TRB Webinar: Guidelines for Geofoam Applications in Slope Stability Projects

David Arellano, University of Memphis
Steven Bartlett, University of Utah
Ben Arndt, Yeh & Associates, Inc.
Moderated by: Mohammed Mulla, North Carolina DOT

July 27, 2017

Webinar Outline

- Overview of problem statement and background on use of geofoam
- Engineering properties of block-molded expanded polystyrene for slope stabilization
- Design methodology overview
- Construction practices & cost considerations
- Update on previous standard for slope stability applications
- Question and answer session

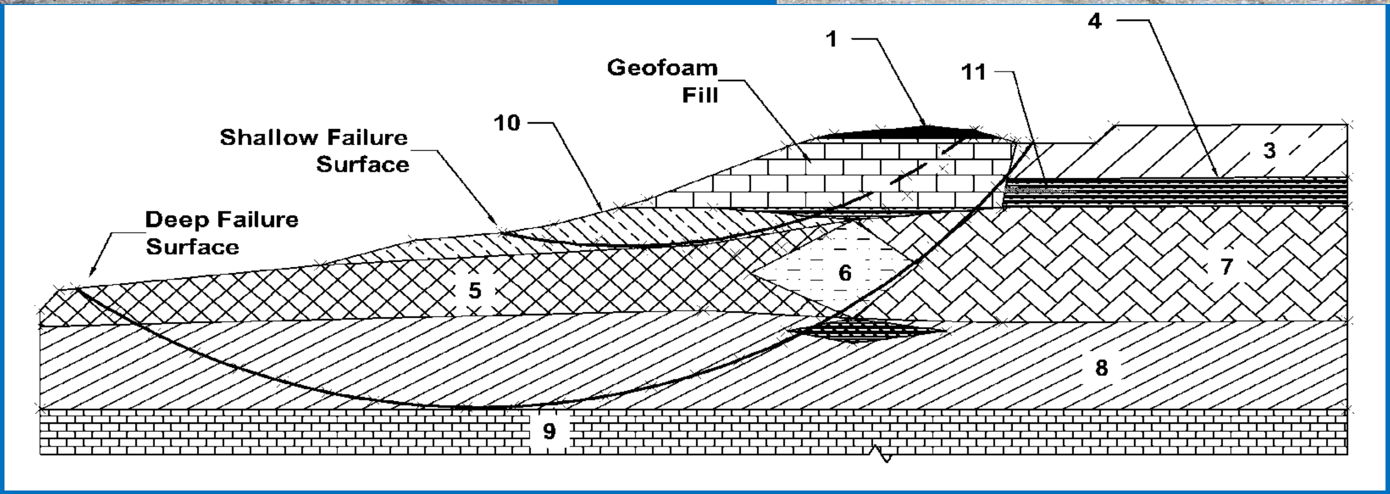
Overview of problem statement & background on use of geofoam

David Arellano, University of Memphis

Slope stabilization

US 160
Durango, CO. Photos: Sutmoller

Slope stabilization



Overview of EPS Block Placement
Configuration

Completed Road

Geofoam Types (ASTM D 6817)

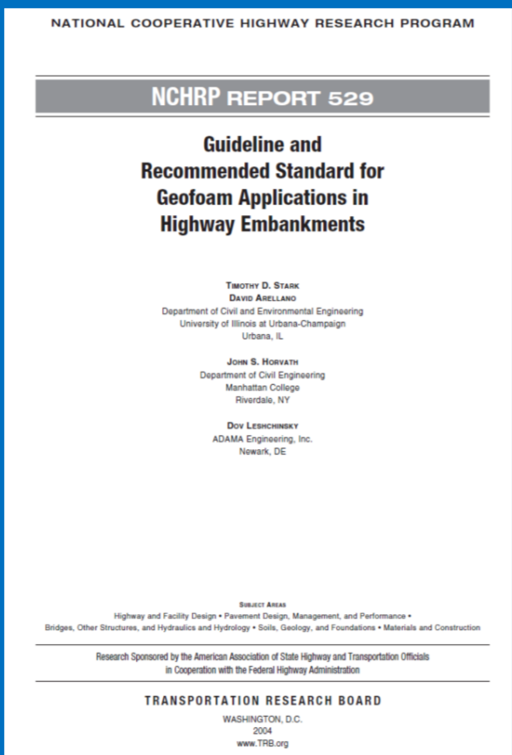
ASTM D6817 Physical Property Requirements of EPS Geofoam

Type	EPS12	EPS15	EPS19	EPS22	EPS29	EPS39	EPS46
Density, min., $kg/m^3 (lb/ft^3)$	11.2 (0.70)	14.4 (0.90)	18.4 (1.15)	21.6 (1.35)	28.8 (1.80)	38.4 (2.40)	45.7 (2.85)
Compressive Resistance, min., kPa (psi) at 1 %	15 (2.2)	25 (3.6)	40 (5.8)	50 (7.3)	75 (10.9)	103 (15.0)	128 (18.6)
Compressive Resistance, min., kPa (psi) at 5 %	35 (5.1)	55 (8.0)	90 (13.1)	115 (16.7)	170 (24.7)	241 (35.0)	300 (43.5)
Compressive Resistance, min., kPa (psi) at 10 % [A]	40 (5.8)	70 (10.2)	110 (16.0)	135 (19.6)	200 (29.0)	276 (40.0)	345 (50.0)
Flexural Strength, min., kPa (psi)	69 (10.0)	172 (25.0)	207 (30.0)	240 (35.0)	345 (50.0)	414 (60.0)	517 (75.0)
Oxygen index, min., volume %	24.0	24.0	24.0	24.0	24.0	24.0	24.0

Problem Statement

- New roadway alignments and/or widening of existing roadway embankments will be required to solve the current and future highway capacity problem.
- Roadway construction often exacerbates the landslide problem in hilly areas by alternating the landscape, slopes, and drainages and by changing and channeling runoff (Spiker and Gori, 2003).
- Geofoam provides an alternative slope stabilization and repair technique that is based on reducing the driving forces.

