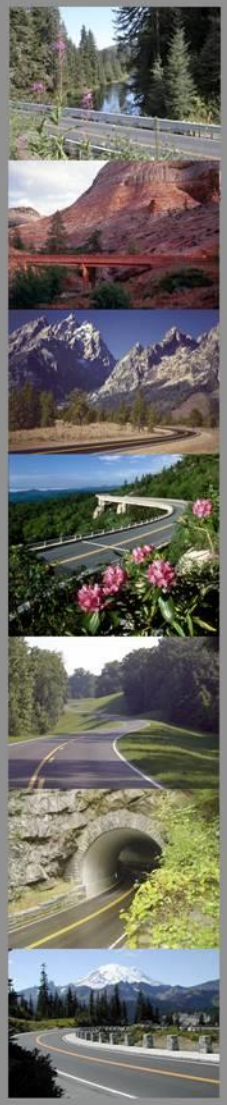
November 2012 Page 3 of 17

R02 GEOTECHNICAL SOLUTIONS FOR SOIL IMPROVEMENT, RAPID EMBANKMENT CONSTRUCTION, AND STABILIZATION OF PAVEMENT WORKING PLATFORM

SHRP2

U.S. Department of Transportation
Federal Highway Administration
Federal Lands Highway

Engineering America's Scenic Highways



FHWA Geotechnical Resources
GeoTech Tools Web Application

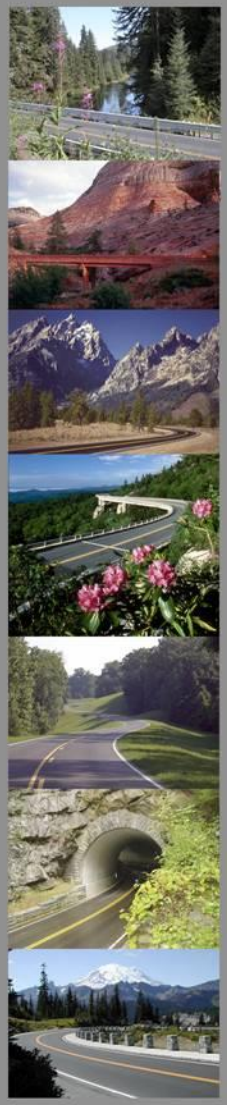
Example: Aggregate Columns

Aggregate Columns

Aggregate columns refer to both rammed aggregate piers and stone columns. Rammed aggregate piers are constructed by using a high-energy down-hole tamper to compact the aggregate and create individual stiff column elements. Stone columns are similar, but are constructed using a down-hole vibratory probe. Aggregate columns are applicable to new embankment construction over unstable soils and embankment widening.

- ☐ Technology Fact Sheets
- ☐ Photos
- Case Histories
  - ☐ MSE Wall Support, VA
  - ☐ Slope Stabilization, New York
  - ☐ Liquefaction Potential Reduction, Missouri
  - ☐ Slope Rehabilitation, Washington, DC
- ☐ Design Guidance
- ☐ Quality Control/Quality Assurance
- ☐ Cost Information
- ☐ Specifications
- ☐ Bibliography

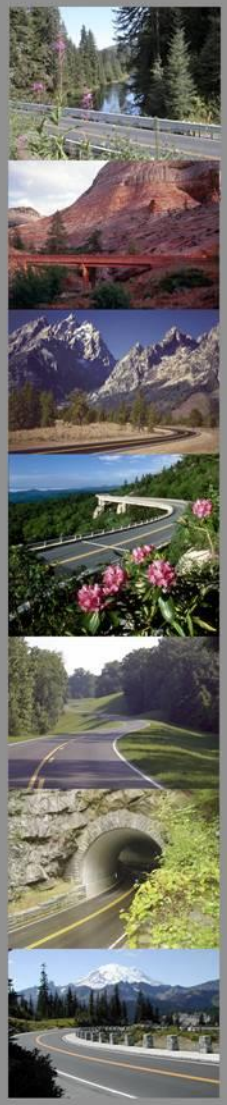
Check All | Clear



FHWA Geotechnical Resources
GeoTech Tools Web Application

Technologies Addressed

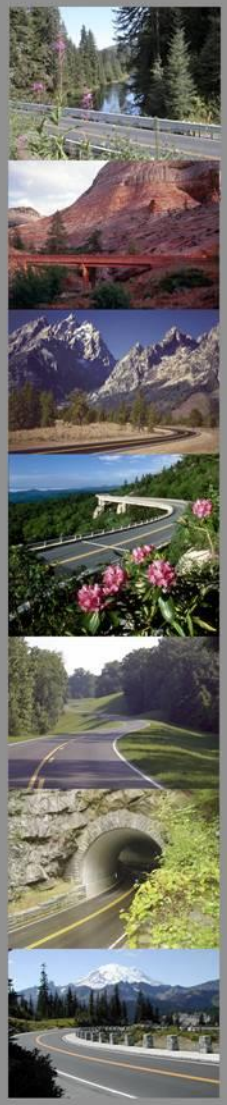
- Aggregate Columns
- Beneficial Reuse of Waste Materials
- Bio-Treatment for Subgrade Stabilization
- Blast Densification
- Bulk-Infill Grouting
- Chemical Grouting/ Injection Systems
- Chemical Stabilization of Subgrades & Bases
- Column-Supported Embankments
- Combined Soil Stabilization with Vertical Columns
- Compaction Grouting
- Continuous Flight Auger Piles
- Deep Dynamic Compaction
- Deep Mixing Methods



FHWA Geotechnical Resources
GeoTech Tools Web Application

Technologies Addressed

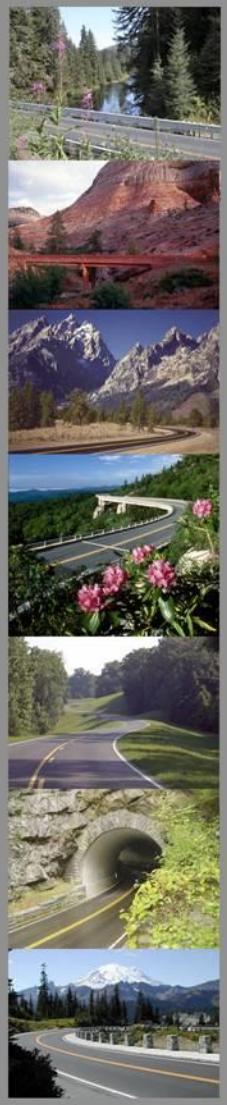
- Drilled/Grouted & Hollow Bar Soil Nailing
- Electro-Osmosis
- Excavation & Replacement
- Fiber Reinforcement in Pavement Systems
- Geocell Confinement in Pavement Systems
- Geosynthetic Reinforced Construction Platforms
- Geosynthetic Reinforced Embankments
- Geosynthetic Reinforcement in Pavement Systems
- Geosynthetic Separation in Pavement Systems
- Geosynthetics in Pavement Drainage
- Geotextile Encased Columns
- High-Energy Impact Rollers
- Hydraulic Fill + Vacuum Consolidation + PVDs
- Injected Lightweight Foam Fill



FHWA Geotechnical Resources
GeoTech Tools Web Application

Technologies Addressed

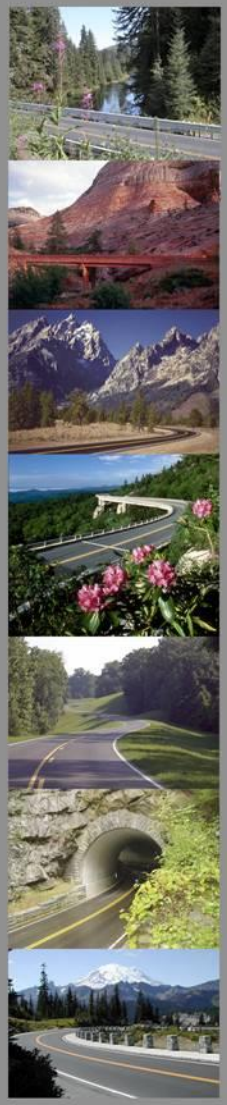
- Intelligent Compaction
- Jet Grouting
- Light Weight Fills
- Mechanical Stabilization of Subgrades & Bases
- MSE Walls
- Micropiles
- Onsite Use of Recycled Pavement Materials
- Partial Encapsulation
- PVDs & Fill Preloading
- Rapid Impact Compaction
- Reinforced Soil Slopes
- Sand Compaction Piles
- Screw-In Soil Nailing
- Shoot-In Soil Nailing
- Shored MSE Walls
- Traditional Compaction
- Vibrocompaction
- Vibro-Concrete Columns



GRS-IBS Design and Construction

U.S. Department of Transportation
Federal Highway Administration
Federal Lands Highway

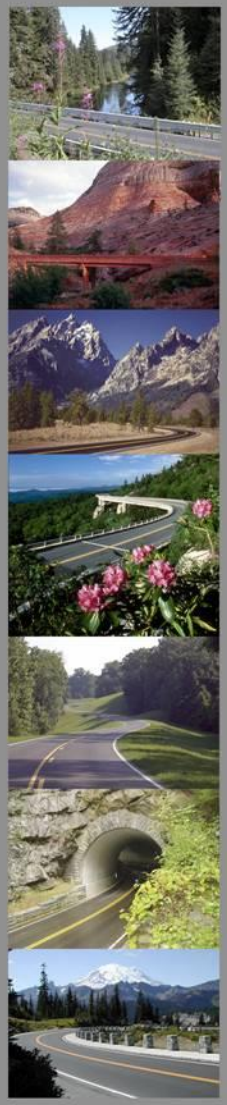
Engineering America's Scenic Highways



Unstable Slope Management Program (USMP)

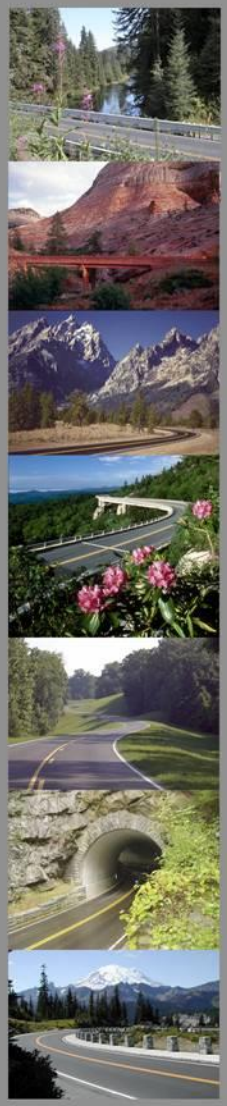
U.S. Department of Transportation
Federal Highway Administration
Federal Lands Highway

Engineering America's Scenic Highways



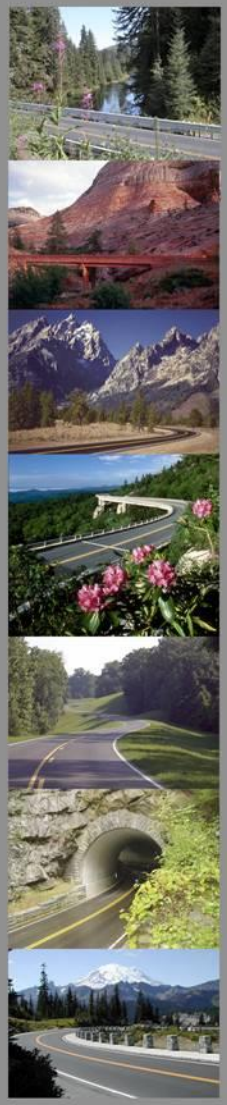
USMP: Step-by-Step

1. Evaluate transportation system use and needs; target USMP implementation
2. Rate identified transportation corridors based on maintenance input
3. Prioritize Rated Slopes
4. Develop conceptual designs and estimates by geotechnical specialist for highly rated slopes only
5. Evaluate benefit-costs and reprioritize rated slopes for proactive project selection
6. Track slopes in USMP; watching for trends of deterioration that require proactive risk reduction intervention



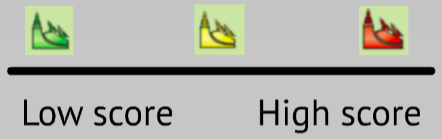
Function of USMP

- Prioritize & manage unstable slopes
- Includes soil and rock slopes
- Developed for low or medium volume roads (not major interstate highways)
- Uses proven unstable slope systems
- Generate one standard set of criteria
- Efficient field survey process (Form or App)
- Monitor and track deterioration
- Prioritize preventative maintenance

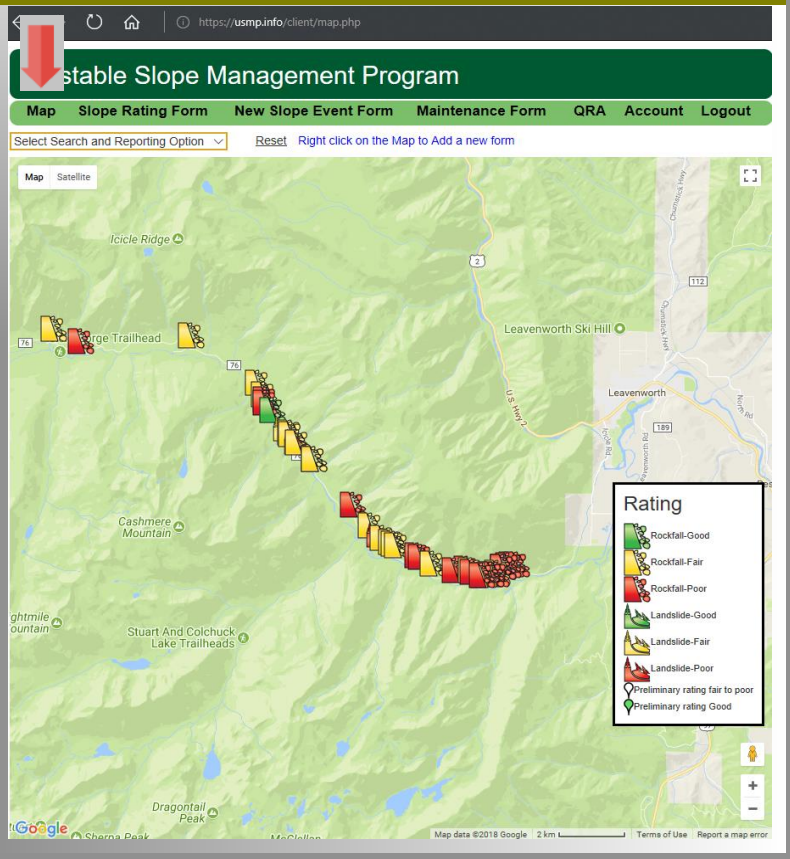


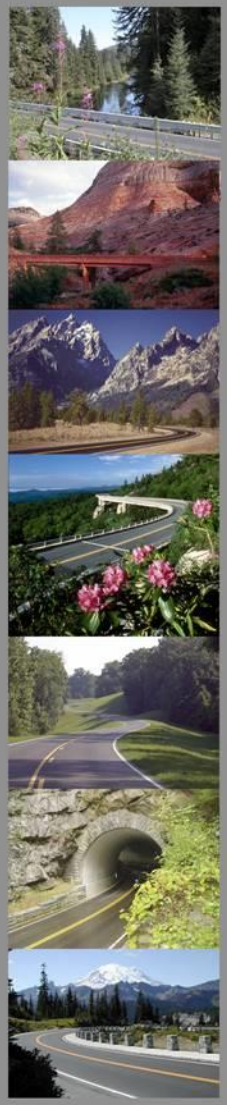
USMP Website Map Functionality

- *Shows an overview of rated sites*
  - *Landslides*
  - *Rockfalls*
  - *Color separates good, fair, and poor scores*



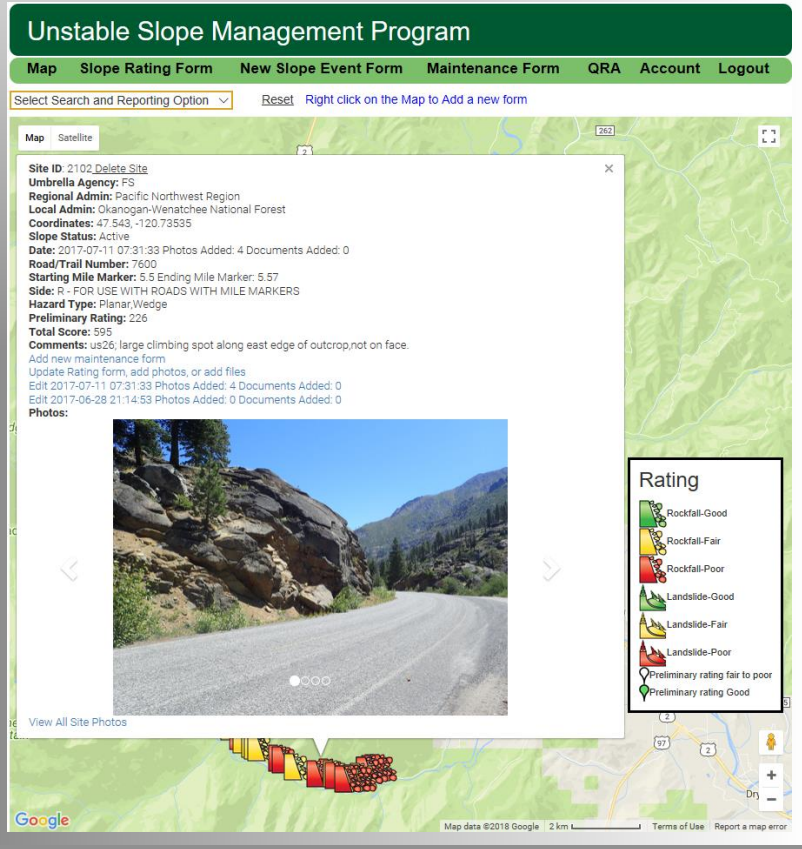
- *Users can zoom and pan around to different management areas*

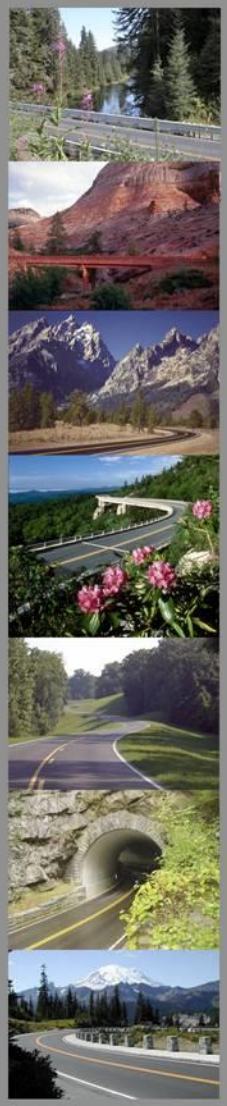




USMP Website Map Functionality

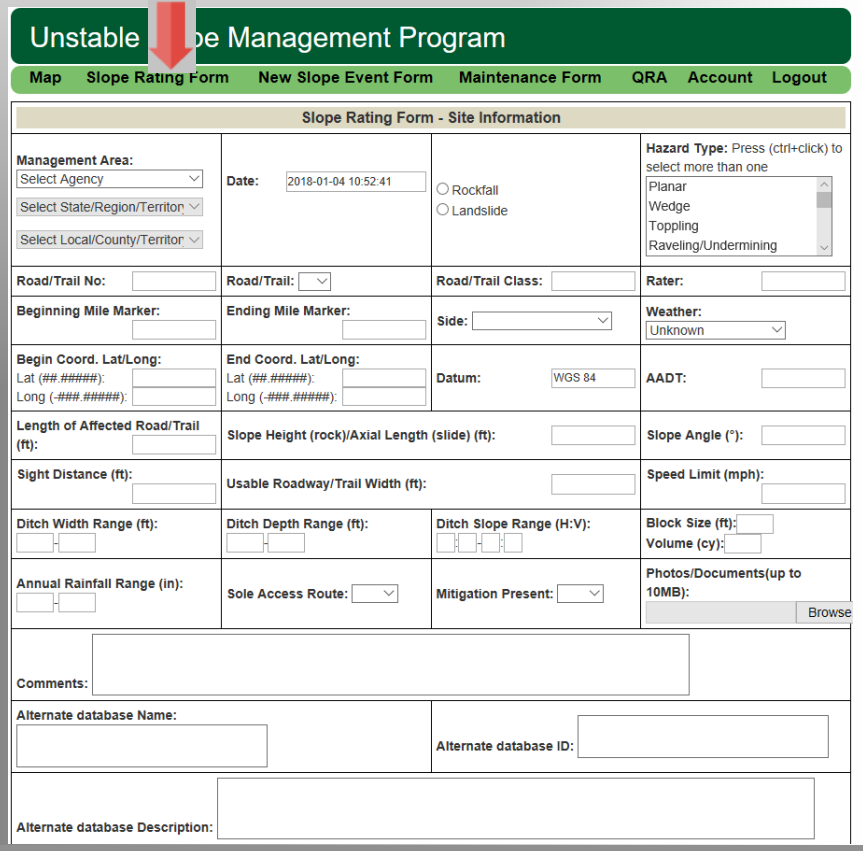
- Allows for a quick overview of the site
- Includes five photos from the most recent edit
- Has links to:
  - History of edits
  - All site photos
  - All files uploaded