Previous NCHRP Results: NCHRP 24-11


NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 529

Guideline and
Recommended Standard for
Geofoam Applications in
Highway Embankments

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SUBJECT AREAS
Highway and Facility Design • Pavement Design, Management, and Performance •
Bridges, Other Structures, and Hydraulics and Hydrology • Soils, Geology, and Foundations • Materials and Construction

Research Sponsored by the American Association of State Highway and Transportation Officials
in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD
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2004
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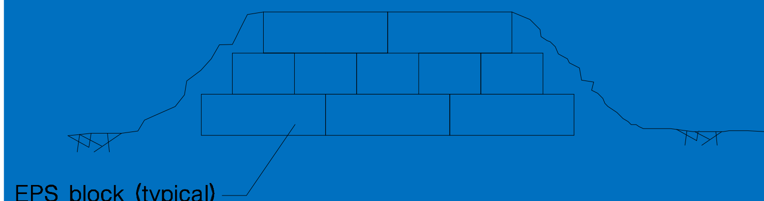
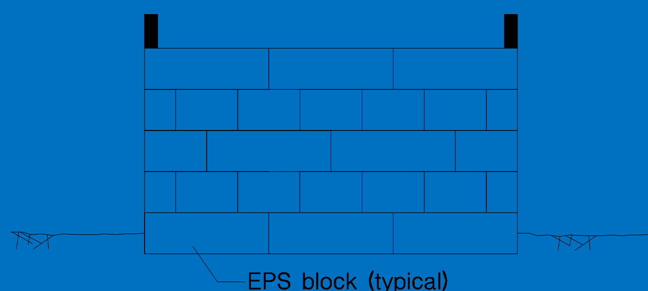


(a) Sloped-side fill.



(b) Vertical-face fill.

Rte 1 & 9, Jersey City, NJ

Port of Longview, Longview, WA

Photos: Sutmoller

NCHRP 24-11(02)

Project No. 24-11(02) **COPY NO. _____**

Guidelines for Geofoam Applications in Slope Stability Projects

PRELIMINARY DRAFT FINAL REPORT

Prepared for
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
Transportation Research Board
of
The National Academies

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES
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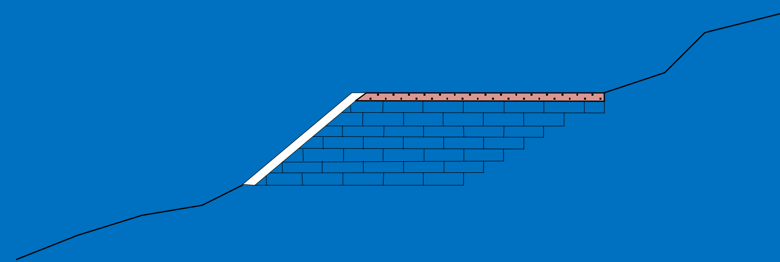
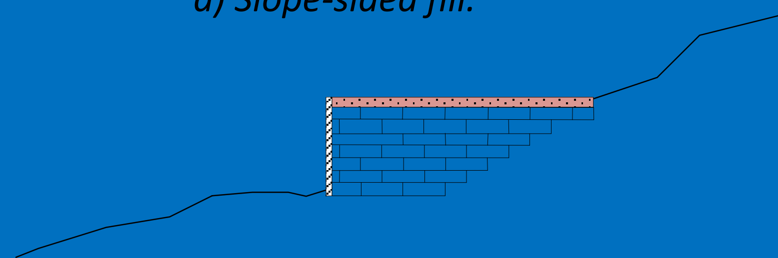
January 7, 2011



a) Slope-sided fill.

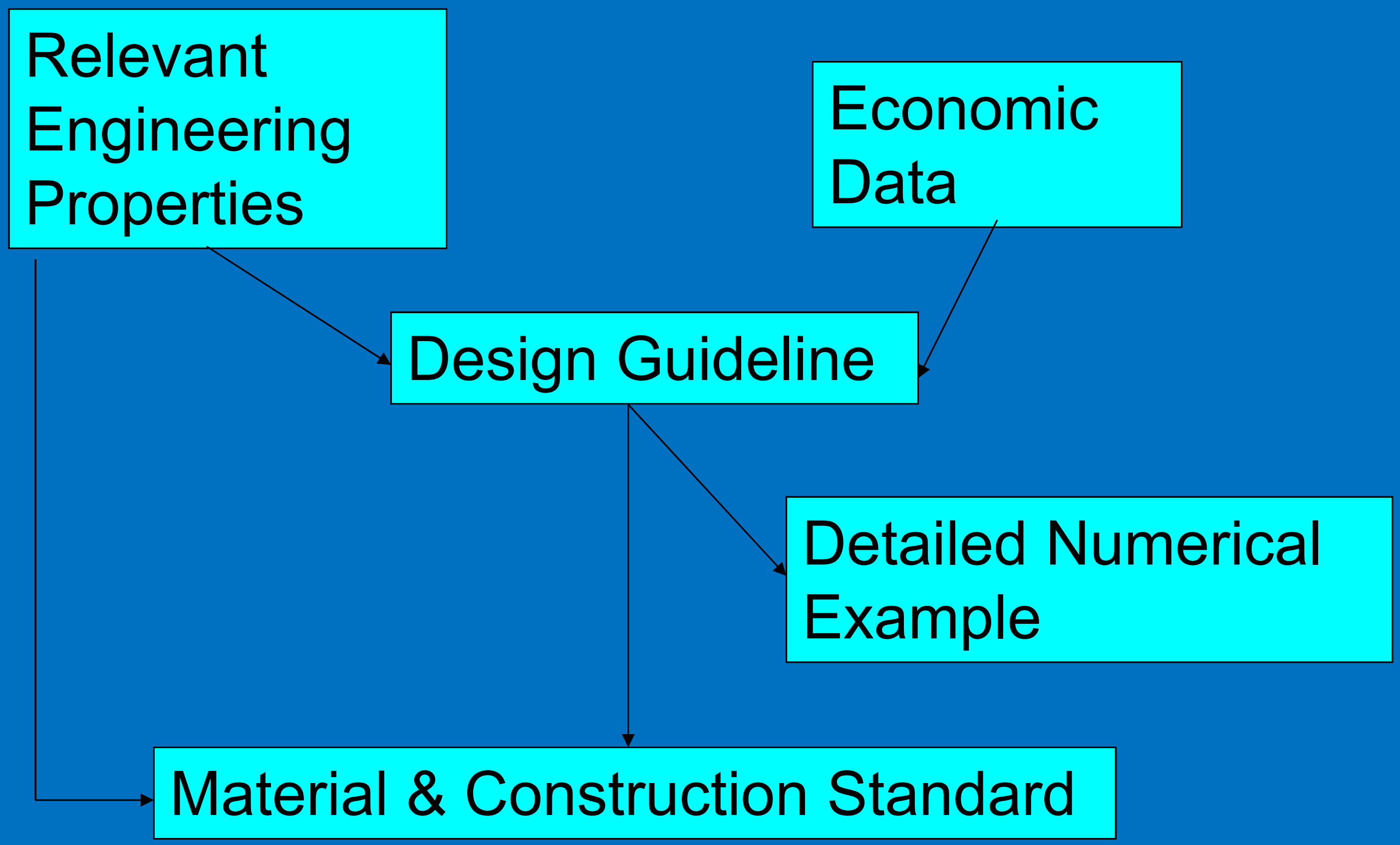


b) Vertical-sided fill (Geofoam wall).