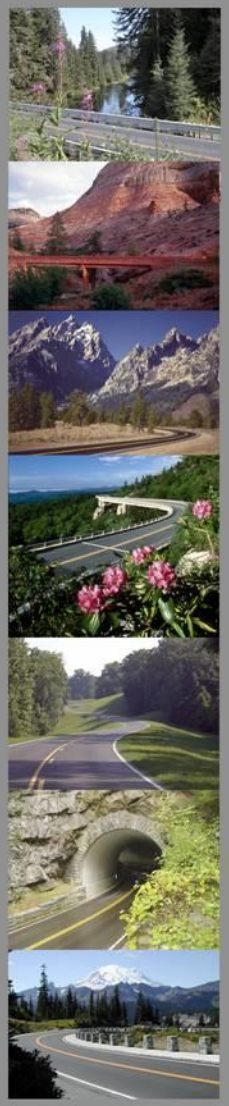




USMP Rating Form

- Many measurements auto-calculate
- Photos and documents can be uploaded

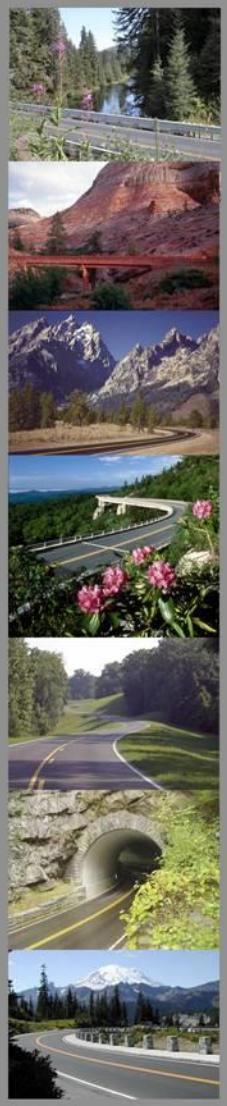




Preliminary Ratings

- Rapid assessment tool to limit time spent at a good slope
- Three landslide or rockfall hazard ratings and two risk rating categories required

Preliminary Ratings					
Category Rating:	**3**	**9**	**27**	**81**	**Score:**
A. Landslide - Roadway Width Affected:	0-5 percent	6-25 percent	26-50 percent	51-100 percent	0
B. Landslide - Slide/Erosion Effects:	Visible crack or slight deposit of material / minor erosion	1 inch offset, or 6-inch deposit of material / major erosion will affect travel in < 5 years	2-inch offset or 12-inch deposity / mod. erosion impacting travel annually	4-inch offset or 24-inch deposity / severe erosion impacting travel consistently	0
C. Landslide - Roadway Length Affected:	25 ft	100 ft	225 ft	400 ft	0
D. Rockfall - Ditch Effectiveness: (consider launch features)	Good	Moderate	Limited	No Catchment	0
E. Rockfall - Rockfall History:	Few Falls	Occasional Falls	Many Falls	Constant Falls	0
F. Rockfall - Block Size or Volume per Event:	1ft or 3yd^3	2ft or 6yd^3	3ft or 9yd^3	4ft or 12yd^3	0
G. All - Impact on Use:	Full use continues with minor delay	Partial use remains Use modification required, short (3mi / 30min.) detour available	Use is blocked - long (>30min.) detour available or less than 1 day closure	Use is blocked - no detour available or closure longer than 1 week	0
H. All - AADT/Usage/Economic or Recreational Importance (highest rating applies):	50 Rarely Used Insignificant economic / rec. importance	200 Occasionally used Minor economic / rec. importance	450 Frequently used Moderate economic / rec. importance	800 Constantly used Significant economic / rec. importance	**Use AADT in calculation:** ☑ 0
Preliminary Rating Landslide Total (A+B+C+G+H):					0
Preliminary Rating Rockfall Total (D+E+F+G+H):					0
Preliminary Rating Good (15-21 pts) | Fair (22-161 pts) | Poor (>161 pts)					0



Detailed Slope Hazard & Risk Rating Categories

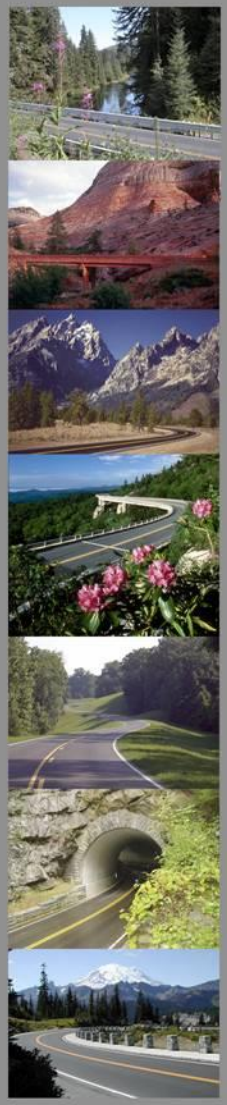
Slope Hazard Ratings								
Category Rating:				3	9	27	81	Score:
I. All - Slope Drainage:				Slope appears dry or well drained; surface runoff well controlled	Intermittent water on slope; mod. not well drained; or surface runoff moderately controlled	Water usually on slope; poorly drained; or surface runoff poorly controlled	Water always on slope; very poorly drained; or surface water runoff control not present	0
J. All - Annual Rainfall:				0-10"	10-30"	30-60"	60"+	0
K. All - Slope Height (Rockfall) / Axial Length of slide (Landslide):				25ft	50ft	75ft	100ft	0
Select One Unstable Slope Type	Landslides / Erosion	L. Thaw Stability:		Unfrozen / Thaw Stable	Slightly Thaw Unstable	Moderately Thaw Unstable	Highly Thaw Unstable	0
		M. Instability - Related Maint. Frequency:		Every 10 years	Every 5 years	Every 2 years	Every year	0
		N. Movement History:		Minor movement or sporadic creep	Up to 1 inch annually or steady annual creep	Up to 3 inches per event, one event per year	>3" per event, >6" annually, more than 1 event per year (includes all debris flows)	0
	Rockfalls	O. Rockfall-Related Maint. Frequency:		Normal, scheduled maintenance	Patrols after every storm event	Routine seasonal patrols	Year round patrols	0
		Geological Character Case 1	P. Structural Condition:	favorable	random	Discontinuous adverse	Continuous adverse	0
			Q. Rock Friction:	Rough / Irregular	Undulating	Planar	Clay infilled / Slickensided	0
		Geological Character Case 2	R. Structural Condition:	Few differential erosion features	Occasional differential erosion features	Many differential erosion features	Major differential erosion features	0
			S. Diff. in Erosion Rates:	Small difference	Moderate difference	Large difference	Extreme difference	0
T. LANDSLIDE HAZARD TOTAL (A+B+C+I+J+K+L+M+N):								0
U. ROCKFALL HAZARD TOTAL (D+E+F+I+J+K+O+(greater of P+Q or R+S)):								0

Risk Ratings					
V. Route Width or Trail Width:	36ft 14ft	28ft 10ft	20ft 6ft	12ft 2ft	0
W. Human Exposure Factor:	12.5% of the time	25% of the time	37.5% of the time	50% of the time	0
X. % of Decision Sight Distance (Judge avoidance ability on trails):	Adequate, 100% of the low design value	Moderate, 80% of the low design value	Limited, 60% of the low design value	Very limited, 40% of the low design value	0
Y. Right of Way (R/W) Impacts (If Left Unattended):	No R/W implications	Minor effects beyond R/W	Private property, no structures affected	Structures, roads, RR, utilities, or Parks affected	0
Z. Environmental/Cultural Impacts if Left Unattended:	None/No Potential to Cause Effects	Likely to Effect/No Hist. Prop. Affected	Likely to adversely Affect/Finding of No Adverse Effect	Current adverse effects/Adverse Effect	0
AA. Maintenance Complexity:	Routine Effort / In-House	In-House maint. / special project	Specialized equip. / contract	Complex / dangerous effort / location / contract	0
BB. Event Cost:	$0-2k	$2-25k	$25-100k	>$100k	0
CC. Risk Totals (C+H+V+W+X+Y+Z+AA+BB):					0
TOTAL USMP SCORE: LANDSLIDES (T+CC) OR ROCKFALL (U+CC): Good (<200 pts) | Fair (200-400 pts) | Poor (>400 pts)					0

Total USMP score translates to good, fair, and poor conditions for map symbols

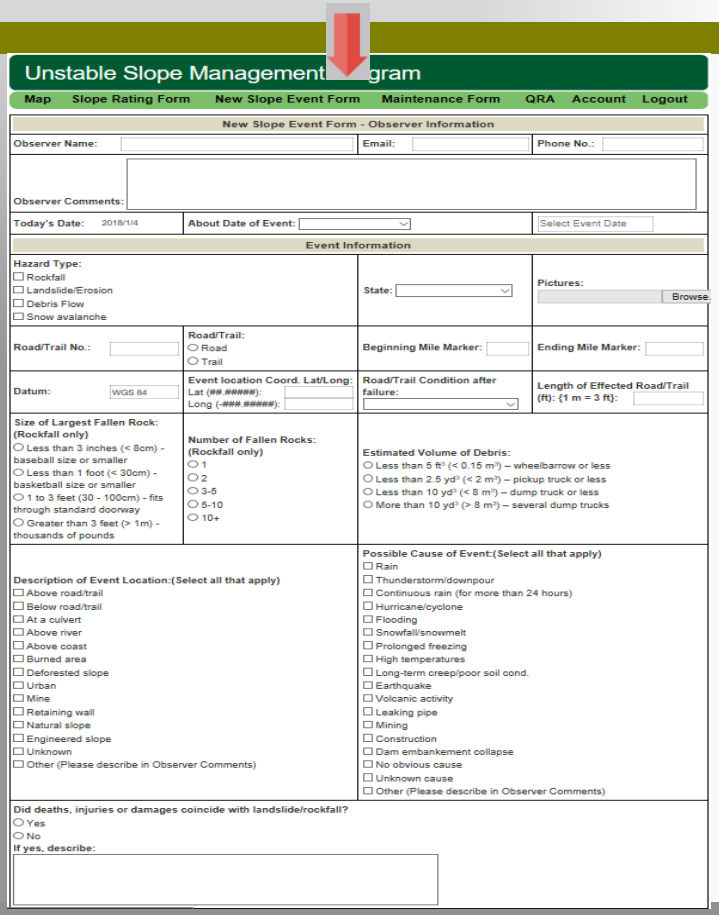
U.S. Department of Transportation
Federal Highway Administration
Federal Lands Highway

Engineering America's Scenic Highways



New Slope Event Form

- **Intended for any employee to provide basic information about new unstable slope events**



Unstable Slope Management [illegible]gram

Map | Slope Rating Form | New Slope Event Form | Maintenance Form | QRA | Account | Logout

New Slope Event Form - Observer Information

Observer Name: | Email: | Phone No.:

Observer Comments:

Today's Date: 2018/1/4 | About Date of Event: | Select Event Date

Event Information

Hazard Type:
- ☐ Rockfall
- ☐ Landslide/Erosion
- ☐ Debris Flow
- ☐ Snow avalanche

State: | Pictures: Browse...

Road/Trail No.: | Road/Trail: ○ Road ○ Trail | Beginning Mile Marker: | Ending Mile Marker:

Datum: WGS 84 | Event location Coord. Lat/Long: Lat (##.#####): Long (-###.#####): | Road/Trail Condition after failure: | Length of Effected Road/Trail (ft): (1 m = 3 ft):

Size of Largest Fallen Rock: (Rockfall only)
- ○ Less than 3 inches (< 8cm) - baseball size or smaller
- ○ Less than 1 foot (< 30cm) - basketball size or smaller
- ○ 1 to 3 feet (30 - 100cm) - fits through standard doorway
- ○ Greater than 3 feet (> 1m) - thousands of pounds

Number of Fallen Rocks: (Rockfall only)
- ○ 1
- ○ 2
- ○ 3-5
- ○ 5-10
- ○ 10+

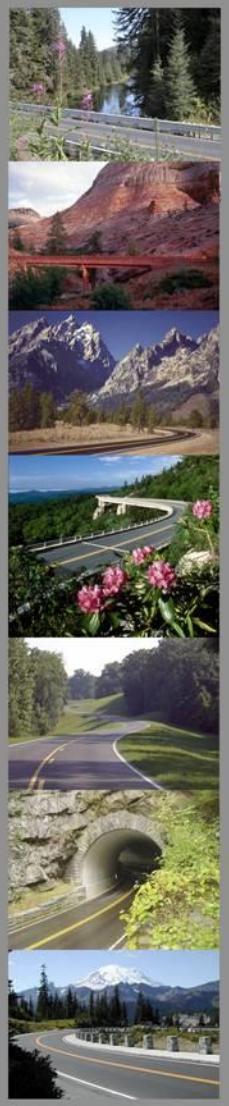
Estimated Volume of Debris:
- ○ Less than 5 ft³ (< 0.15 m³) – wheelbarrow or less
- ○ Less than 2.5 yd³ (< 2 m³) – pickup truck or less
- ○ Less than 10 yd³ (< 8 m³) – dump truck or less
- ○ More than 10 yd³ (> 8 m³) – several dump trucks

Description of Event Location:(Select all that apply)
- ☐ Above road/trail
- ☐ Below road/trail
- ☐ At a culvert
- ☐ Above river
- ☐ Above coast
- ☐ Burned area
- ☐ Deforested slope
- ☐ Urban
- ☐ Mine
- ☐ Retaining wall
- ☐ Natural slope
- ☐ Engineered slope
- ☐ Unknown
- ☐ Other (Please describe in Observer Comments)

Possible Cause of Event:(Select all that apply)
- ☐ Rain
- ☐ Thunderstorm/downpour
- ☐ Continuous rain (for more than 24 hours)
- ☐ Hurricane/cyclone
- ☐ Flooding
- ☐ Snowfall/snowmelt
- ☐ Prolonged freezing
- ☐ High temperatures
- ☐ Long-term creep/poor soil cond.
- ☐ Earthquake
- ☐ Volcanic activity
- ☐ Leaking pipe
- ☐ Mining
- ☐ Construction
- ☐ Dam embankement collapse
- ☐ No obvious cause
- ☐ Unknown cause
- ☐ Other (Please describe in Observer Comments)

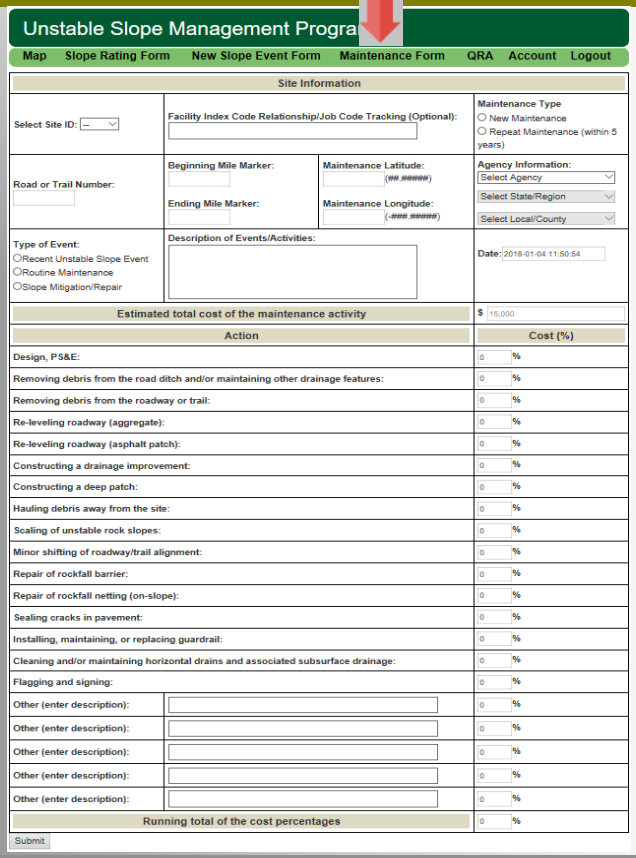
Did deaths, injuries or damages coincide with landslide/rockfall?
- ○ Yes
- ○ No

If yes, describe:



Maintenance Form

- **Simplified maintenance information is documented**
- **This information with periodic re-rating information provides expenditures and deterioration rates for slope assets**



Unstable Slope Management Progra

Map | Slope Rating Form | New Slope Event Form | Maintenance Form | QRA | Account | Logout

Site Information

Select Site ID: --

Facility Index Code Relationship/Job Code Tracking (Optional):

Maintenance Type
- New Maintenance
- Repeat Maintenance (within 5 years)

Road or Trail Number:

Beginning Mile Marker:

Ending Mile Marker:

Maintenance Latitude: (##.######)

Maintenance Longitude: (-###.######)

Agency Information:
Select Agency
Select State/Region
Select Local/County

Type of Event:
- Recent Unstable Slope Event
- Routine Maintenance
- Slope Mitigation/Repair

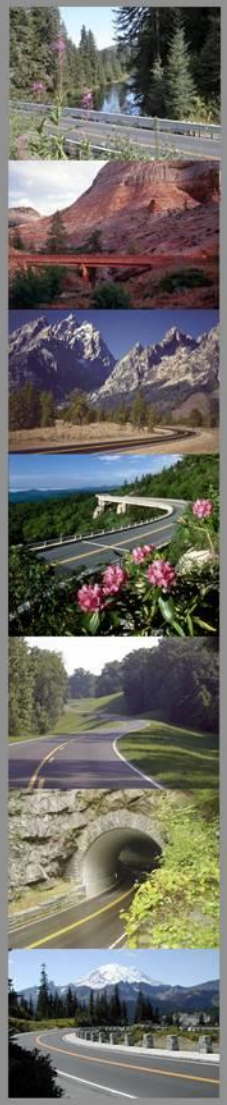
Description of Events/Activities:

Date: 2018-01-04 11:50:54

Estimated total cost of the maintenance activity	$ 15,000

Action	Cost (%)
Design, PS&E:	0 %
Removing debris from the road ditch and/or maintaining other drainage features:	0 %
Removing debris from the roadway or trail:	0 %
Re-leveling roadway (aggregate):	0 %
Re-leveling roadway (asphalt patch):	0 %
Constructing a drainage improvement:	0 %
Constructing a deep patch:	0 %
Hauling debris away from the site:	0 %
Scaling of unstable rock slopes:	0 %
Minor shifting of roadway/trail alignment:	0 %
Repair of rockfall barrier:	0 %
Repair of rockfall netting (on-slope):	0 %
Sealing cracks in pavement:	0 %
Installing, maintaining, or replacing guardrail:	0 %
Cleaning and/or maintaining horizontal drains and associated subsurface drainage:	0 %
Flagging and signing:	0 %
Other (enter description):	0 %
Other (enter description):	0 %
Other (enter description):	0 %
Other (enter description):	0 %
Other (enter description):	0 %
Running total of the cost percentages	0 %

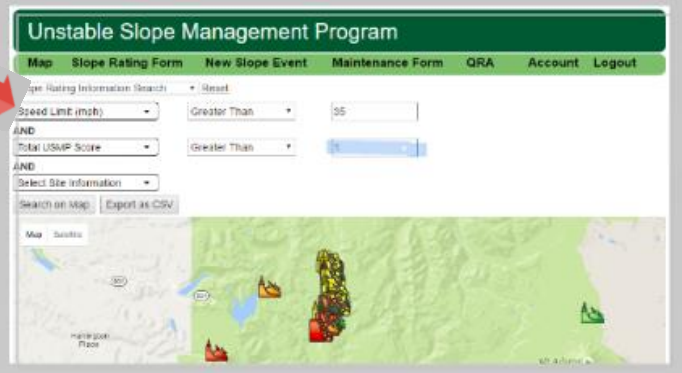
Submit

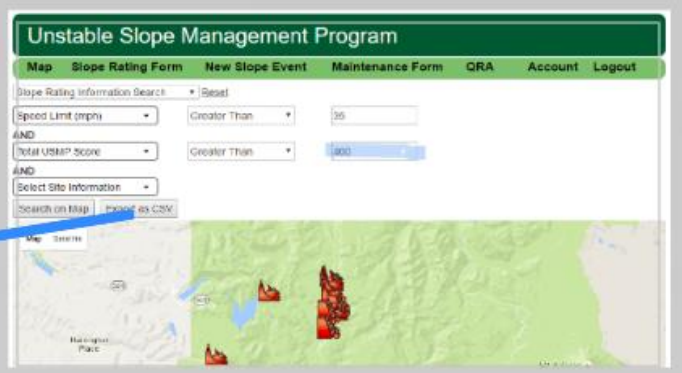


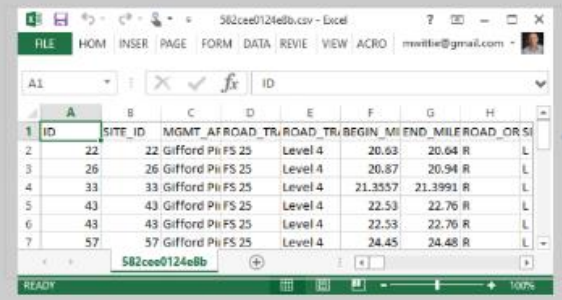
Searching and Reporting

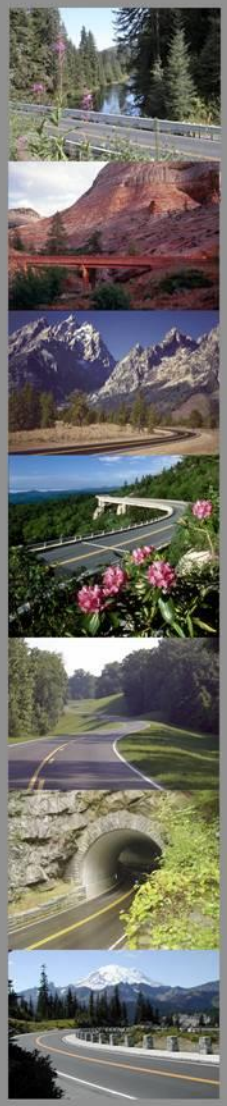
Searching and Reporting

- *Search for sites through three-tiered search criteria to funnel search*
- *Export visible sites as a CSV*
- *Data can be imported into other databases or GIS programs for analysis*



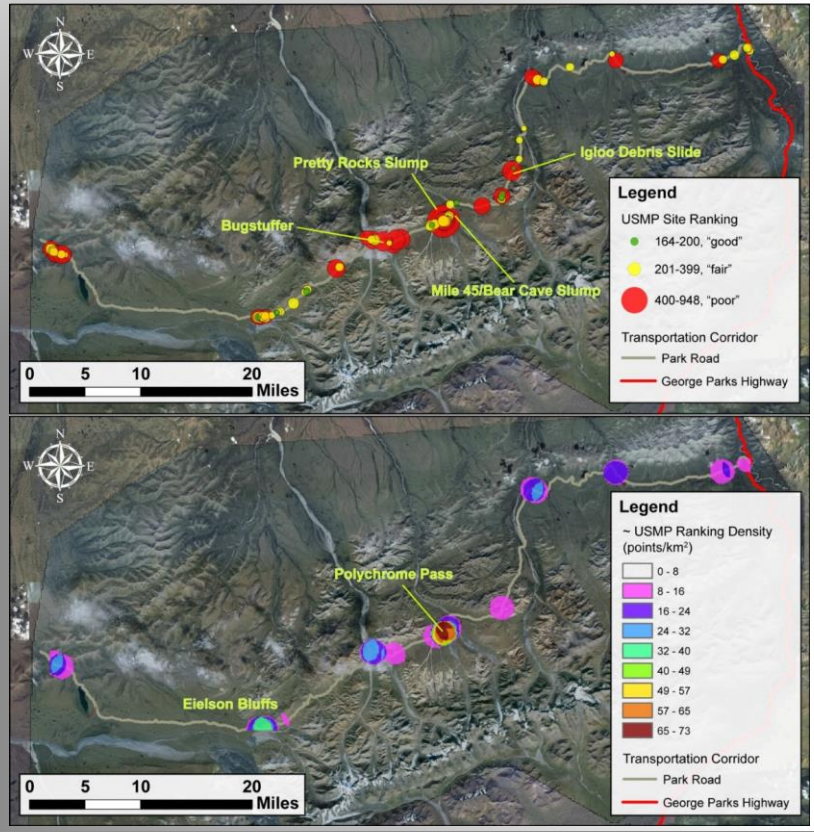


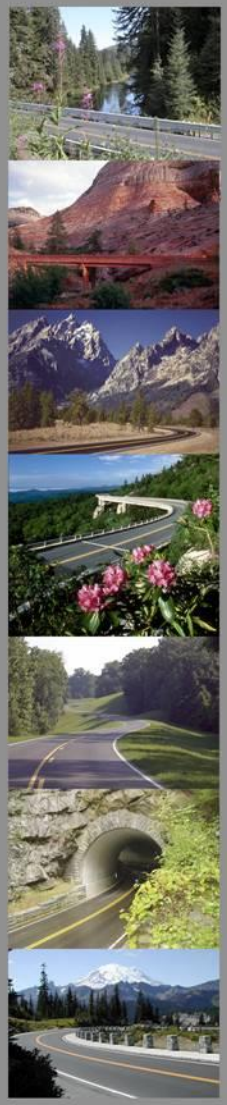




Example Project
Denali National Park

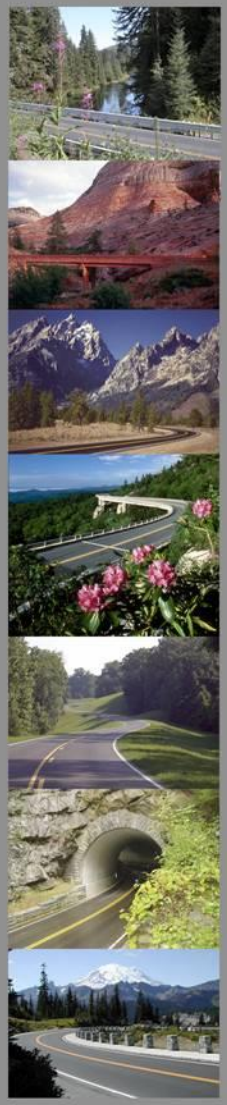
- 92 Mile Denali Park road
- Primary access
- 141 USMP sites rated by temporary park staff





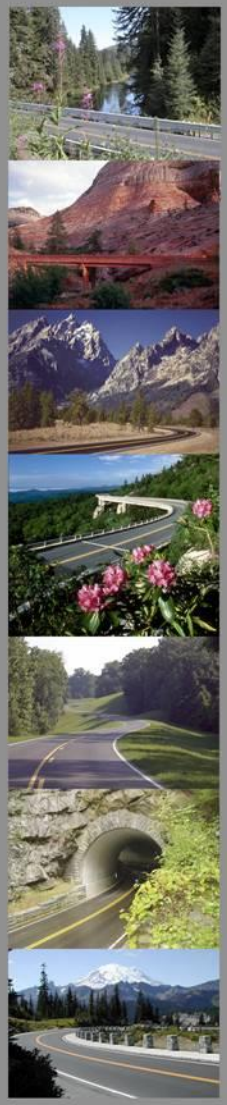
Example Project
Denali National Park

SITE ID		SITE INFORMATION					HAZARD TOTAL	RISK TOTAL	TOTAL SCORE
DENA SITE NAME	USMP SITE ID [Assigned]	ROAD/ TRAIL NO.	BEGIN. MILE MARKER	END. MILE MARKER	SIDE	HAZARD TYPE			
Mile 45.4a – Pretty Rocks Slide	957	10	45.34	45.41	L	Landslide, across road, translational/rotational?	530	418	948
Mile 52.9 – Toklas Bluffs Corner	964	10	52.87	52.96	R	Rockfall, wedge	455	140	595
Mile 50.4 Debris Flow	887	10	50.36	50.40	R	Landslide, debris flow, across road	379	205	583
Mile 51.9 – Bugstuffer	960	10	51.92	51.95	R	Landslide, debris flow, across road	405	170	575
Mile 50.8 – Whoop-te-do	959	10	50.75	50.81	L	Landslide, rotational, mostly below but beginning to come i	316	254	569
Mile 35.2 Debris Flow (bus)	927	10	35.25	35.27	L	Landslide, debris flow, across road	367	195	562
Mile 49.9 Debris Flow	936	10	49.88	49.90	R	Landslide, debris flow, across road	375	186	561
Mile 67.4a – Eagle's Nest Drainag	981	10	67.37	67.41	R	Landslide, debris flow, across road	415	141	556
Mile 57.9 Debris Flow 1990's	889	10	57.88	57.89	R	Landslide, debris flow, across road	330	220	550
Mile 40.1 Debris Flow (more active	854	10	40.15	40.18	R	Lanslide, debris flow, across road	391	139	530
Mile 37.7b – Igloo Debris Slide	980	10	37.72	37.75	R	Landslide, above road, translational	315	199	514
Mile 45.3b – Polychrome Debris Sl	956	10	45.31	45.32	R	Landslide, rotational, above/onto road	281	229	510
Mile 68.2a Bad Rockfall	910	10	68.18	68.23	R	Rockfall, differential erosion from pyroclastic breccia	280	221	500
Mile 44.6b Rockfall	864	10	44.59	44.64	R	Rockfall, wedge	242	241	483
Mile 68.0c Landslide with Hdrains	971	10	68.06	68.08	L	Landslide, below road, rotational	228	238	465
Mile 24.9 – Sanctuary Hill Roadwa	799	10	24.90	24.96	R	Landslide, frost-heave, across/in road	322	137	459
Mile 45.2a Rockfall	870	10	45.17	45.21	R	Rockfall, wedge	221	233	454
Mile 45.3a rockfall	933	10	45.27	45.32	R	Rockfall, wedge	214	239	453
Mile 25.2 – Sanctuary Hill	801	10	25.20	25.37	R	Landslide, frost-heave, across/in road	328	116	444
Mile 68.2b Debris Flow 2012	972	10	68.23	68.24	R	Landslide, debris flow, onto road	305	136	440
Mile 67.3 – Eagle's Nest Rockfall	968	10	67.31	67.37	R	Rockfall, indeterminate	254	186	440
Mile 68.2c Rockfall	911	10	68.24	68.26	R	Rockfall, differential erosion from pyroclastic breccia	238	194	432
Mile 53.4 – Toklat Tent	966	912	0.16	0.22	L	Landslide, debris flow potentially across road	280	145	425
Mile 68.1b Rockfall	909	10	68.12	68.18	R	Rockfall, differential erosion from pyroclastic breccia	238	174	412
Mile 67.4b Rockfall	969	10	67.40	67.48	R	Rockfall, indeterminate (some distinct wedge and topple)	245	163	408
Mile 44.8 – Bear Cave Slump	955	10	44.81	44.83	L	Landslide, below road, rotational	198	199	398



USMP App

- Apps only include the rating, new slope event, and maintenance forms (same input categories as online version)
- Final Android and iOS apps are available at the Google Play Store and on iTunes
- Collect data and photos in offline mode and can be uploaded one at a time to the website when back online

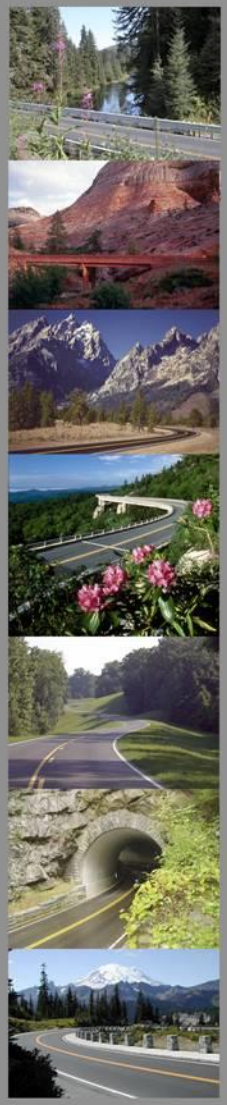


USMP Manual and Guidance Documents

UNSTABLE SLOPE MANAGEMENT PROGRAM FOR FEDERAL LAND MANAGEMENT AGENCIES

Publication No. FHWA-FLH-18-00x Draft: December 2017

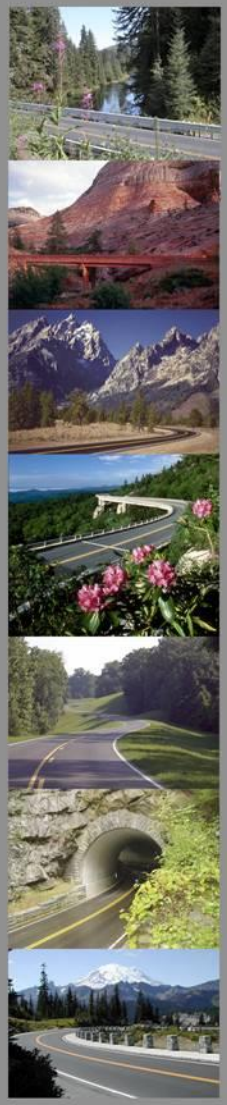
U.S. Department of Transportation
Federal Highway Administration



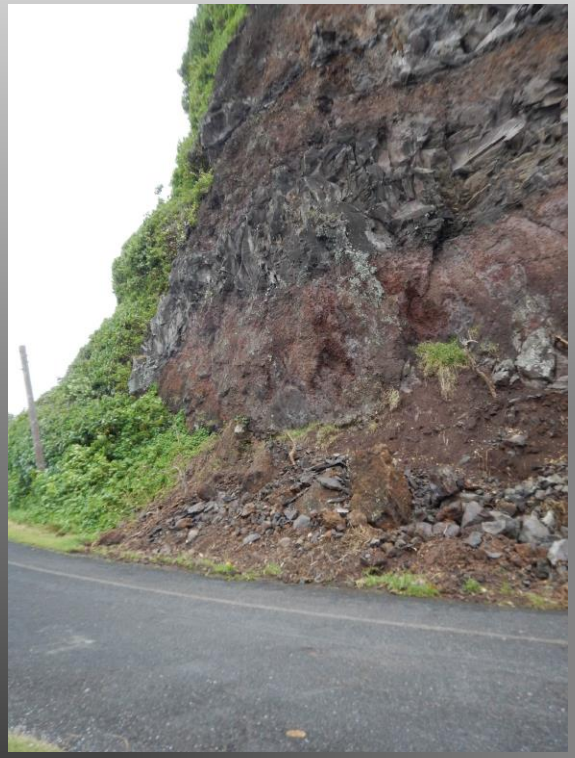
Other USMP Products

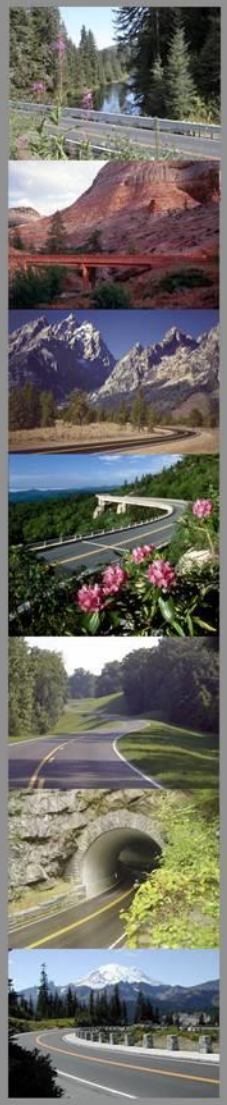
- 6-minute video on “Why the USMP for FLMAs is Beneficial”
- 40-minute video that shows “How to Rate an Unstable Slope”
- Training presentations for the three, two-day workshops held in 2017

https://westerntransportationinstitute.org/research_projects/development-of-unstable-slope-management-program-for-federal-land-management-agencies-phase-2/



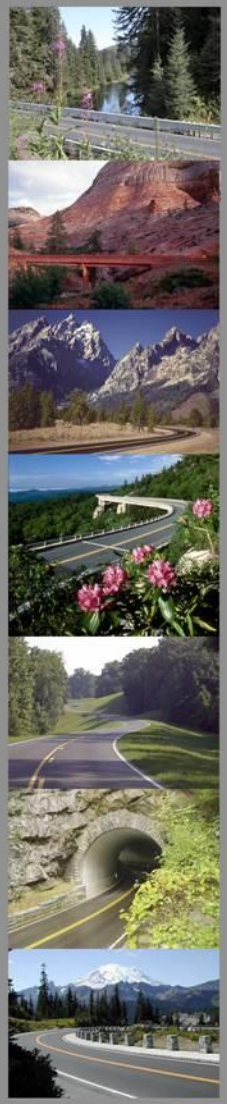
USMP Questions?





U.S. Department of Transportation
Federal Highway Administration
Federal Lands Highway

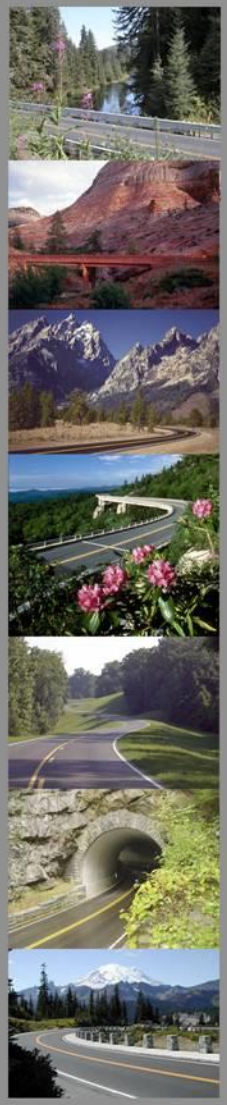
Engineering America's Scenic Highways



ROCKFALL MITIGATION

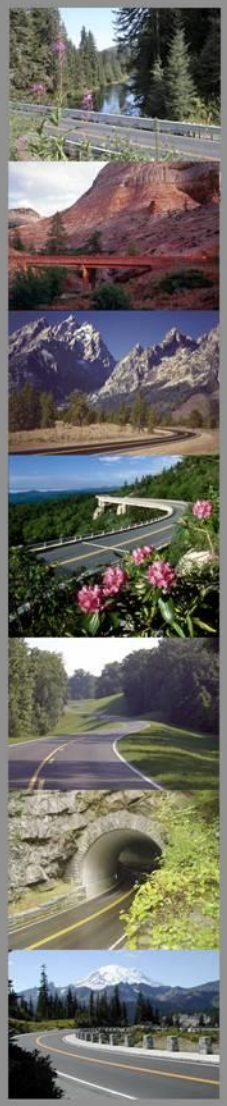
U.S. Department of Transportation
Federal Highway Administration
Federal Lands Highway

Engineering America's Scenic Highways



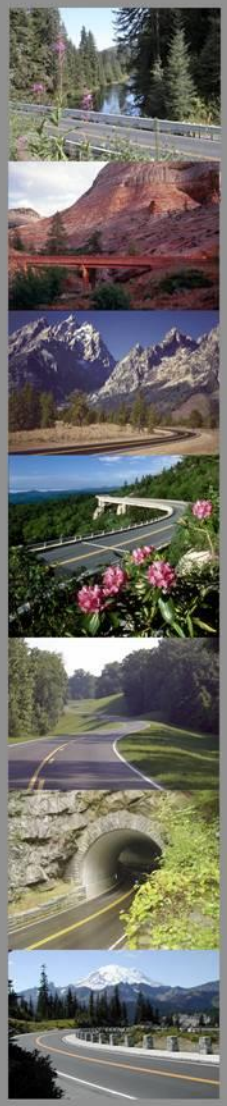
OUTLINE

- Assessment
- Design Tools
- Decision Tools
- Rock and Soil Failure Modes
- Rockfall Mitigation Methods
- Mitigation Projects