Research Objective

- To develop a comprehensive document that provides both state-of-the-art knowledge and state-of-practice design guidance to those who have primary involvement with roadway embankment projects with design guidance for use of EPS-block geofoam in slope stability applications.

Primary Research Products 24-11(02)



Engineering properties of block-molded expanded polystyrene for slope stabilization

Steve Bartlett, University of Utah

Key Properties

- Density
  - Indicator of quality, strength and compressive resistance of EPS
  - Required for vertical stress and buoyancy calculations
- Compressive Resistance (Elastic Young's Modulus)
  - 1 % axial strain values used to determine allowable loads
  - Dead loads and live loads limited to prevent excessive long-term creep
- Interface Friction
  - Geofoam to Geofoam
  - Geofoam to Backfill (sand)
- Shear Strength (Seismic Design Only)
  - Shear strength of shear keys (if used)

Design properties - ASTM D6817

Physical Properties of Foam-Control EPS Geofoam[1,2]								
TYPE - ASTM D6817		EPS12	EPS15	EPS19	EPS22	EPS29	EPS39	EPS46
Density, min.	lb/ft^3 (kg/m^3)	0.70 (11.2)	0.90 (14.4)	1.15 (18.4)	1.35 (21.6)	1.80 (28.8)	2.40 (38.4)	2.85 (45.7)
Compressive resistance @ 1% deformation, min.	psi psf (kPa)	2.2 320 (15)	3.6 520 (25)	5.8 840 (40)	7.3 1050 (50)	10.9 1570 (75)	15.0 2160 (103)	18.6 2680 (128)
Elastic Modulus	psi (kPa)	220 (1500)	360 (2500)	580 (4000)	730 (5000)	1090 (7500)	1500 (10300)	1860 (12800)
Flexural Strength min.	psi (kPa)	10.0 (69)	25.0 (172)	30.0 (207)	35.0 (240)	50.0 (345)	60.0 (414)	75.0 (517)
Water Absorption by total immersion, max.,	volume %	4.0	4.0	3.0	3.0	2.0	2.0	2.0
Oxygen Index, min.,	volume %	24.0	24.0	24.0	24.0	24.0	24.0	24.0
Buoyancy Force	lb/ft^3 (kg/m^3)	61.7 (990)	61.5 (980)	61.3 (980)	61.1 (980)	60.6 (970)	60.0 (960)	59.5 (950)

This standard is commonly used to specify the minimum required values for construction

Density

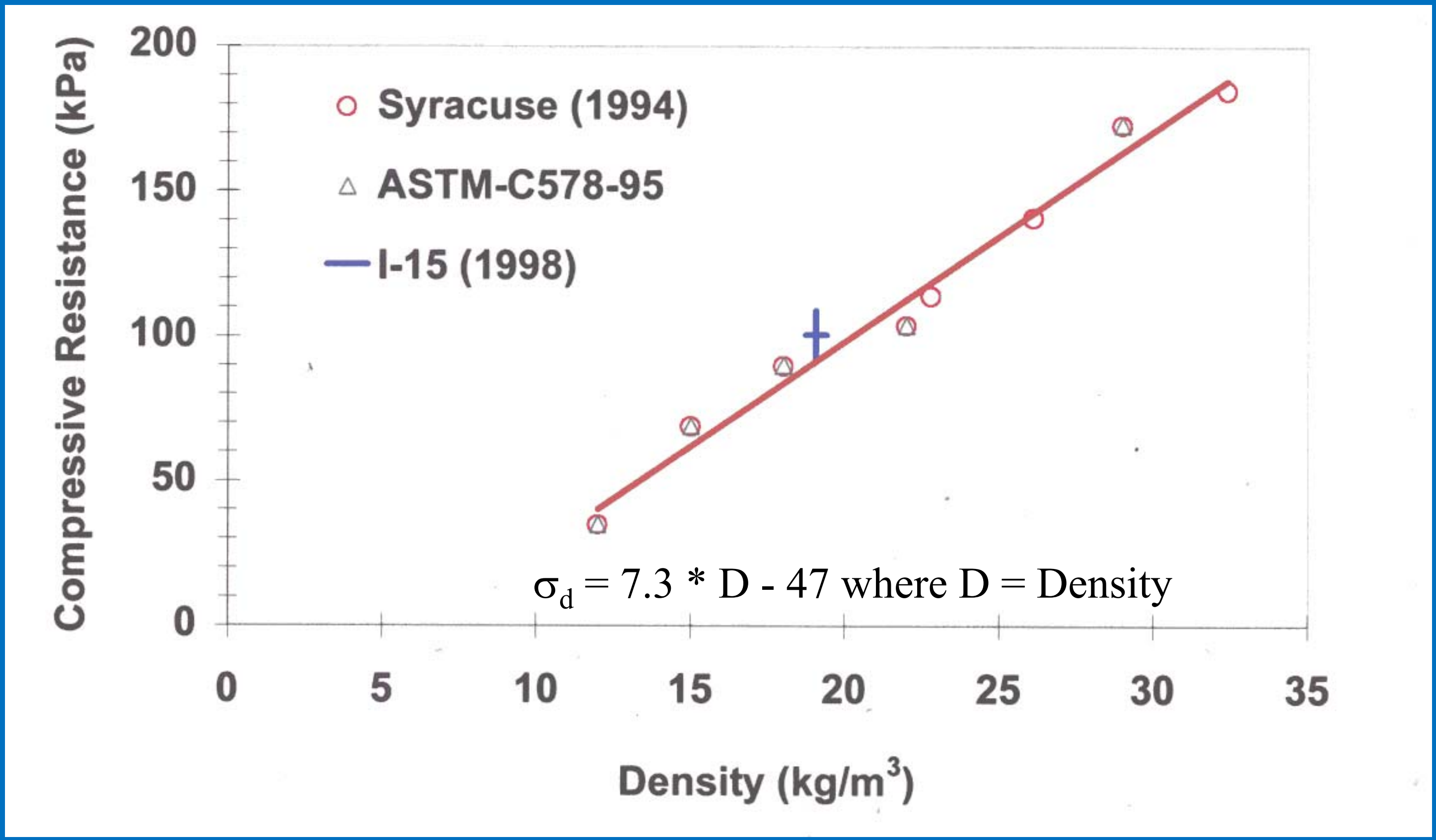
raw styrene beads steam expanded (1st steam heating)

EPS block density is controlled by the amount of styrene beads used to make the block. More beads produce higher density.

block molding (2nd steam heating)

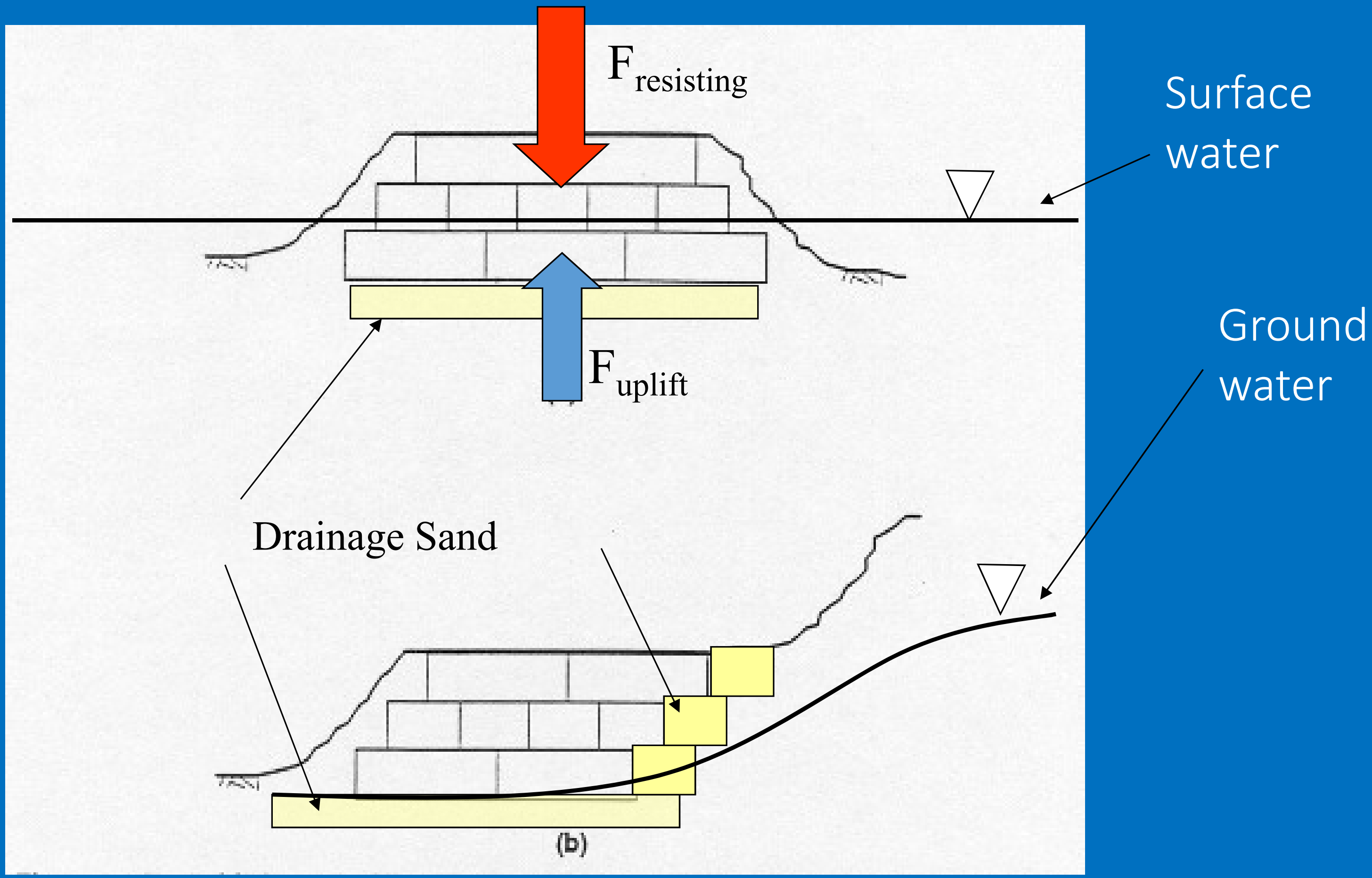
block placement

Density

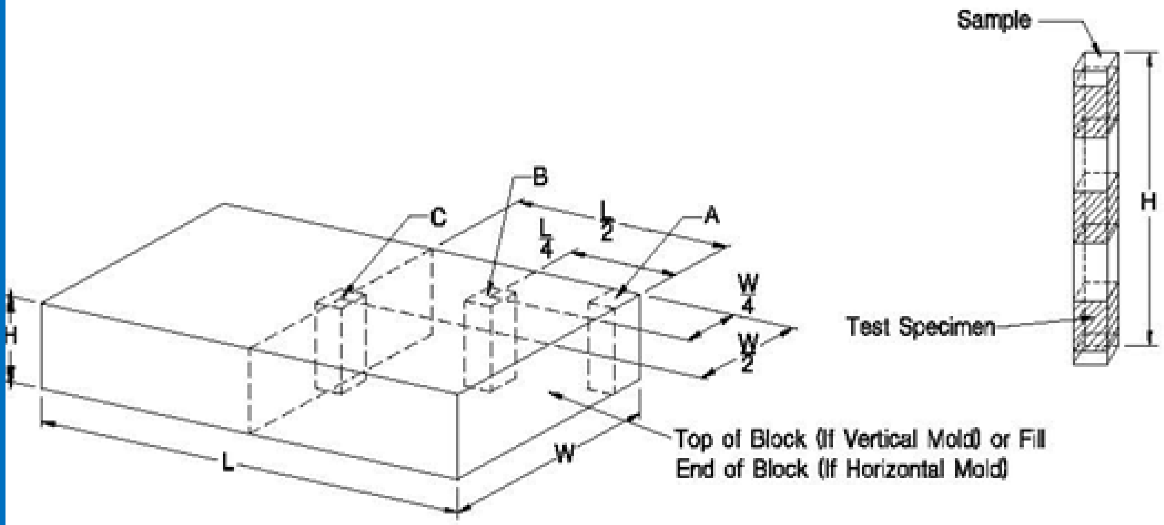