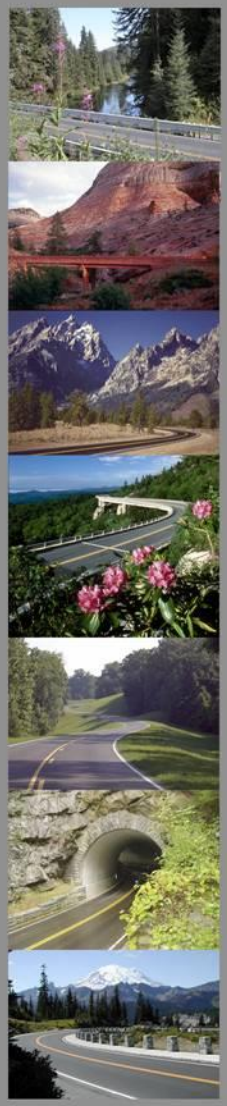
Rockfall Assessment

1. Scoping
2. Field Investigations
3. Stability Analyses
4. Rockfall Mitigation
5. Construction Requirements



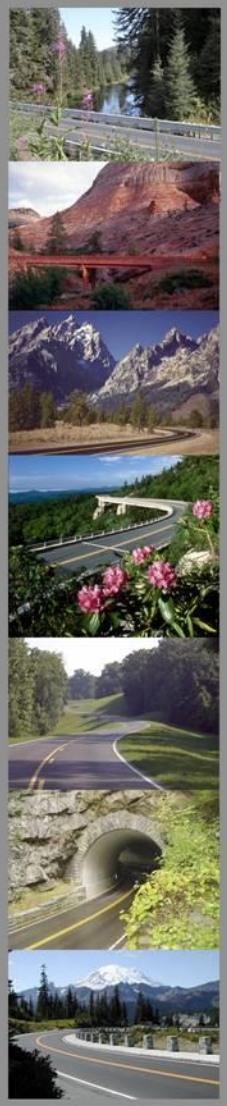
Design tools

- Richie Ditch Criteria- 1960's
- ODOT- Rockfall Area Catchment Design (RCAD) 2001
- Colorado Rockfall Simulation Program (CRSP)
- RocScience Software
  - RocPlane, Dips, Slide, Swedge



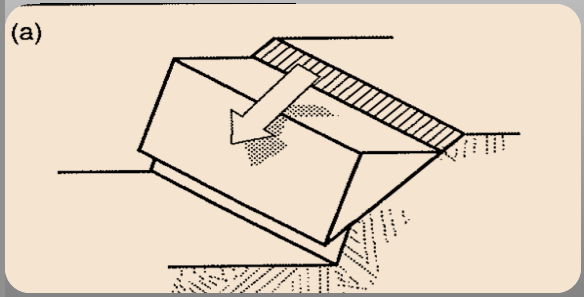
Decision Tools

- Where should you use your funds?
- Rating Systems
  - Quantitative & comparable data to manage slopes
    - Rockfall Hazard Rating System (RHRS)
    - Colorado Rockfall Hazard Rating System (CRHRS)
    - **Unstable Slope Management System (USMP)**

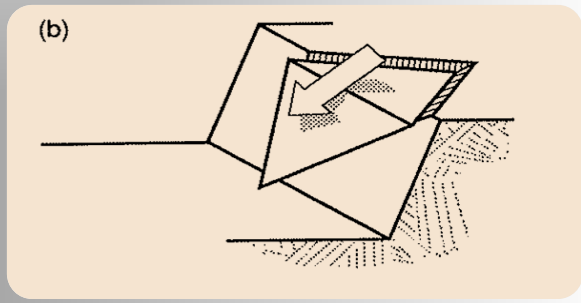


Failure Modes-ROCK

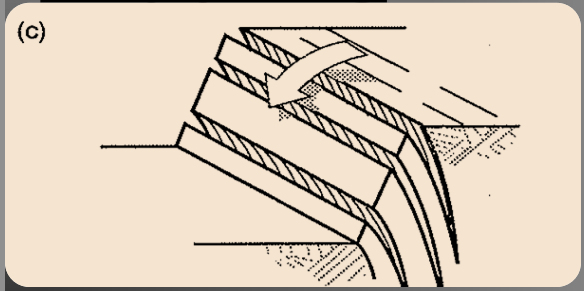
Planar



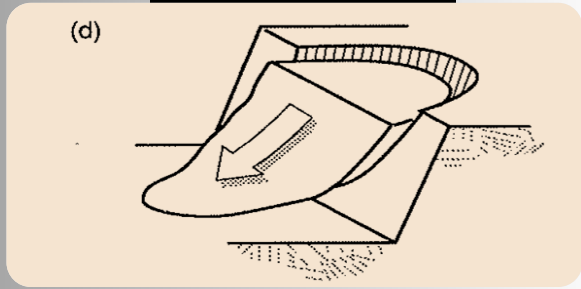
Wedge

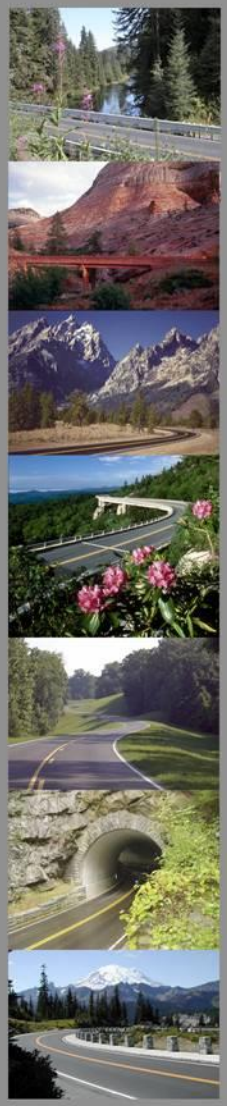


Toppling



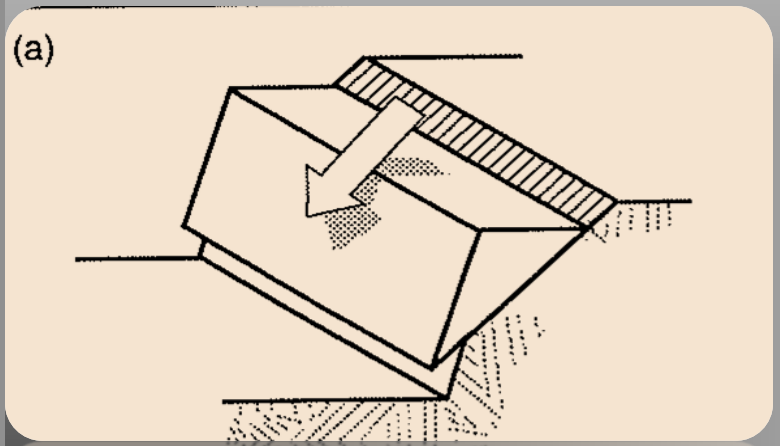
Circular

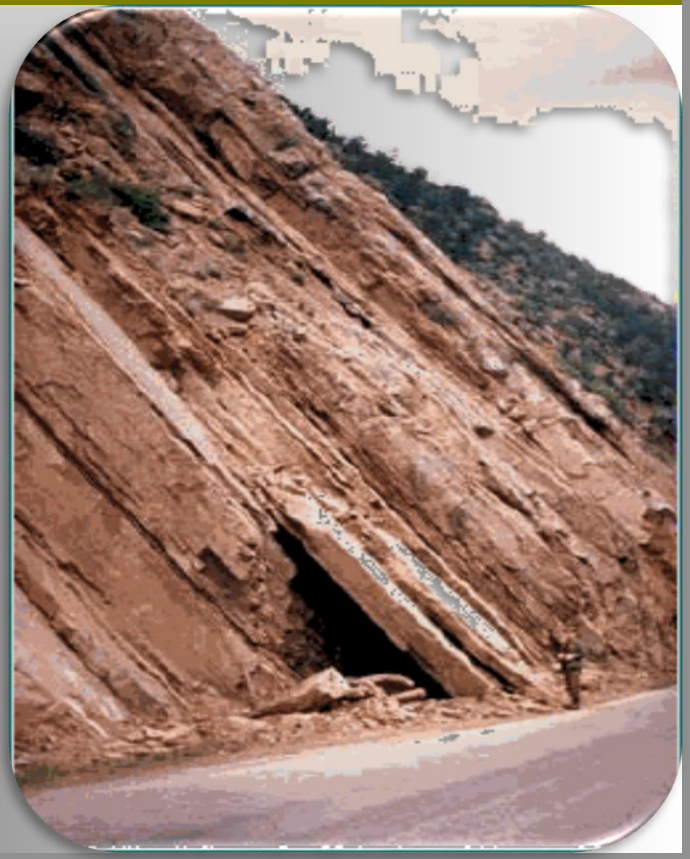


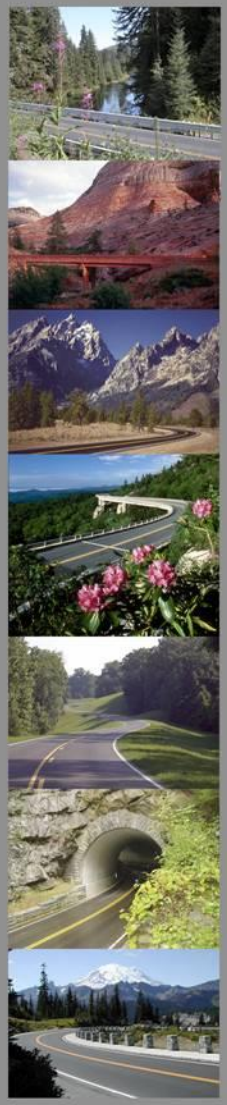


Planar Failure

Discontinuity daylights out of slope face

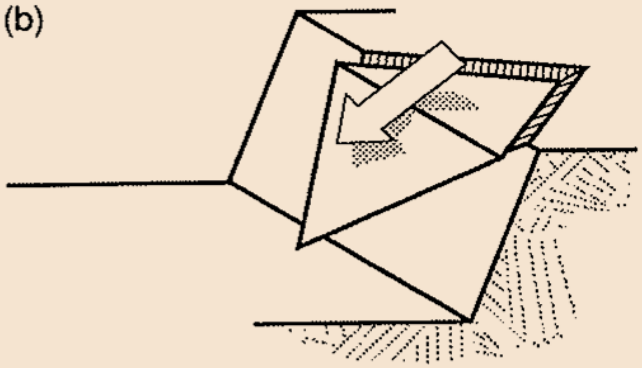


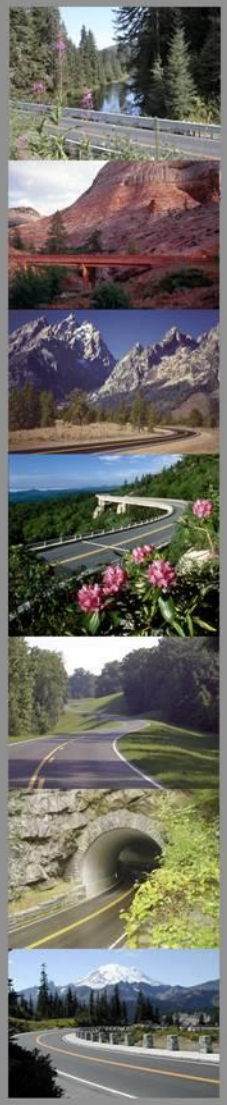




Wedge Failure

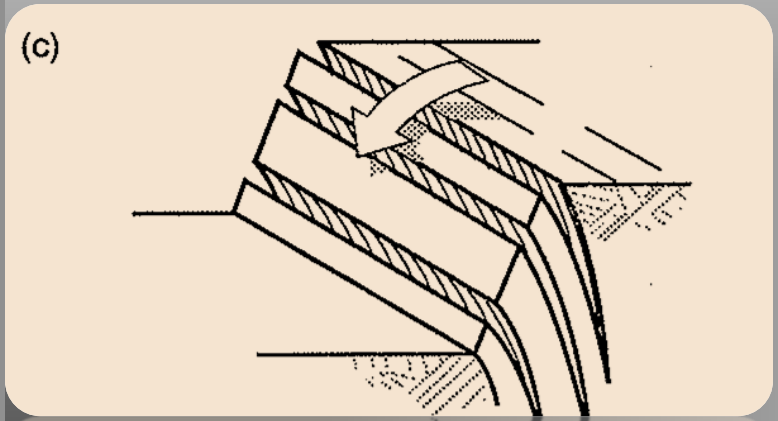
Two intersecting discontinuities with line of intersection daylighting out of the slope

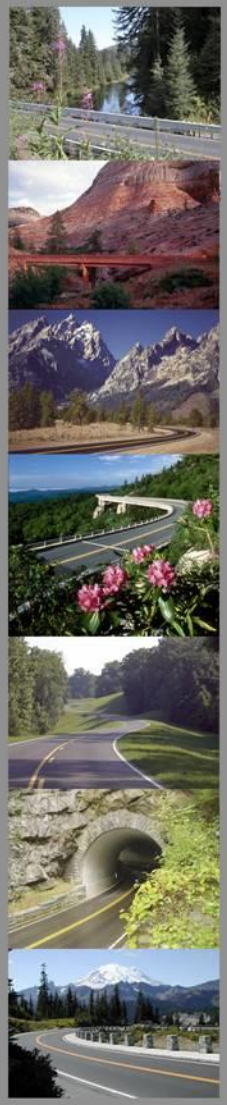




Toppling Failure

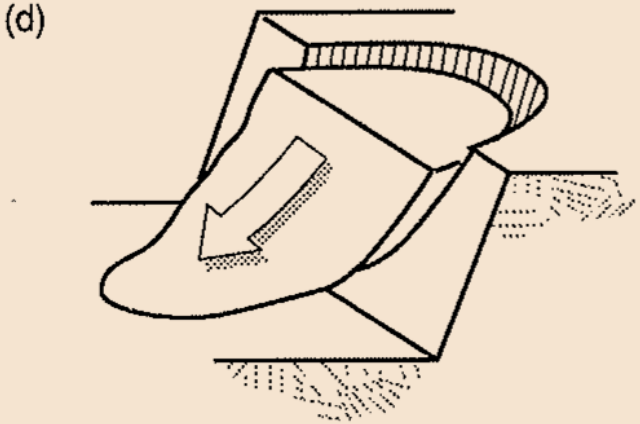
Discontinuity dip steeply into the slope

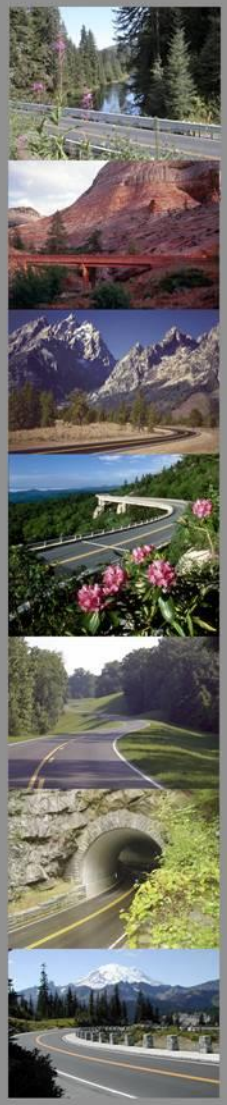




Circular Failure

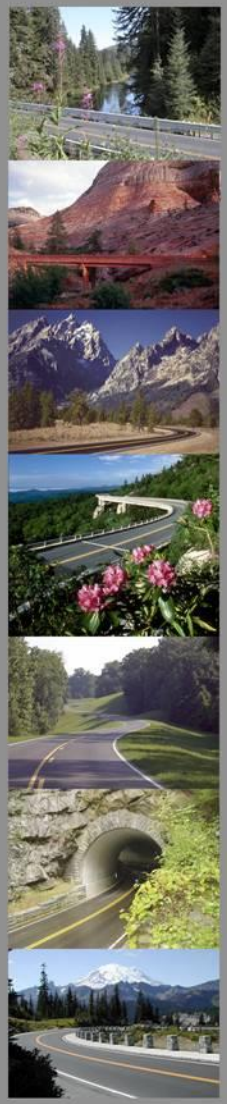
Rock in soil matrix or heavily fractured rock with no defined structural pattern



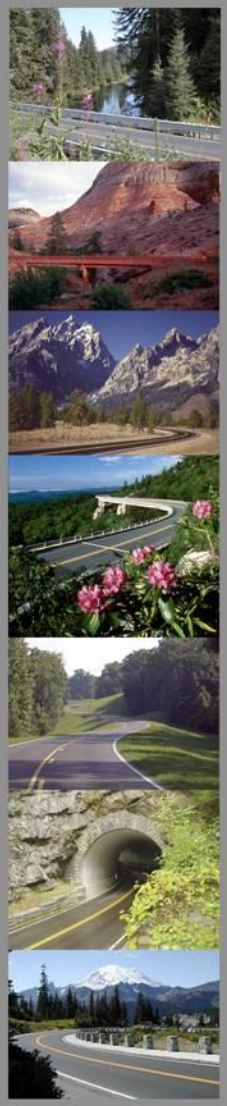


Failure Mode- Colluvial: Rock in Soil

- Where erosion of soil exposes and undermines rocks contained in a slope creates rockfall events.
- Often initiated by excavating the slope at an angle greater than the internal friction angle of the mass.

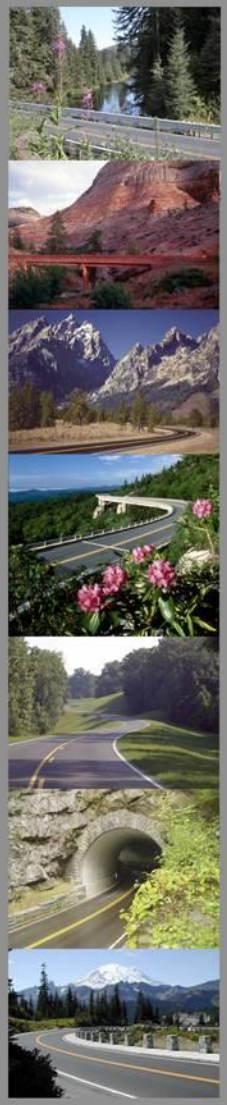


Colluvial: Rock in Soil



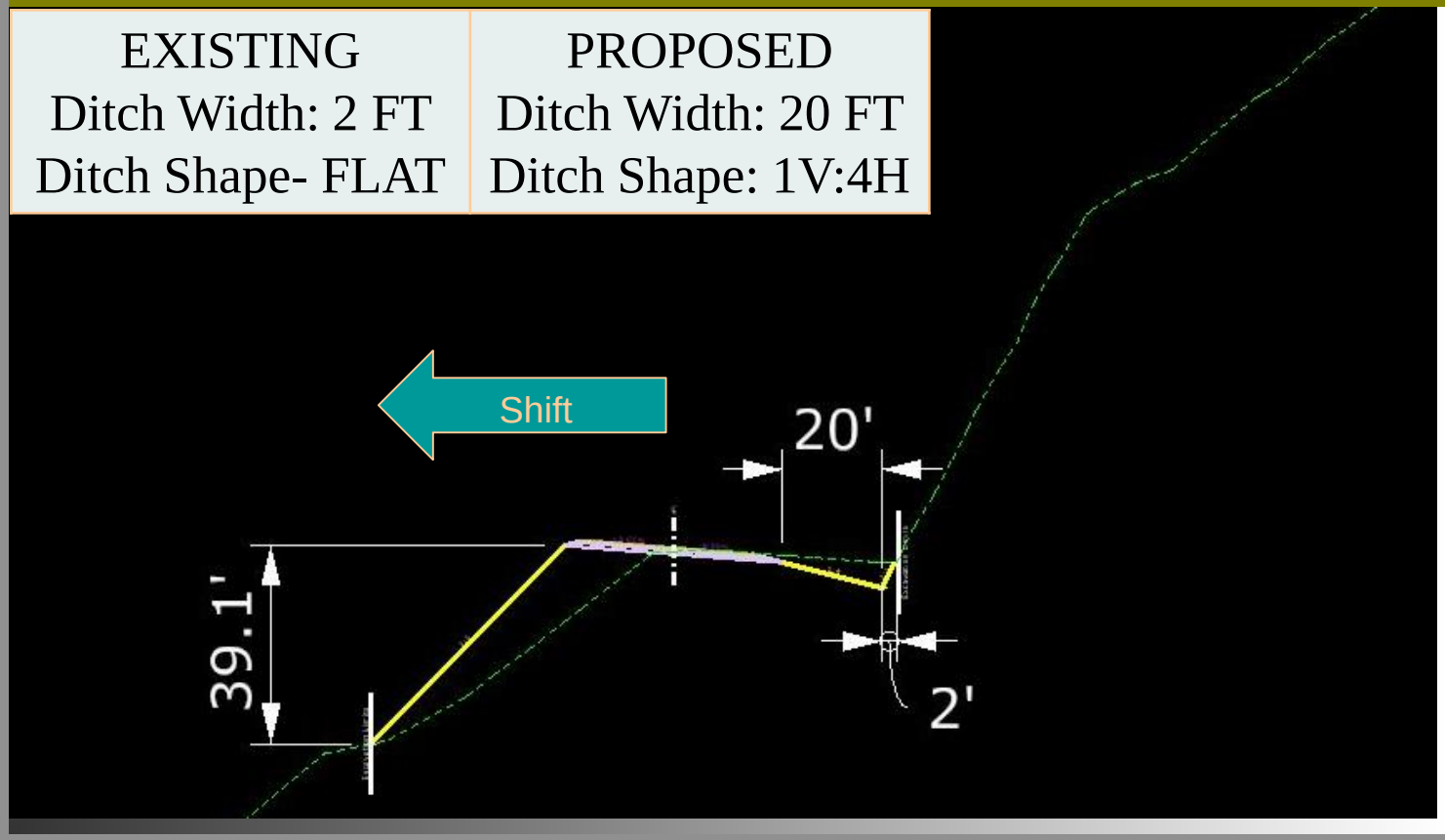
Rockfall Mitigation Alternatives

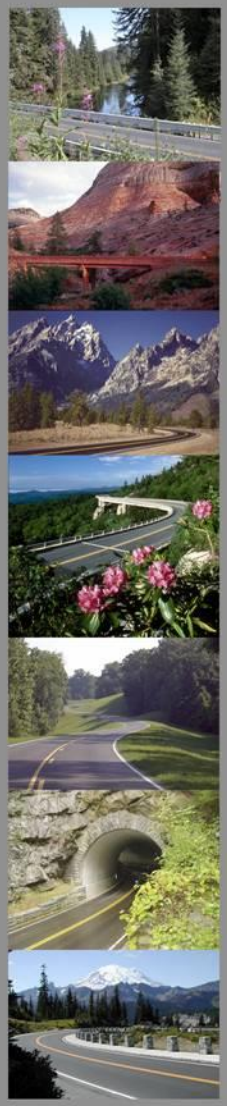
- Realignment
  - Avoid Area
  - Rockfall Ditch
- Condition improvement
  - Scaling
  - Establish Vegetation/ Stop erosion
- Stabilization Measures
  - Draped/ Pinned Mesh
  - Rock Bolting



Rockfall Mitigation- Shift & Widen Ditch

EXISTING	PROPOSED
Ditch Width: 2 FT	Ditch Width: 20 FT
Ditch Shape- FLAT	Ditch Shape: 1V:4H



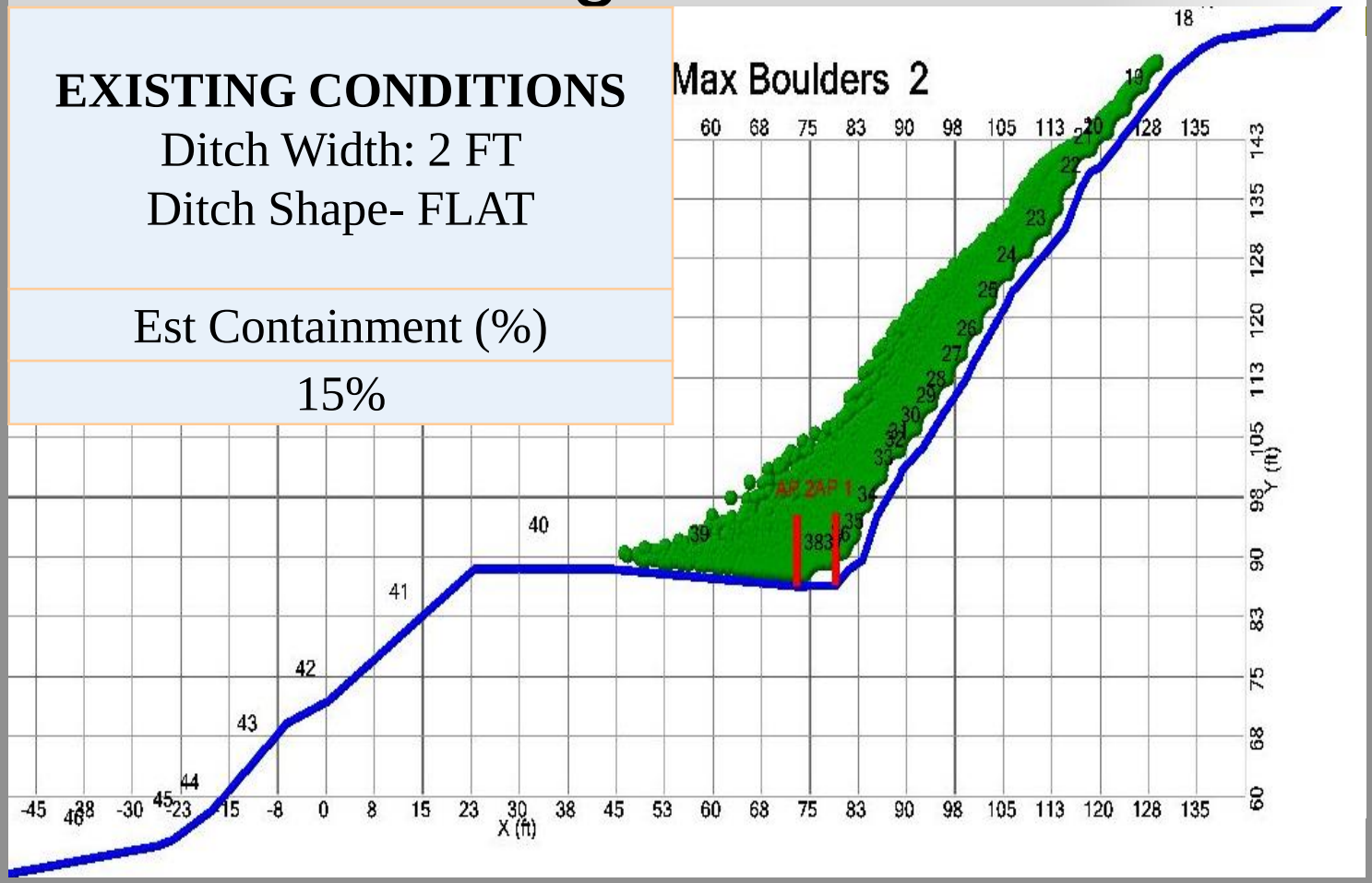


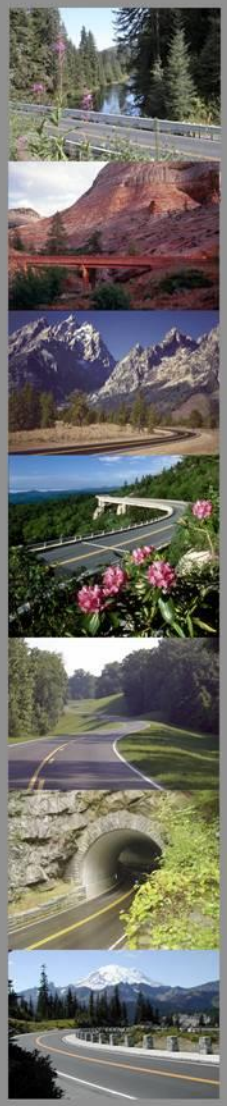
% Rockfall Retained? Existing Conditions

EXISTING CONDITIONS
Ditch Width: 2 FT
Ditch Shape- FLAT

Est Containment (%)

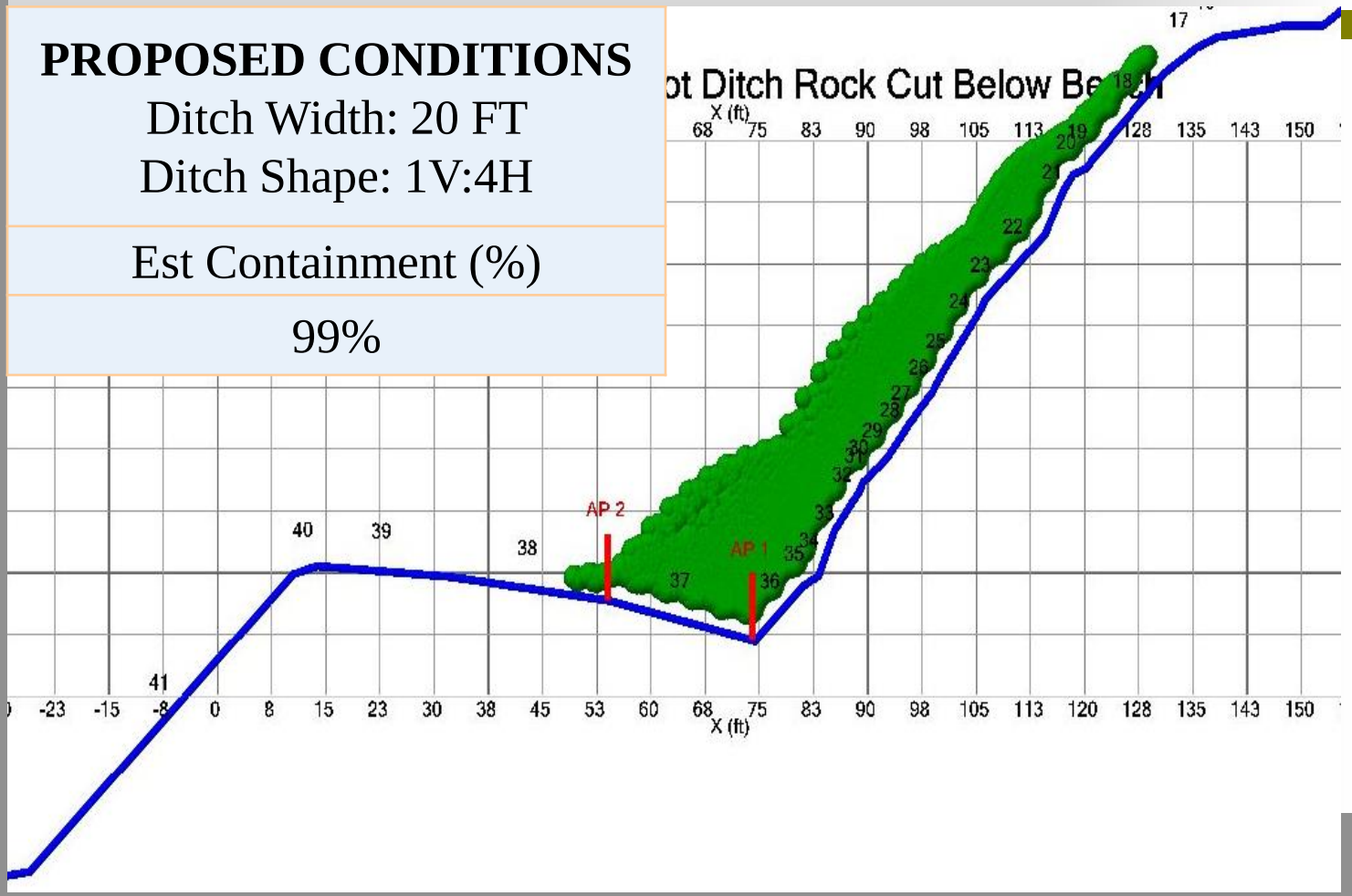
15%

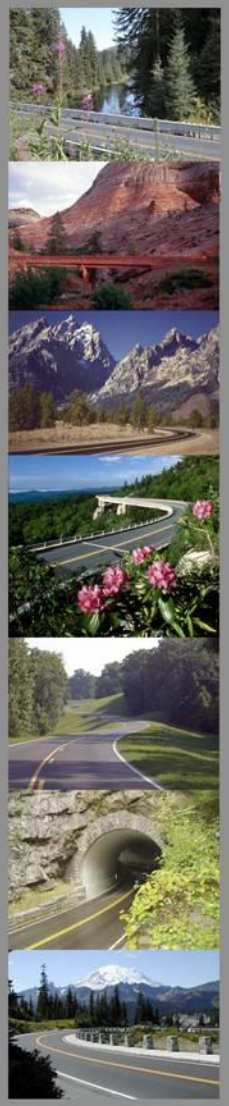




% Rockfall Retained? Proposed Conditions

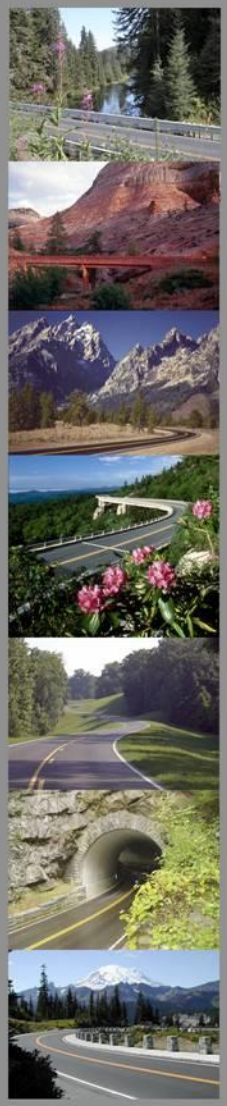
PROPOSED CONDITIONS
Ditch Width: 20 FT
Ditch Shape: 1V:4H
Est Containment (%)
99%





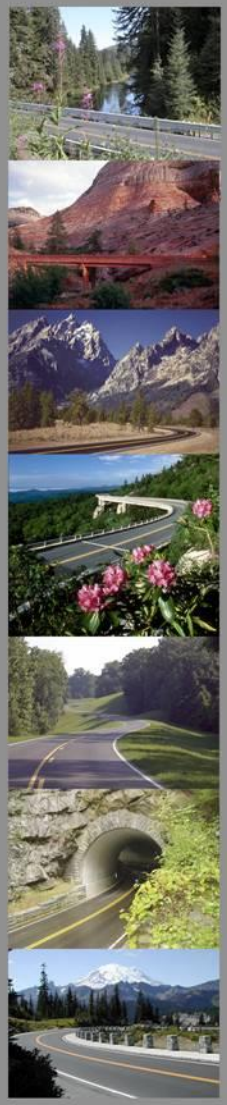
Overall % Improvement

EXISTING CONDITIONS Ditch Width: 2 FT Ditch Shape- FLAT	PROPOSED CONDITIONS **Ditch Width: 20 FT** **Ditch Shape: 1V:4H**	**% Improvement**
Est Containment (%)	Est Containment (%)	
15%	99%	**84%**



Rockfall Mitigation Alternatives

- Realignment
  - Avoid Area
  - Rockfall Ditch
- Condition improvement
  - Scaling
  - Establish Vegetation/ Stop erosion
- Stabilization Measures
  - Draped/ Pinned Mesh
  - Rock Bolting



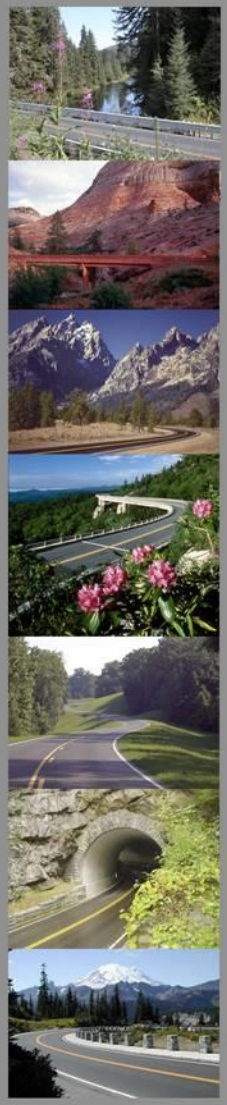
Scaling

Avg ~ 2-5 year cycles

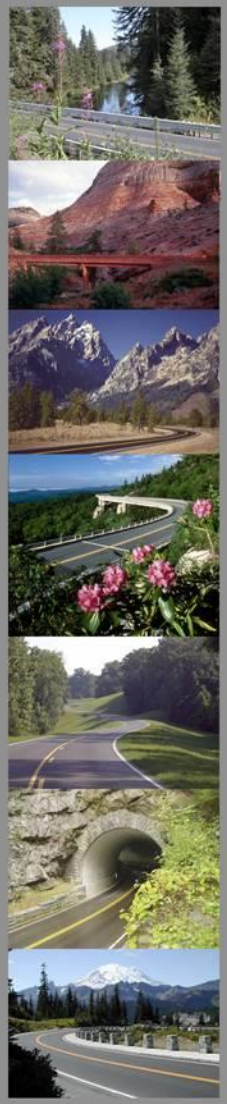
Scaling - Removal of loose rock from slope by means of hand tools and/or mechanical equipment.

Blast Scaling – Uses blasting or chemical expanders.

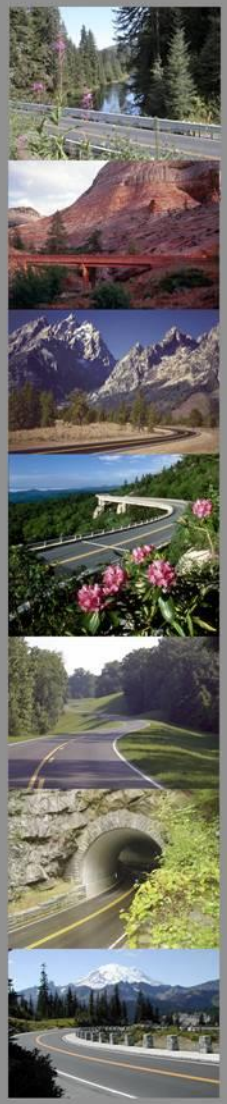
Trim Blasting - Removal of overhanging faces or protruding knobs that may act as launch features on a slope.