Design Compressive Strength Versus Density

Density and Buoyancy

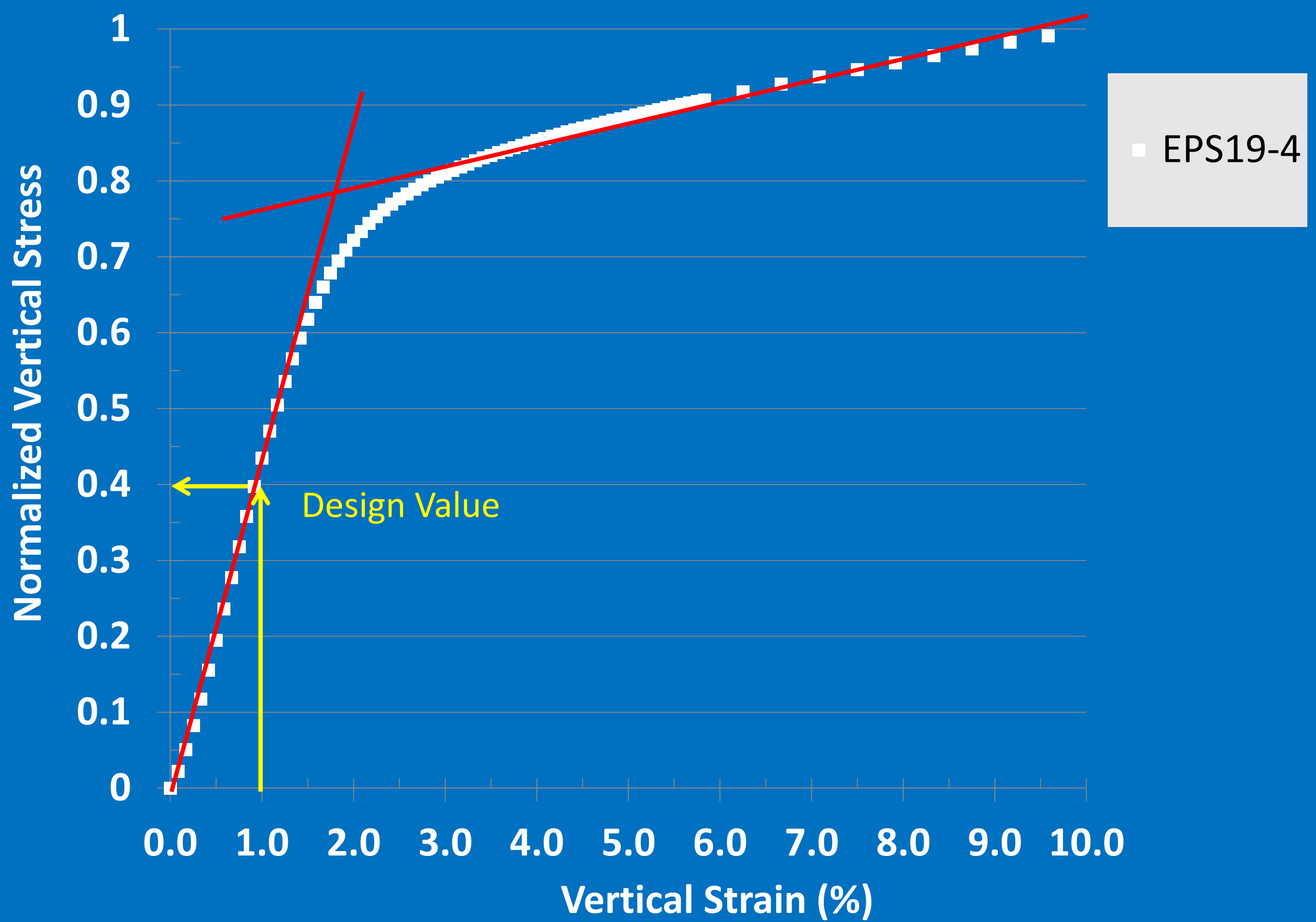


Compressive Resistance

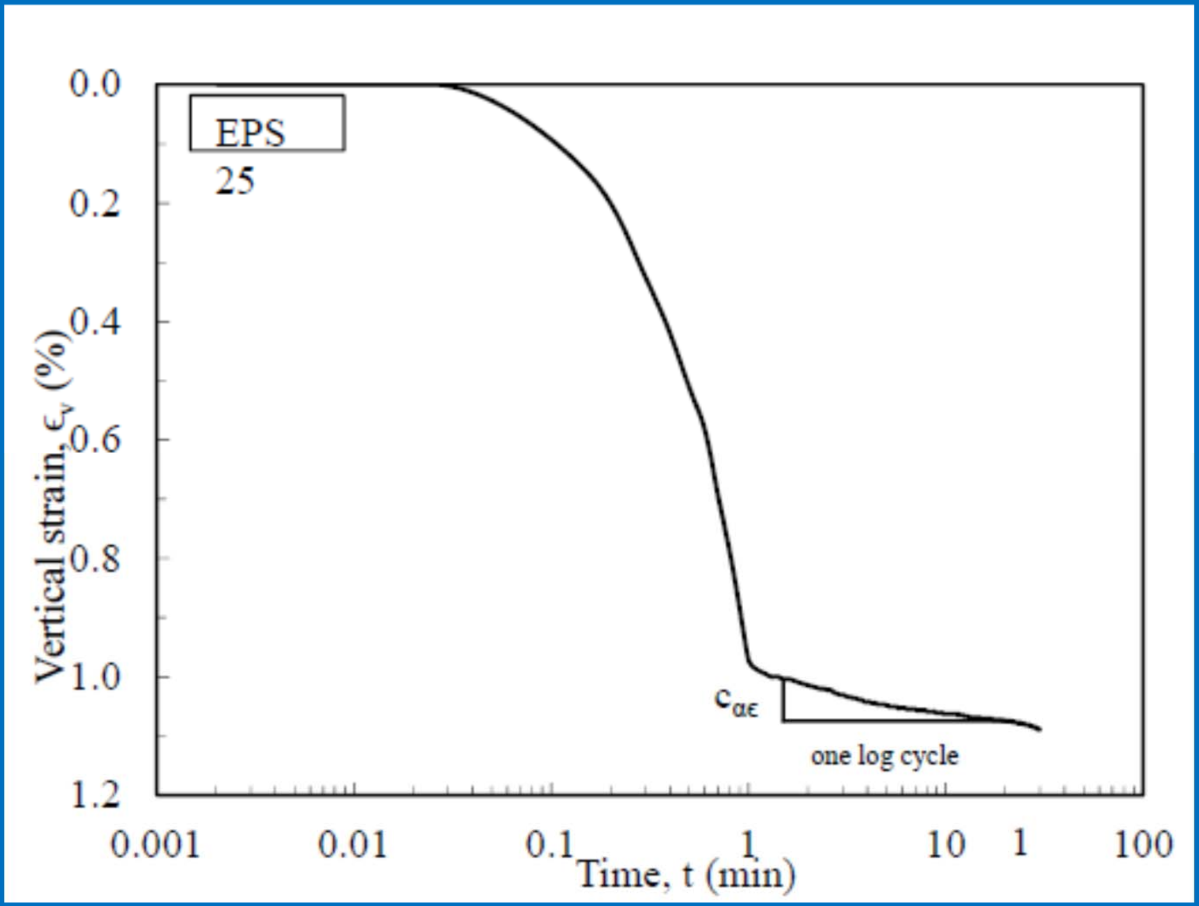


2-in cube samples usually tested for QC

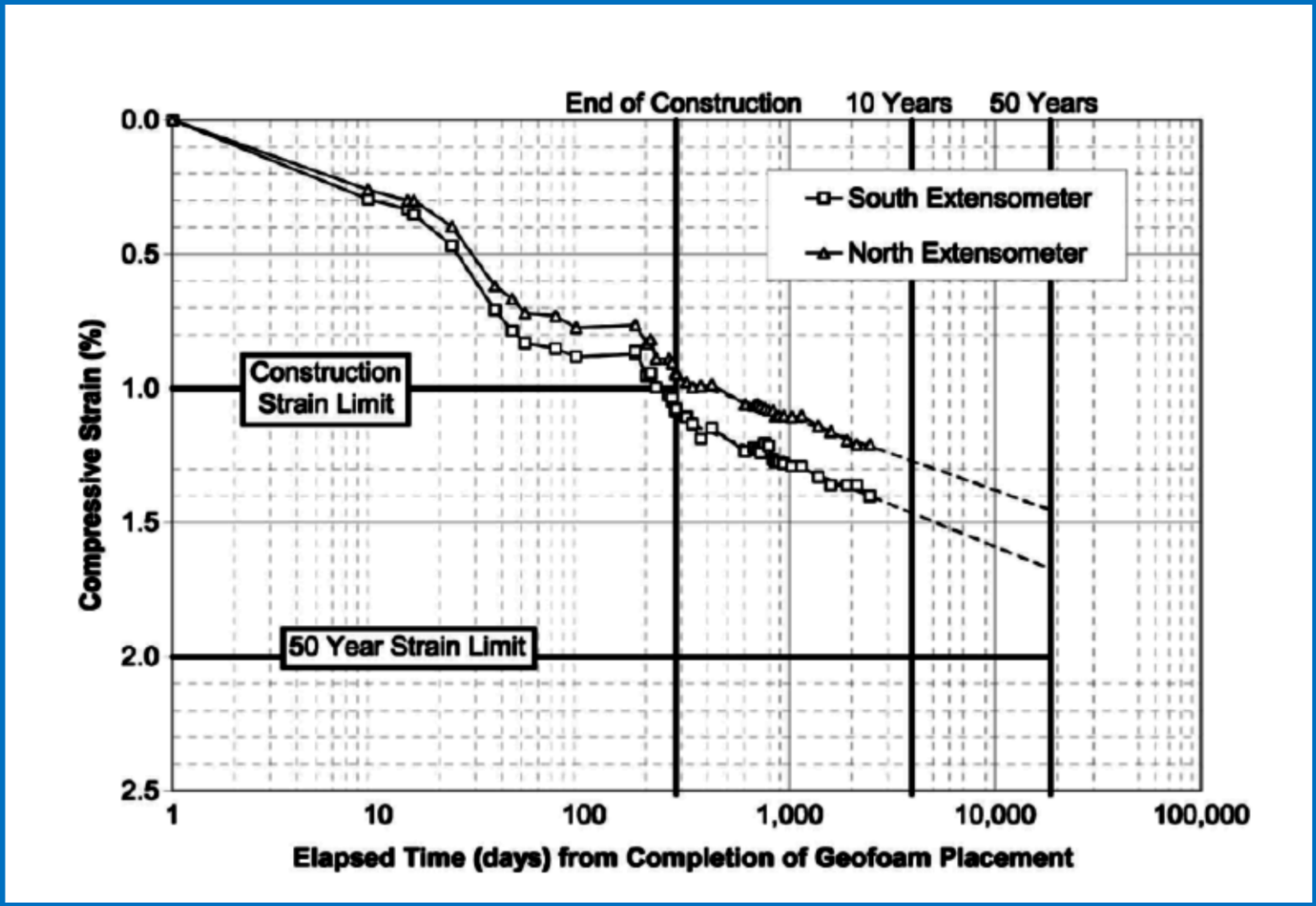
Compressive Resistance