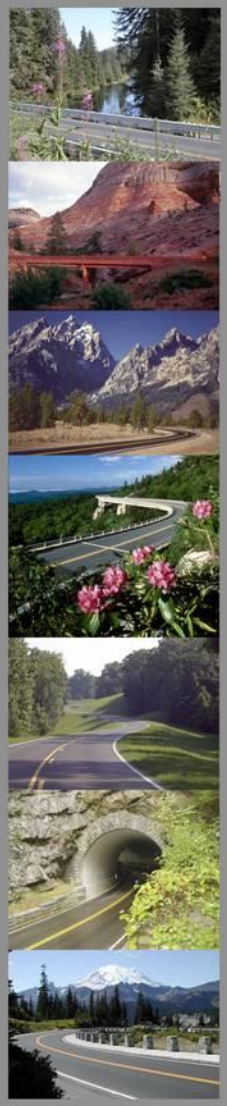
Hand Scaling



Machine Scaling

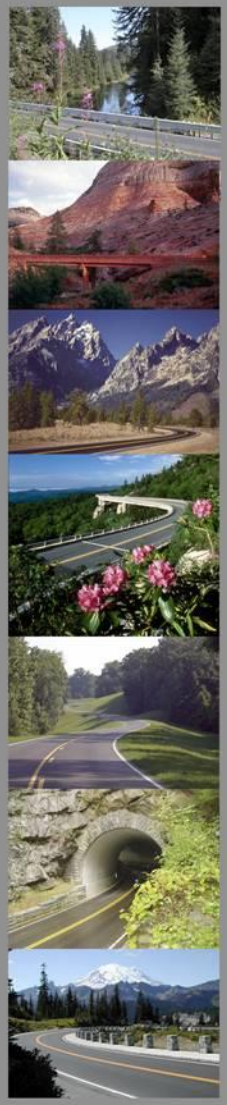


Trim Blasting



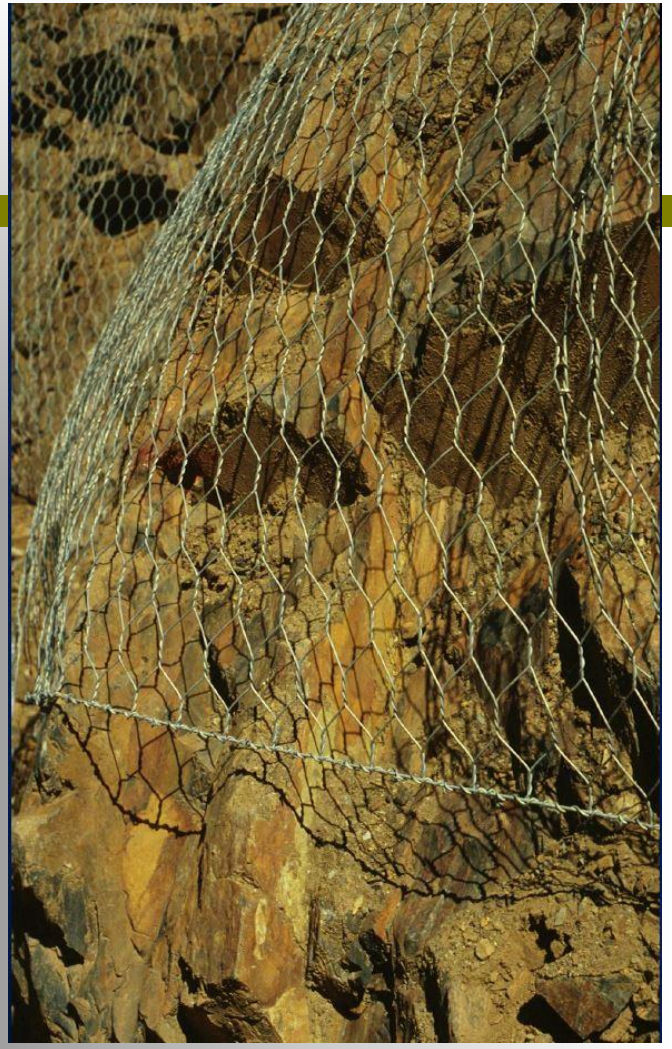
Rockfall Mitigation Alternatives

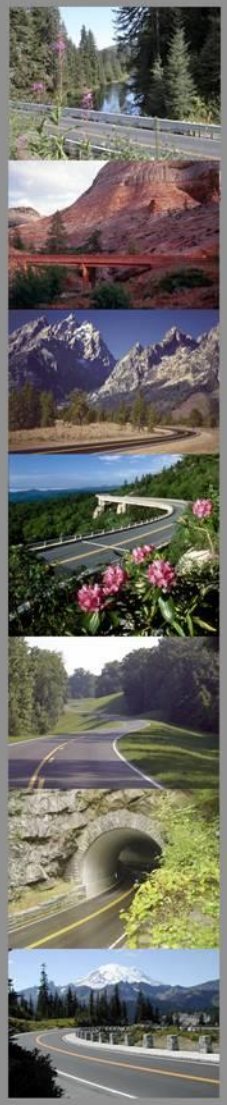
- Realignment
  - Avoid Area
  - Rockfall Ditch
- Condition improvement
  - Scaling
  - Establish Vegetation/ Stop erosion
- Stabilization Measures
  - Draped/ Pinned Mesh
  - Rock Bolting



Draped Mesh

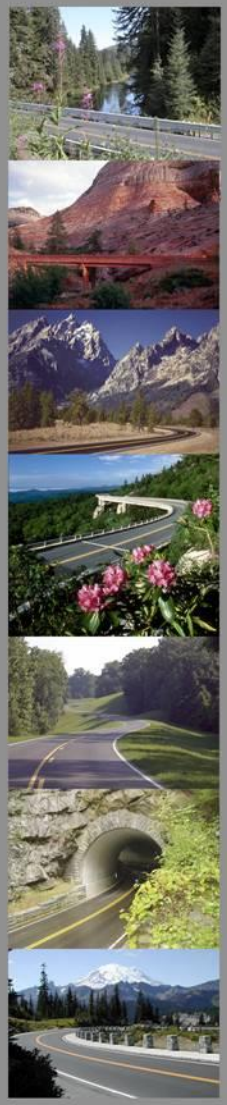
- Hexagonal wire mesh, cable nets, or high-tensile-strength steel mesh.
- Placed on a slope to slow erosion, control the descent of falling rocks, and restrict them to the catchment area





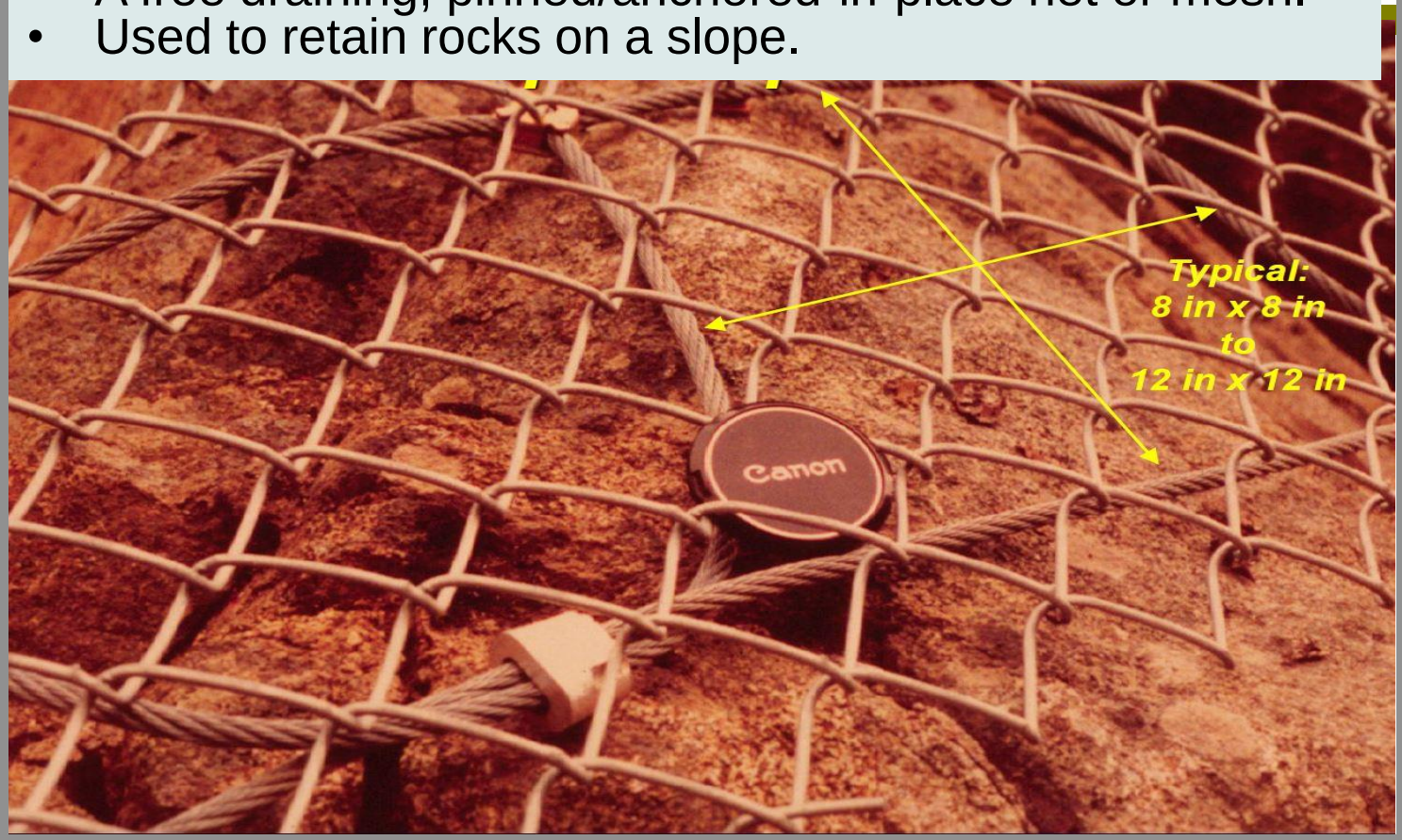
Draped Mesh-Limitations

- Requires a debris collection ditch area.
- Must consider debris and snow loads on anchors.
- Typically limited to <4 ft rock.

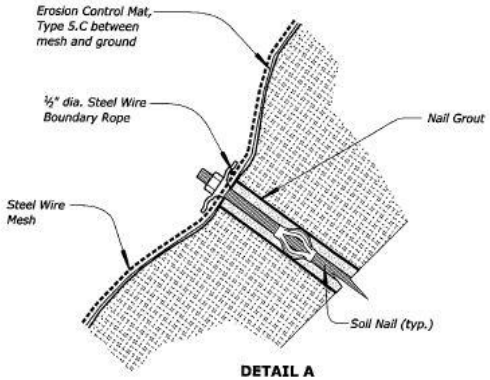


Anchored wire mesh/cable nets

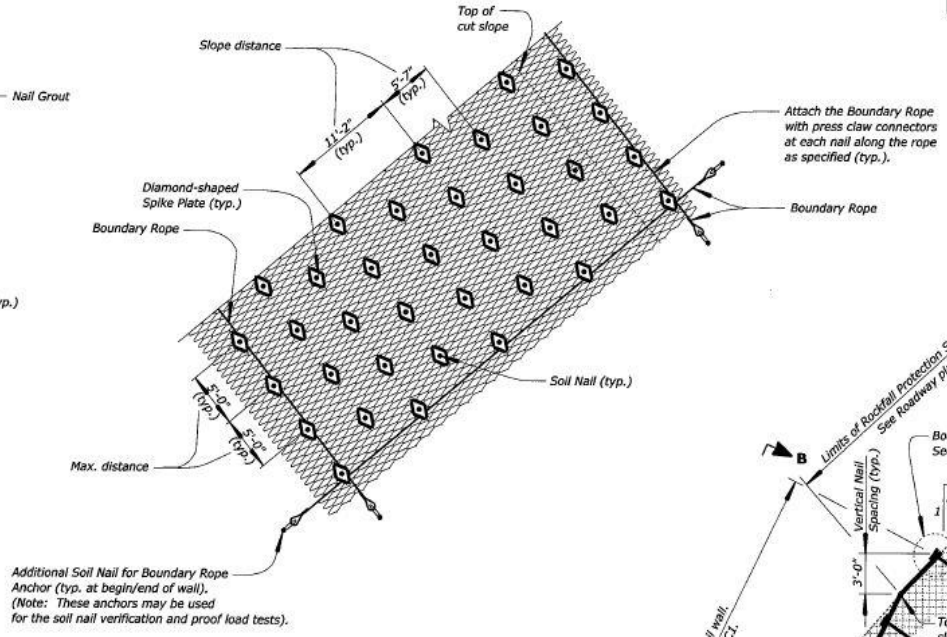
- A free draining, pinned/anchored-in-place net or mesh.
- Used to retain rocks on a slope.



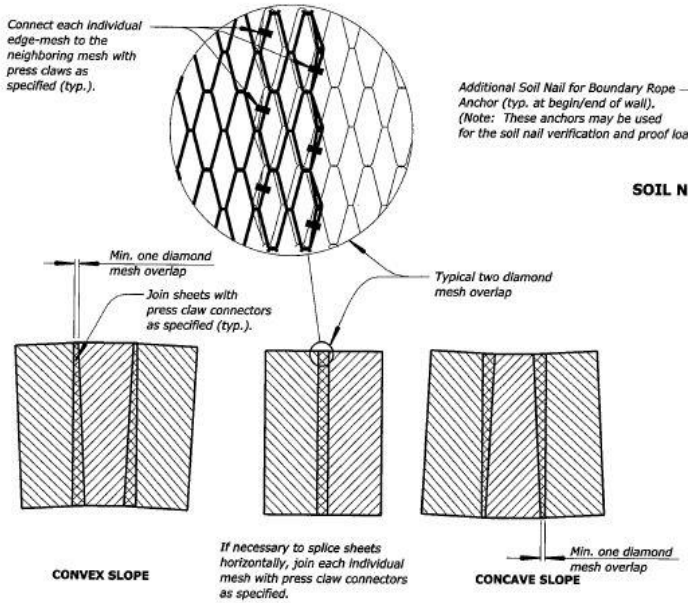
REGION	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
5	CA	PFH 112-1(1) S. FORK SMITH RIVER RD.	S78	S78



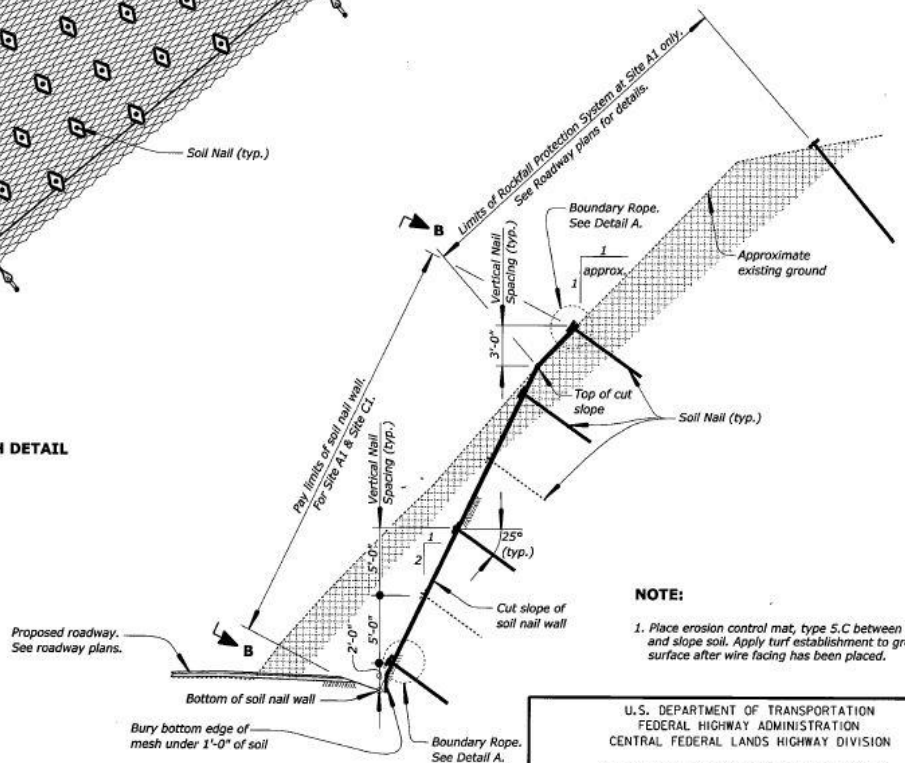
DETAIL A



SOIL NAIL WALL MESH DETAIL (VIEW B-B)



MESH SHEET SPLICING DETAILS



SOIL NAIL WALL WITH ROCK FALL PROTECTION TYPICAL SECTION

NOTE:

1. Place erosion control mat, type S.C between mesh and slope soil. Apply turf establishment to ground surface after wire facing has been placed.

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
CENTRAL FEDERAL LANDS HIGHWAY DIVISION

SOUTH FORK SMITH RIVER ROAD

SIX RIVERS NATIONAL FOREST
DEL NORTE COUNTY, CALIFORNIA

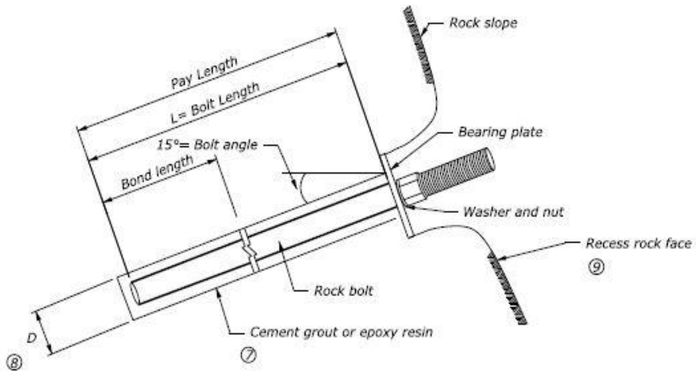
WIRE MESH FACING DETAILS

NO.	DATE	BY	REVISIONS	NO.	DATE	BY	REVISIONS

DESIGNED BY	DRAWN BY	CHECKED BY	SCALE	PROJECT TEAM LEADER	BRIDGE DRAWING	DATE	DRAWING NO.
V. JACOBSON	RICKY WIPF	K. EIKERMANN	NONE	SAMIR SIDHOM	7 of 7	JULY 2008	RG2822-G

STATE	PROJECT	SHEET NUMBER
CA	ERFO YOSE 13(6)14(6)16(8) Repairs at Yosemite NP	G2

NPS PMIS NO.: 241047



TYPICAL ROCK BOLT

NOTE:

1. Use threaded, #8 - grade 75, epoxy coated reinforcement bars. Install bolts according to Table 1 - Minimum Required Active Support Parameters.
2. Locations, lengths, hole diameter and quantities of rock bolts to be determined during construction by the CO.
3. Use 6 inch x 6 inch x ½ inch thick mild steel bearing plates.
4. Install rock bolts to a length of 15 feet at the location designated in the plans or as directed by the CO. Locations and bolt length may be adjusted during construction.
5. Use end hardware that is epoxy coated in the field in a color approved by the CO.
6. Install bearing plates in direct contact with the rock slope or as directed by the CO.

(7) Use cement grout or epoxy resin for the installation of the rock dowels. Install centralizers according to Subsection 260.05(d)

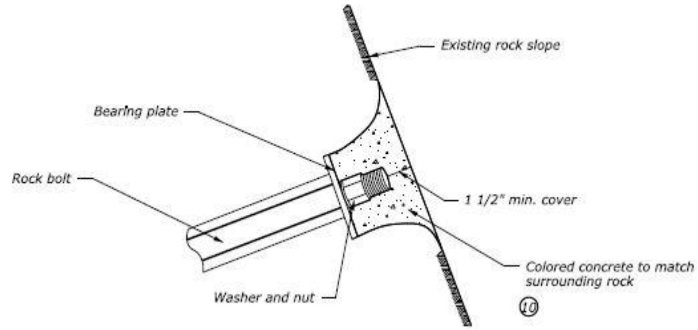
(8) Submit proposed bore diameter.

(9) Recess rock face so that all end hardware can be concealed with colored grout

(10) Submit color sample for approval prior to final application. Two colors likely necessary. Conform to specifications outlined in Section 601.