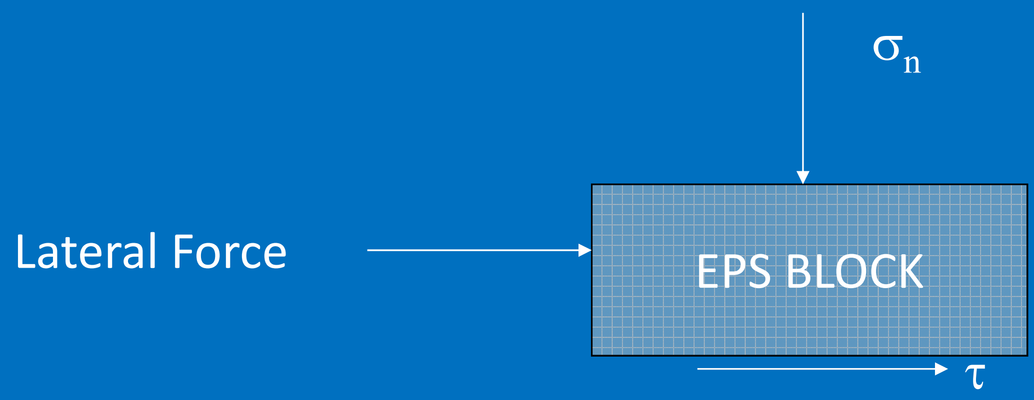
Compressive Resistance and Creep



Compressive Resistance and Creep



Interface Friction



- Interface Friction Need for Design Against Sliding

$\tau = \sigma_n \tan \phi$

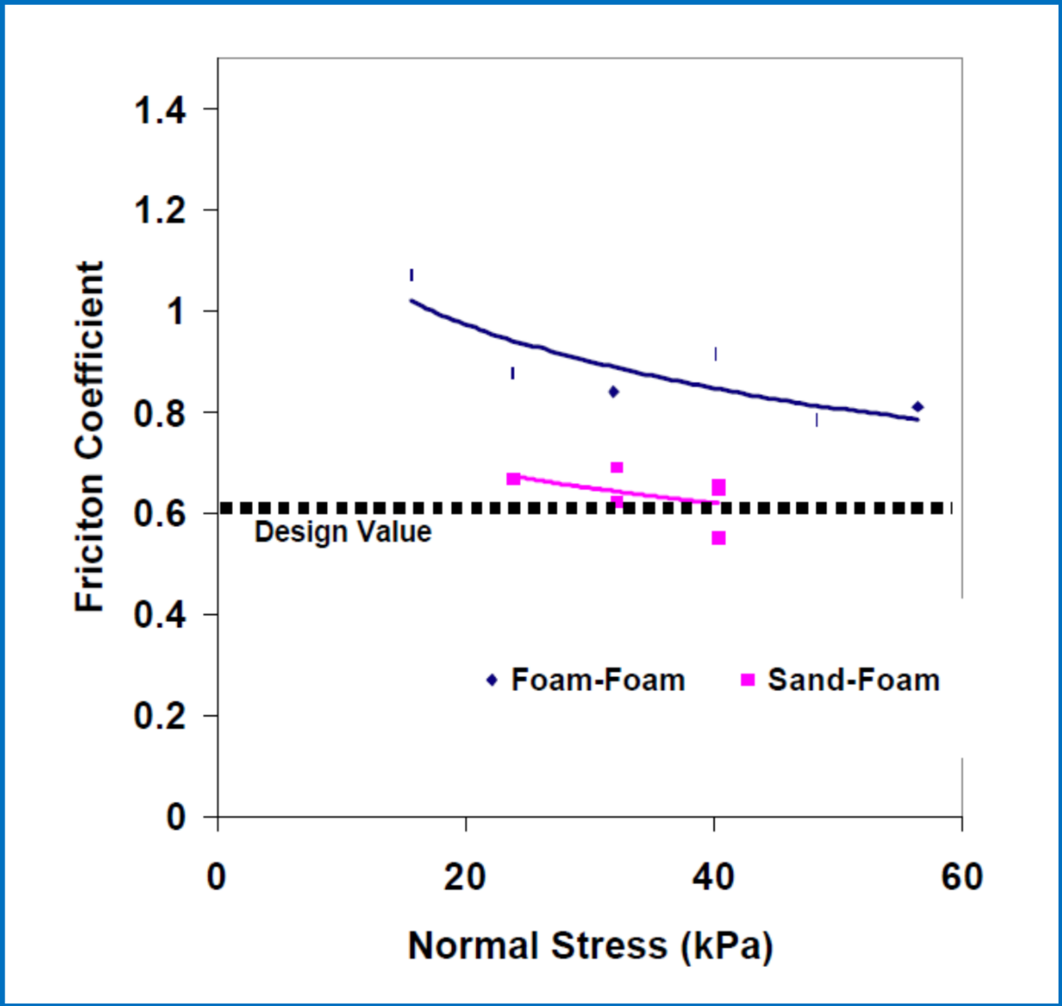
τ = sliding shear resistance