TABLE 1

Minimum Required Active Support Parameters			
Design Element	UNIT	El Portal MP 0.6	Wawona MP 8.0
Downward Bolt Angle	DEGREES	15	15
Minimum Bolt Length	LNFT	15	15
Minimum Bond Length	LNFT	8.5	8
Minimum Lock Off Load	KIPS	10	10



TYPICAL ROCK BOLT FINISHING DETAIL

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
CENTRAL FEDERAL LANDS HIGHWAY DIVISION

U.S. CUSTOMARY SPECIAL

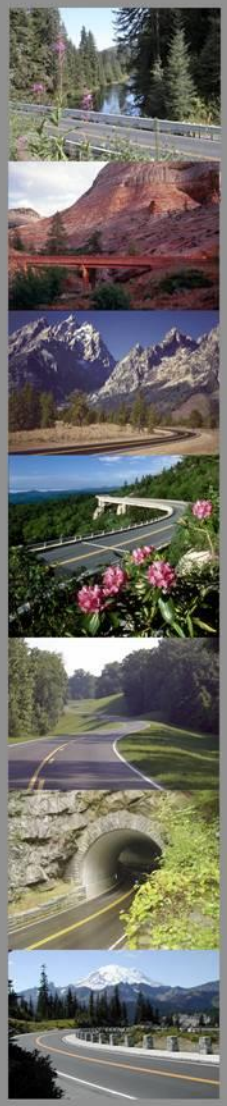
ROCK BOLTS

NO SCALE

SPECIAL 260-A

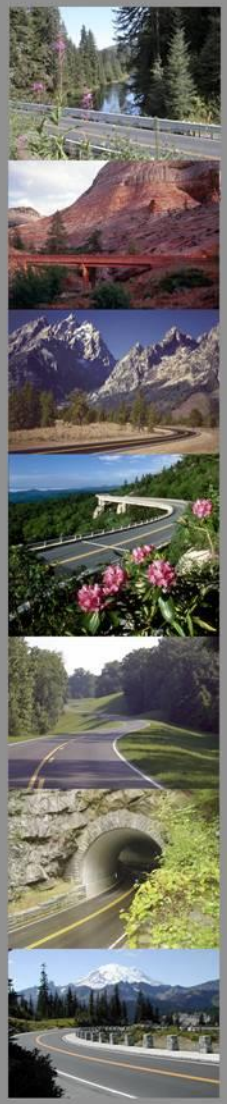
4/21/2017 8:32:42 AM N:\CA\yose13(6)14(6)16(8)\Roadway\CADD_Sheets\G-250\SP260-A.dgn _User: Michael.Daigler_

Federal Lands Highway
Engineering America's Scenic Highways

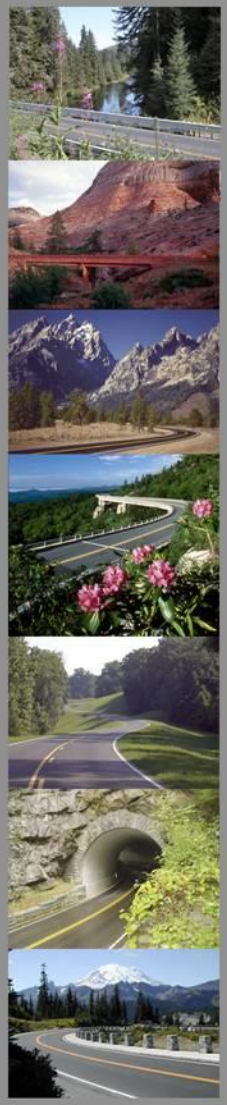


Project- Whitney Portal Road CA

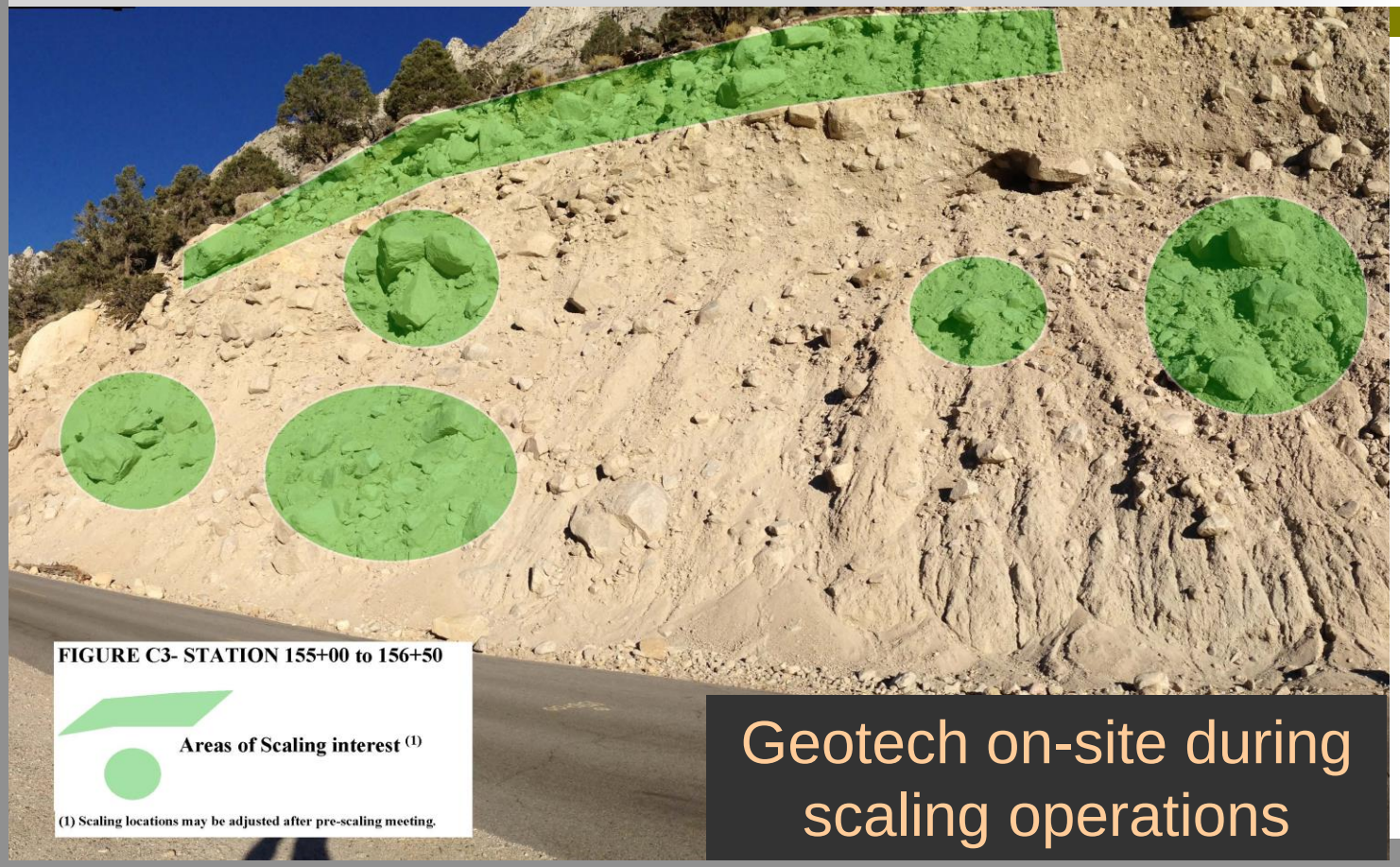
- High rockfall frequency
- Over steepened Colluvial Slopes 150 feet tall
  - Road cuts in the ~1940's
  - Glacial and Ancient Debris Deposits
- Boulders up to 20 feet "Hanging" on the slope.



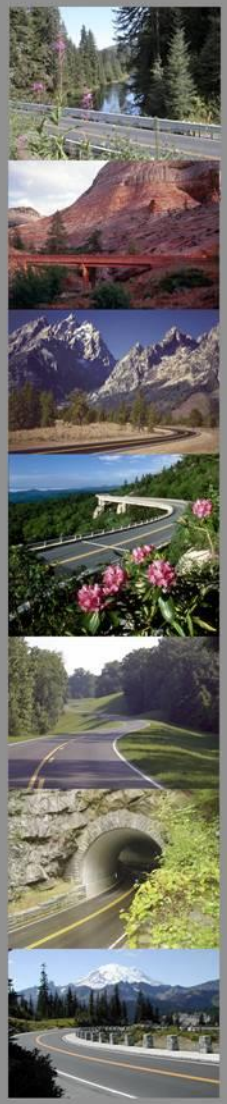
Define Limits



Define Limits



Geotech on-site during scaling operations

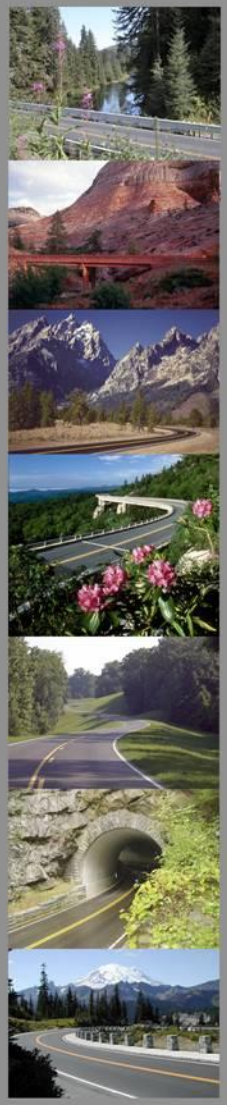


Estimate Quantities

Table 6: Estimated Scaling Effort and Quantity (1)

Station	to	Station	Crew Hours	Estimated Scaling Volume (CUYD) For info only	Anticipated Scaling Effort & Particular Location On Each Slope (2)
132+50	-	133+50	8	40	Heavy scaling at slope brow approximately 40-50 vertical feet on the slope.
136+00	-	136+25	4	20	Heavy scaling at slope brow approximately 20-30 vertical feet on the slope.
155+00	-	156+50	12	60	Light scaling at slope brow approximately 70-90 vertical feet on the slope and intermittent boulders on slope.
156+50	-	158+50			Heavy scaling at slope brow approximately 70-90 vertical feet on the slope and intermittent boulders on slope.
168+00	-	169+00	12	60	Heavy scaling at slope brow approximately 40-50 vertical feet on the slope.
169+00	-	170+00			Light scaling at slope brow approximately 40-50 vertical feet on the slope.
170+00	-	171+50			Heavy scaling at slope brow approximately 40-50 feet vertical feet on the slope and intermittent boulders on slope.
171+50	-	174+00			Light scaling at slope brow approximately 40-50 vertical feet on the slope.

Notes:
(1): Stations, quantities and measurements presented are approximate and may be adjusted during the pre-scaling meeting and/or during scaling operations after mutual agreements between the contractor and the FHWA.
(2): Vertical distance is measured from top of existing pavement on the in-board ditch side and projected onto slope. Slope distance is not presented in the above table but will be greater than vertical distance.

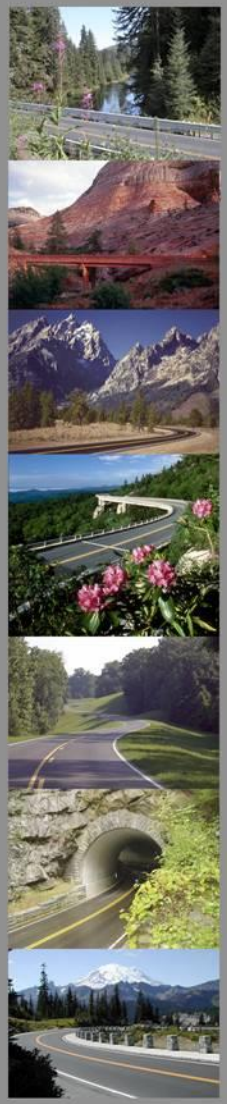


CAUTION: ROCKS IN SLOPE ARE LARGER THAN THEY APPEAR

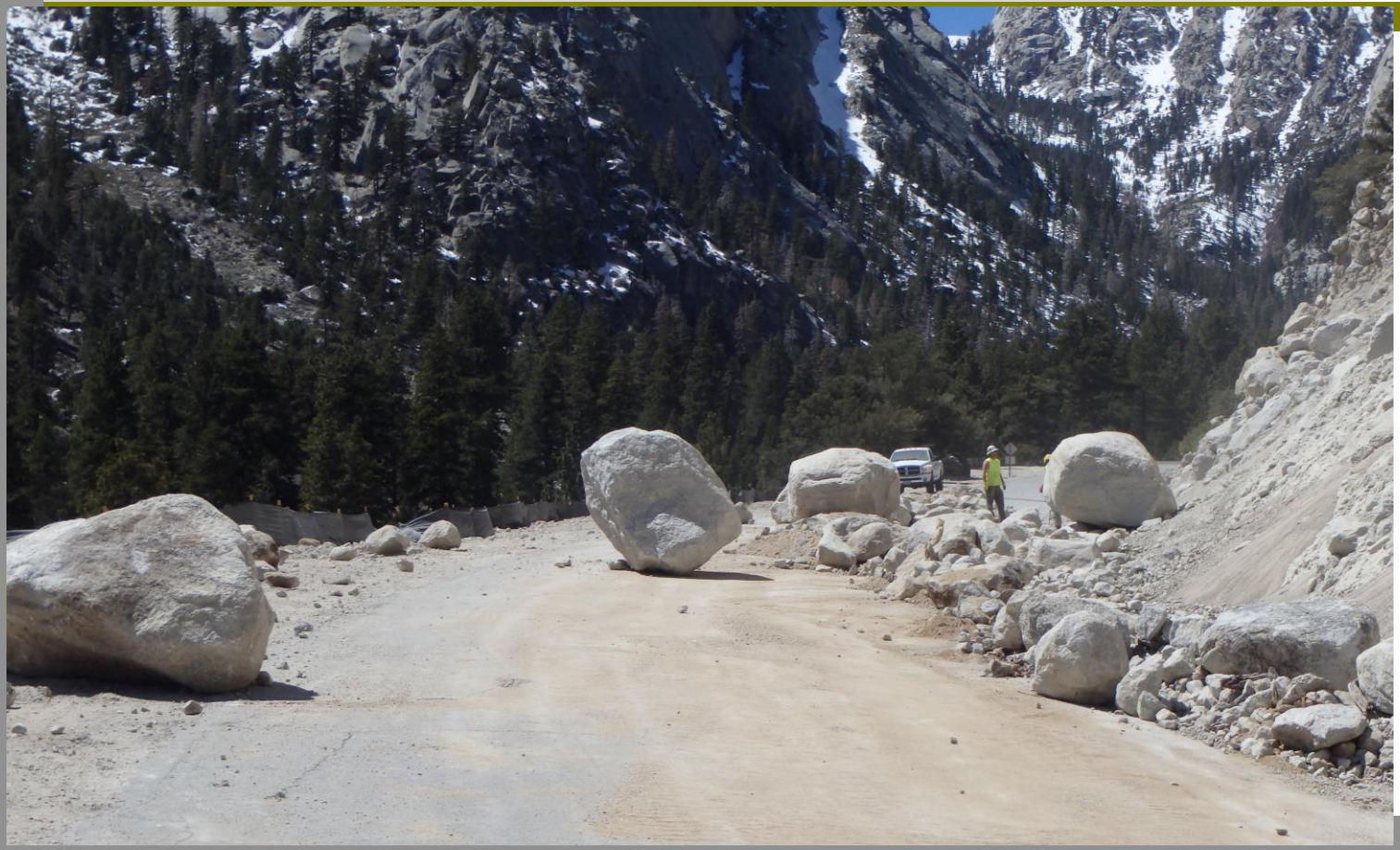
Table 6: Estimated Scaling Effort and Quantity (1)

Station	to	Station	Crew Hours	Estimated Scaling Volume (CUYD) For info only	Anticipated Scaling Effort & Particular Location On Each Slope (2)
132+50	-	133+50	8	40	Heavy scaling at slope brow approximately 40-50 vertical feet on the slope.
136+00	-	136+25	4	20	Heavy scaling at slope brow approximately 20-30 vertical feet on the slope.
155+00	-	156+50	12	200 CUYD	Light scaling at slope brow approximately 70-90 vertical feet on the slope and intermittent boulders on slope.
156+50	-	158+50			Heavy scaling at slope brow approximately 70-90 vertical feet on the slope and intermittent boulders on slope.
168+00	-	169+00	12	60	Heavy scaling at slope brow approximately 40-50 vertical feet on the slope.
169+00	-	170+00			Light scaling at slope brow approximately 40-50 vertical feet on the slope.
170+00	-	171+50			Heavy scaling at slope brow approximately 40-50 feet vertical feet on the slope and intermittent boulders on slope.
171+50	-	174+00			Light scaling at slope brow approximately 40-50 vertical feet on the slope.

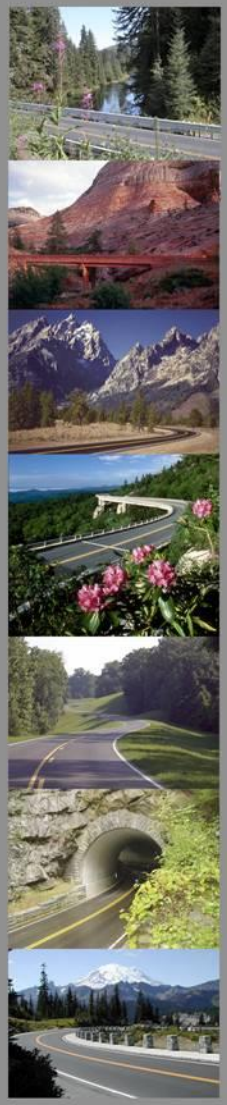
Notes:
(1): Stations, quantities and measurements presented are approximate and may be adjusted during the pre-scaling meeting and/or during scaling operations after mutual agreements between the contractor and the FHWA.
(2): Vertical distance is measured from top of existing pavement on the in-board ditch side and projected onto slope. Slope distance is not presented in the above table but will be greater than vertical distance.



Road Closures

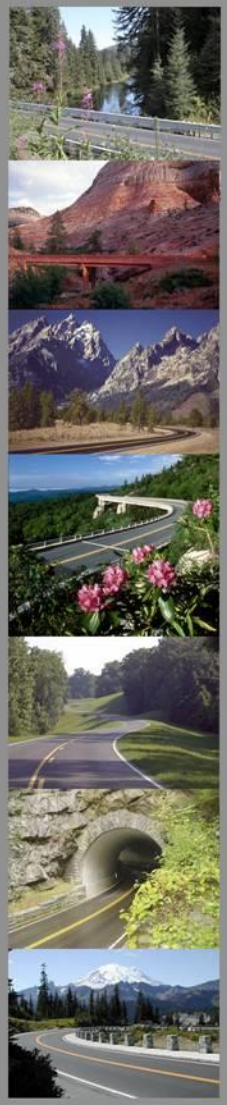


Careful Planning Makes the Job Easier



U.S. Department of Transportation
Federal Highway Administration
Federal Lands Highway

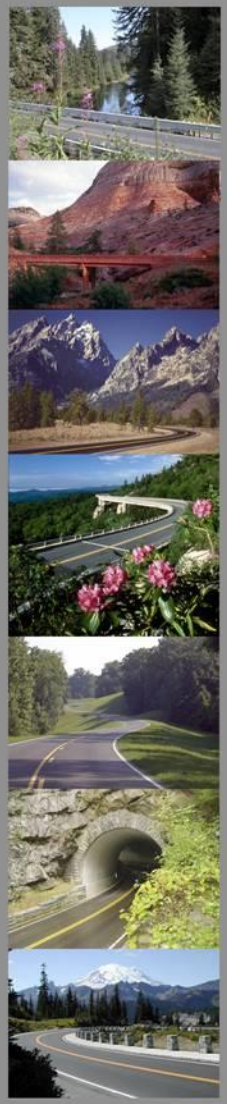
Engineering America's Scenic Highways



El Portal Road Rock Bolting Yosemite National Park, CA

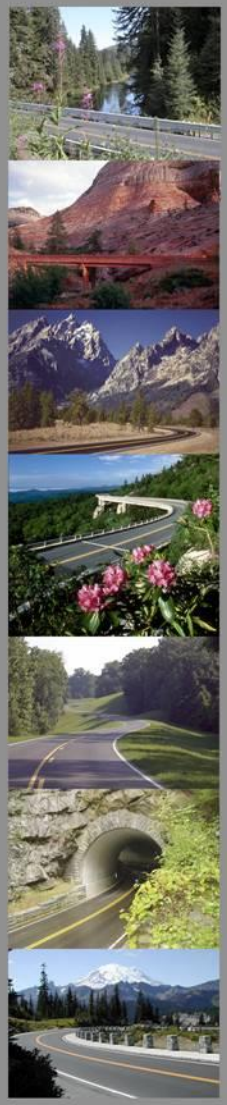
- Planar Failure in rock cut
  - Closed the road for several days
- More potential failures exposed
  - Emergency stabilization was required

Yosemite National Park, CA



Design then Modify During Construction

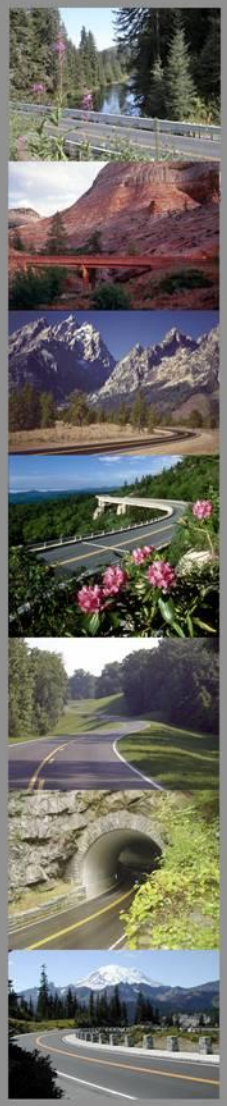
U.S. Department of Transpo
Federal Highway Administrati
Federal Lands Highway



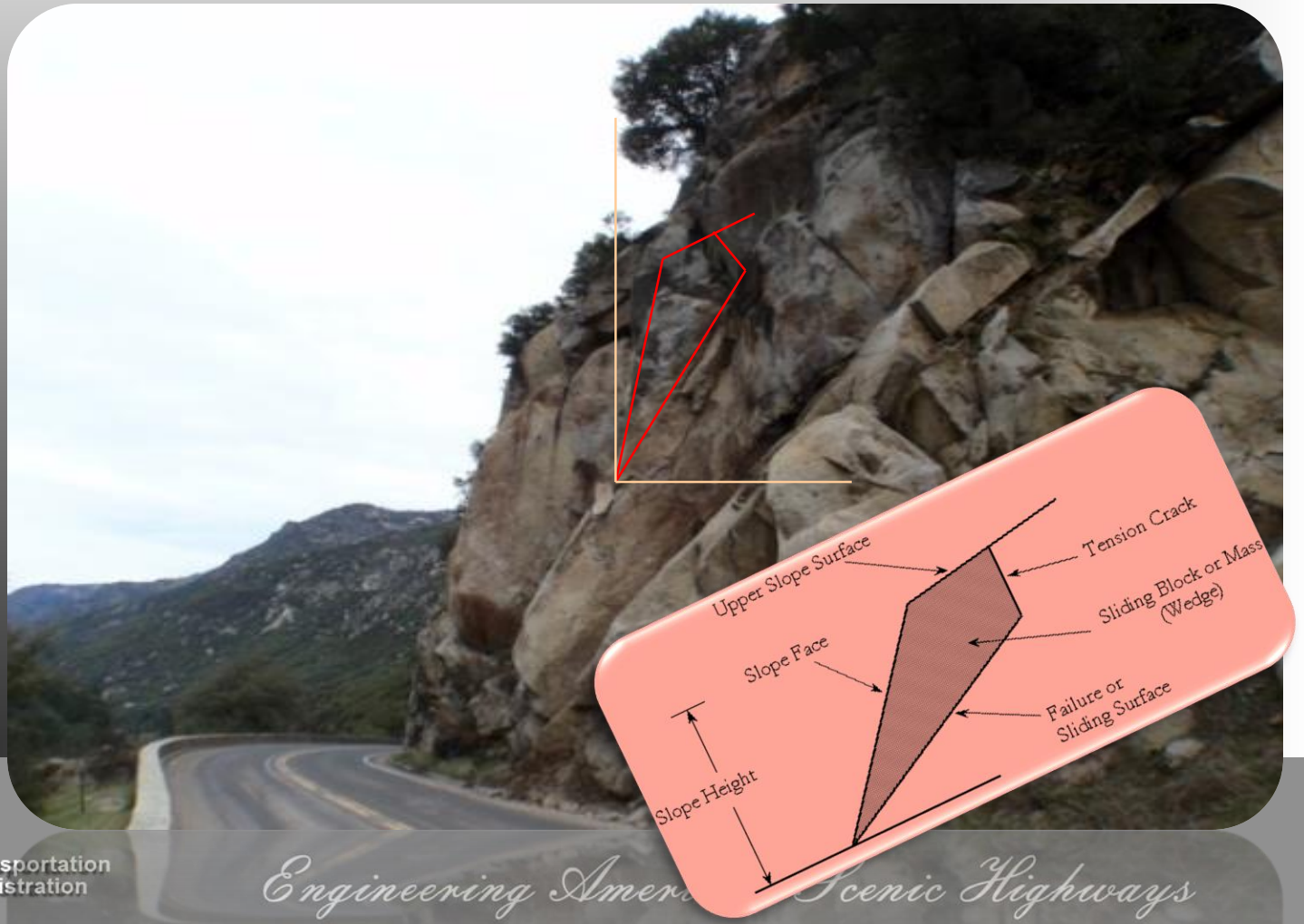
Rock Slope Stability Analysis

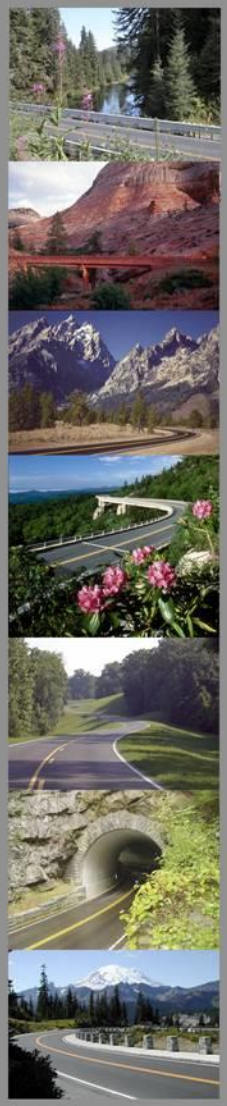
U.S. Department of Transportation
Federal Highway Administration
Federal Lands Highway

Engineering America's Scenic Highways



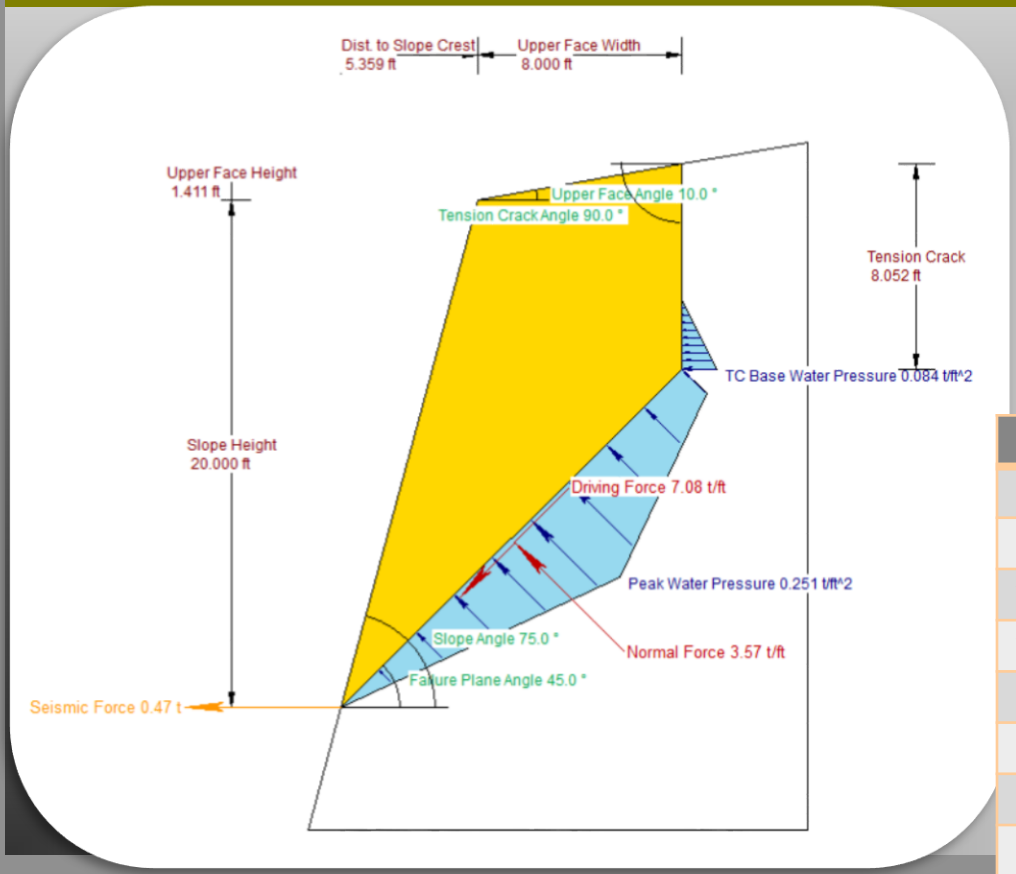
Rock Slope Stability Analysis

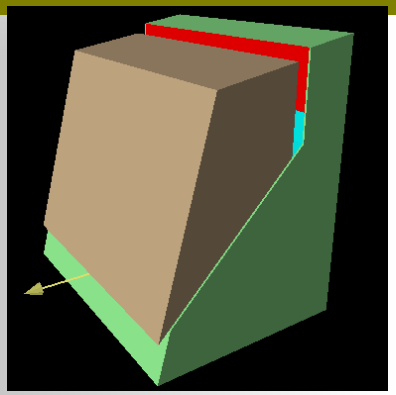




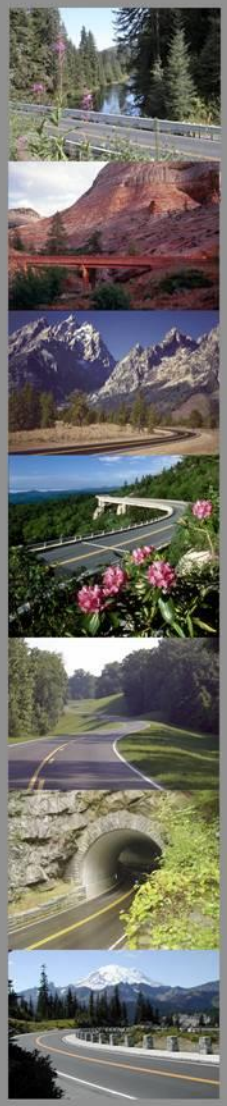
Analysis of Existing Slope Conditions

SAFETY FACTOR = 1.0



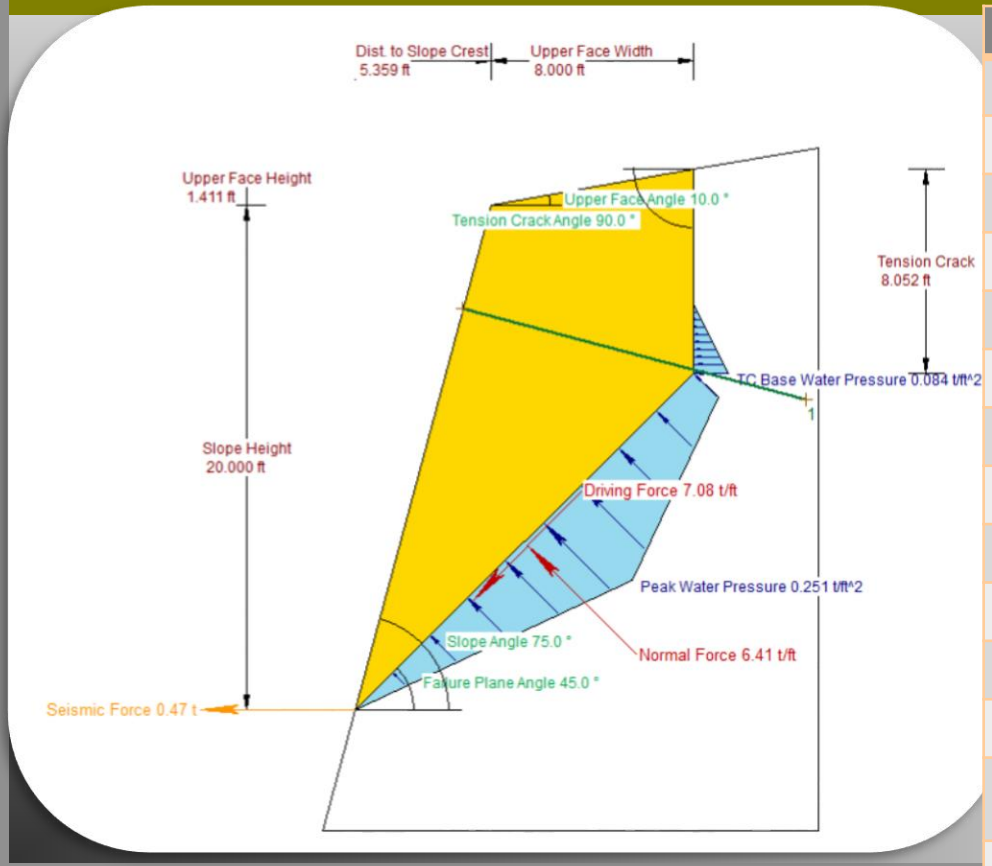


Factor of Safety	1.00
Driving Forces	7.08t/ft
Resisting Forces	7.08t/ft
Wedge Weight	9.43t/ft
Wedge Volume	130.0 ft^3/ft
Shear Strength	6.78t/ft^2
Normal Force	3.57t/ft
Seismic Force	0.47t
Plane Waviness	5◦
Water Force on Failure Plane	2.68 t/ft
Water Force on Tension Crack	0.11t/ft

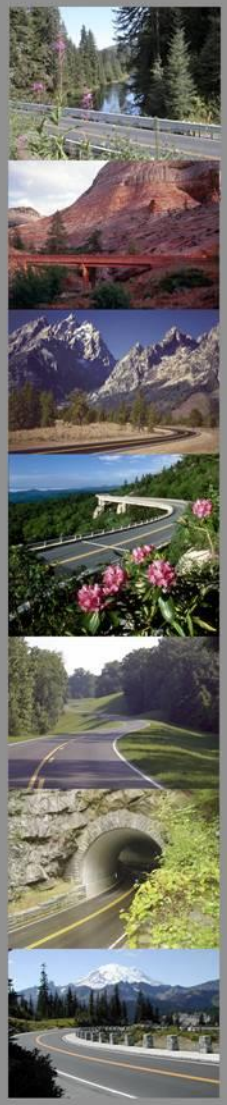


Analysis of Proposed Slope Conditions

SAFETY FACTOR = 1.5

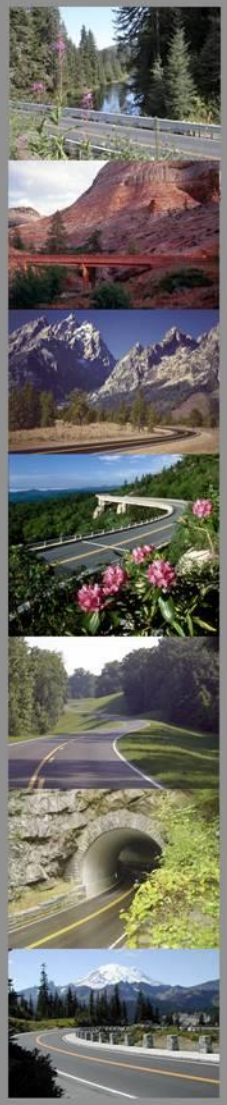


Factor of Safety	1.50
Driving Forces	7.08 t/ft
Resisting Forces	10.62 t/ft
Wedge Weight	9.43 t/ft
Wedge Volume	130.0 ft^3/ft
Shear Strength	8.42 t/ft^2
Normal Force	6.41 t/ft
Seismic Force	0.47t
Plane Waviness	5.0 deg.
Passive Bolt Force	3.28 t
Passive Bolt angle	15.0 deg.
Bolt Length	14.0 ft
Anchor Length	4.58 ft
Water Force on Failure Plane	2.68 t/ft
Water Force on Tension Crack	0.11 t/ft



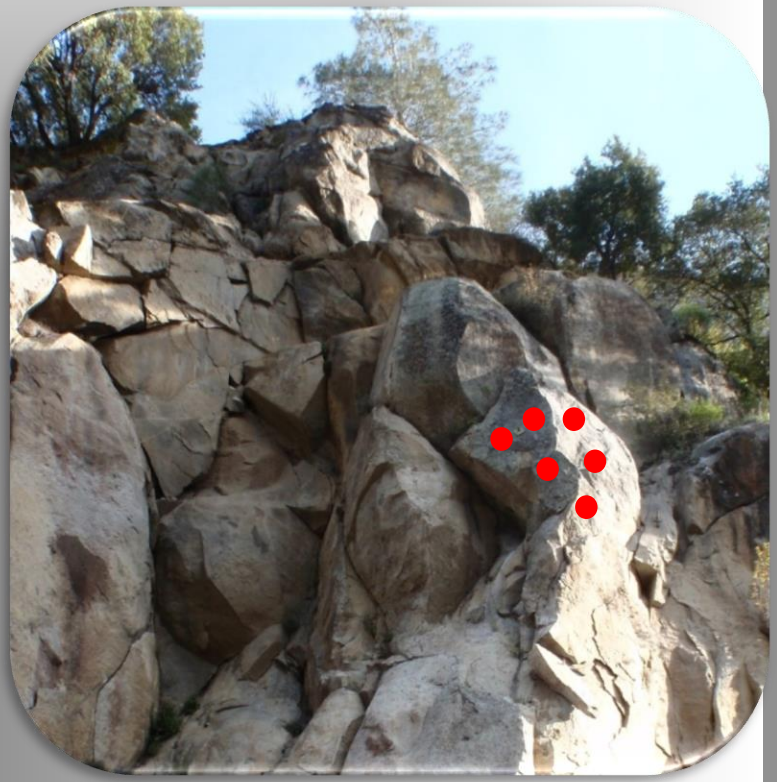
Rock Support System

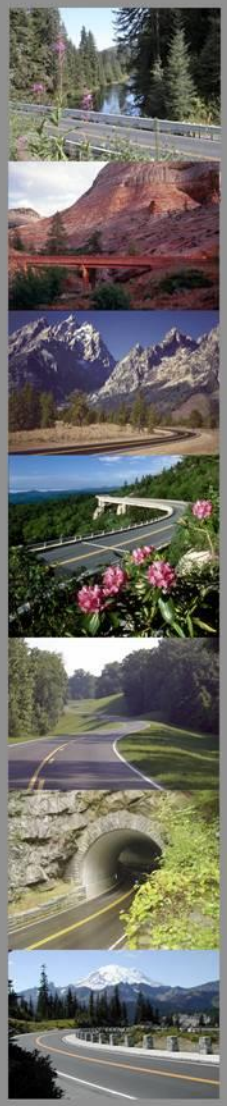
- Support Type
- Bolts vs. Dowels
- Number of bolts
- Bolt size and steel grade
- Bolt spacing
- Bolt length
- Hole diameter
- Anchoring length
- Bolt tension (active or passive)
- Plate size and thickness
- Corrosion Protection



Support Capacity

- Required anchor capacity is 50 kips
- Use 6 bolts (50 kips/6) = 8.33 kips
- Assume a certain bolt size and strength



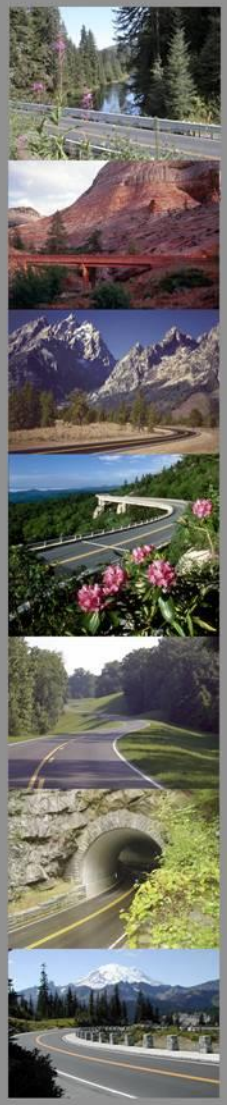


U.S. Department of
Federal Highway Ad
Federal Lands High

Ground Anchor Design

Based on Post Tensioning Institute Publication
"Recommendations for Prestressed Rock & Soil Anchors"
Fourth Edition - First Printing, 2004

Ground Anchor Properties			
Ground Anchor Capacity, (P)	**8.33**	**kips**	
Drill Hole Diameter, (D)	2.50	in	
Yield Strength of Reinforcing Bar, Fy	33.00	kips	#6 Bar/Grade75
Nominal Bar Diameter, (d)	0.75	in	
Compressive Strength of Grout, (f'_c)	3,000.00	psi	
Ultimate Stress of Steel, (f_{ut})	100,000.00	psi	
Area of Steel, (As)	0.44	in^2	
Geotechnical Design			
Geo-strata 1 ultimate bond stress, tu1 =	125.00	psi	
Geo-strata 2 ultimate bond stress, tu2 =	0.00	psi	
Geo-strata 3 ultimate bond stress, tu3 =	0.00	psi	
Geo-strata 4 ultimate bond stress, tu4 =	0.00	psi	
Soil-Grout Bond, α1 =	11.78	kips/ft	
Soil-Grout Bond, α2 =	0.00	kips/ft	
Soil-Grout Bond, α3 =	0.00	kips/ft	
Soil-Grout Bond, α4 =	0.00	kips/ft	
Total Anchor Length = Lb=P/(0.4*α)	**1.77**	**ft**	**Use Min. 2 ft bond**
0.4 =FS of 2.5	Min. Unbonded Length		6 ft
Structural Design	Min. Bar Length =		8 ft
Tensile Capacity, P_t = (0.6*Fy)	19.8	kips	**OK (> 8.33 kips)**
Shear Capacity, Fu = N(As)(f_{ut})	26.4	kips	



U.S. Department of T
Federal Highway Adı
Federal Lands Highv

Ground Anchor Connection Design

Based on Post Tensioning Institute Publication
"Recommendations for Prestressed Rock & Soil Anchors"
Fourth Edition - First Printing 2004

TENSION			
Check Cone Shear			
Service Load, (P)	**8.33**	**kips**	
Compressive Strength of Concrete, (f'c)	3,000.00	psi	
Plate Width, (Pb)	6.00	in	
Concrete Cover, (hc)	12.00	in	From face to back
Equivalent Diameter, (d1)	6.77	in	of wall
Bottom of Cone Diameter, (d2)	30.77	in	
$Acp = 0.25\pi(d2^2-d1^2)$	707.60	in^2	
Pcone strength = 4 X $(f'c)^{(0.5)}$ X Acp	155.03	kips	
Pcone design strength = 0.67*Pcone strength	103.87	kips	OK
PLATE THICKNESS			
Plate Area, (Ap)	36.00	in^2	
Yield Stress, (fy)	36.00	ksi	
Bearing Compression, wbp = P/Ap	231.39	psi	
Mmax = (wbp*(b/2)^2)/2	1041.25	lb-in	
Sx = Mmax/(.55*fy)	0.05	in^3	
Plate Thickness, t = [(6*Sx)/(b/2)]^0.5	**0.32**	**in**	**1/2"x6"x6"**