σ_n = normal stress

$\tan \phi = 0.6$ (Design Value)

$\phi = 31$ degrees (Design Value)

Interface Friction



Shear Strength (Seismic Design)

Shear Strength (Seismic Design Only)

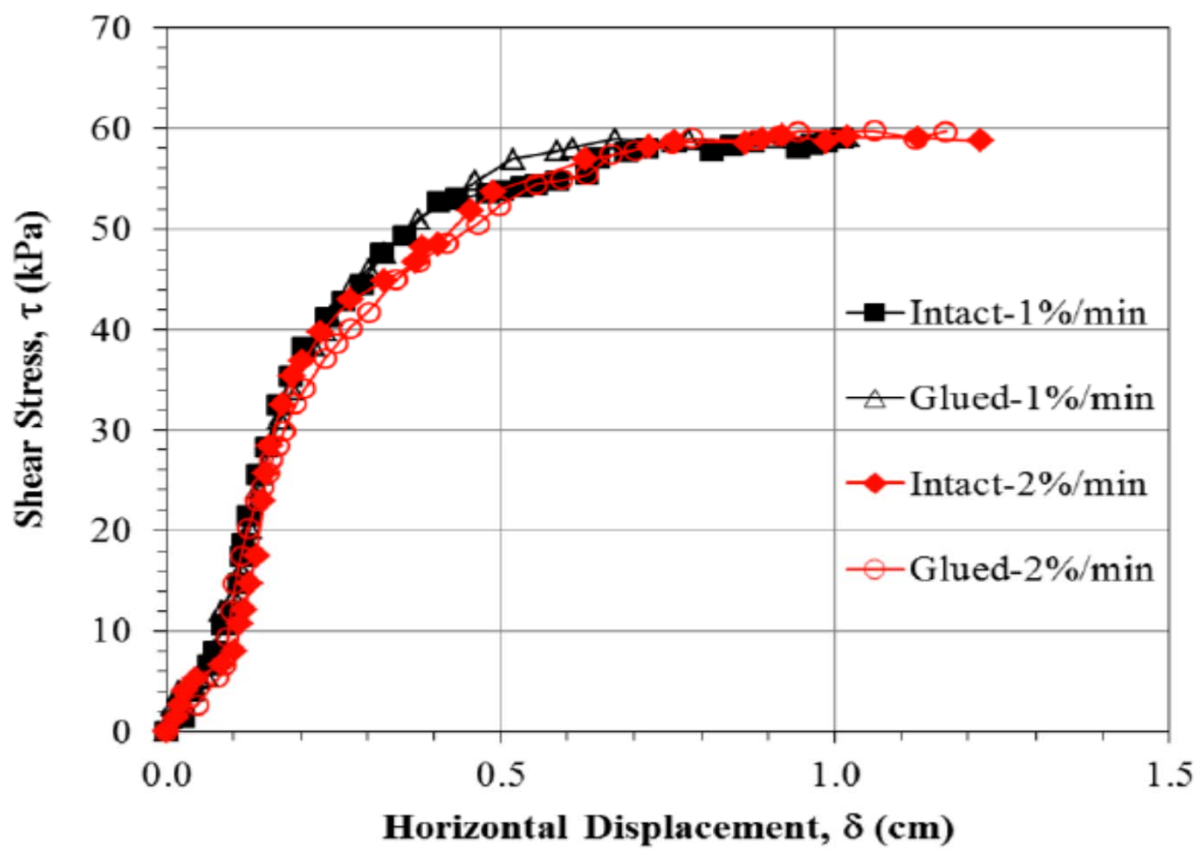
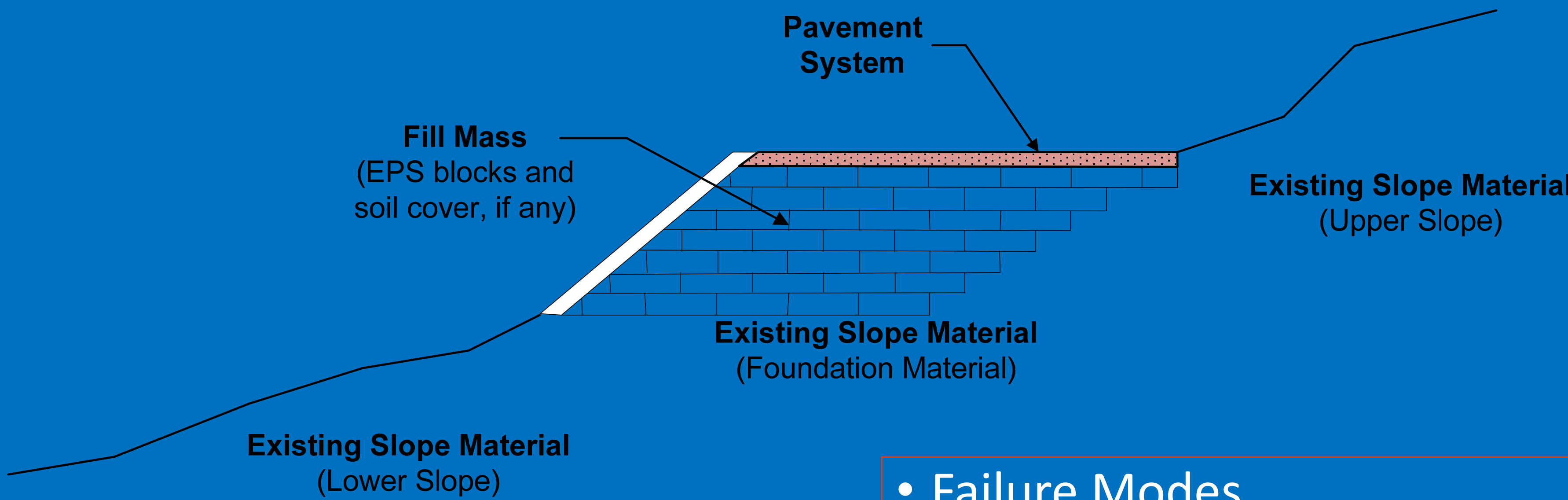


Figure 2.10. Shear stress vs. displacement of EPS specimens under 15 kPa normal stress at different loading rates

Design methodology overview

David Arellano, University of Memphis

Major Components of an EPS-Block Geofoam Slope System

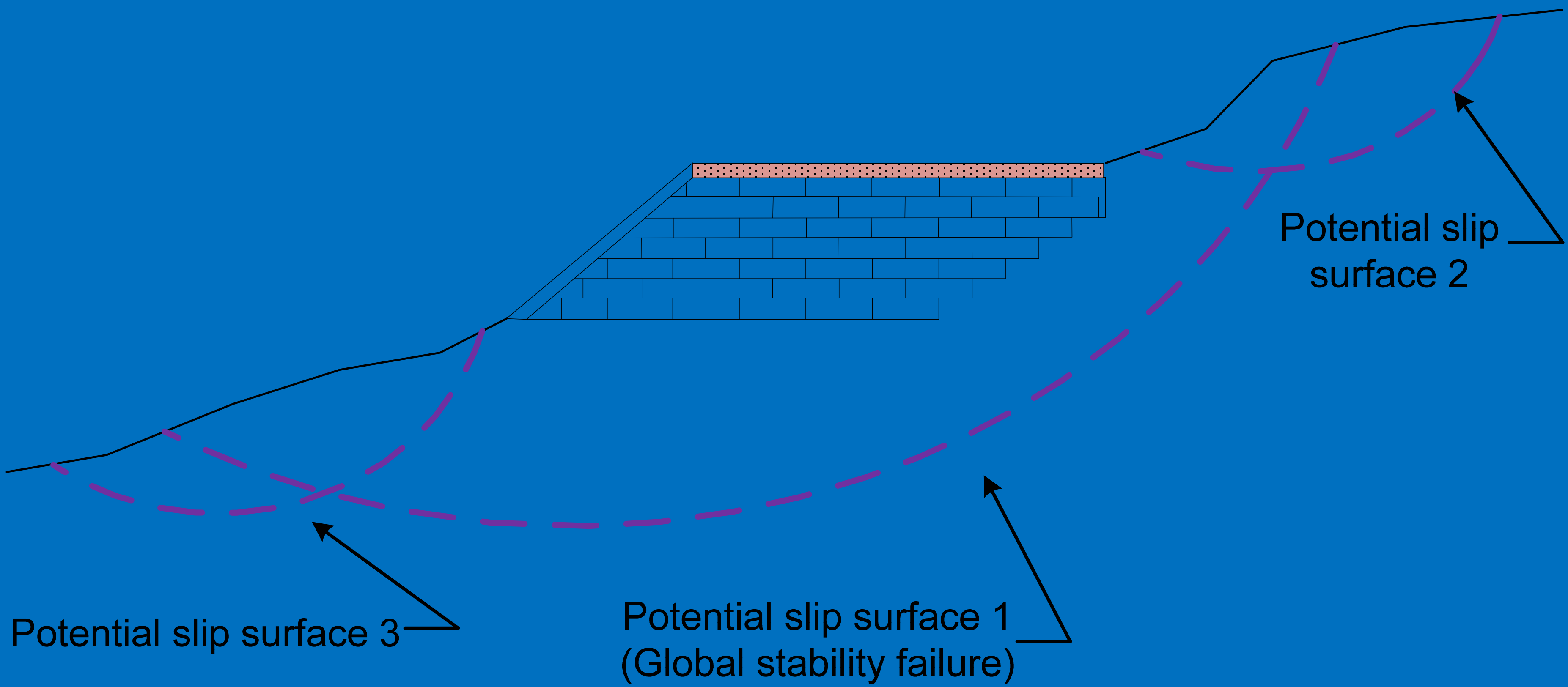


- Failure Modes
  - External instability
  - Internal instability
  - Pavement system failure

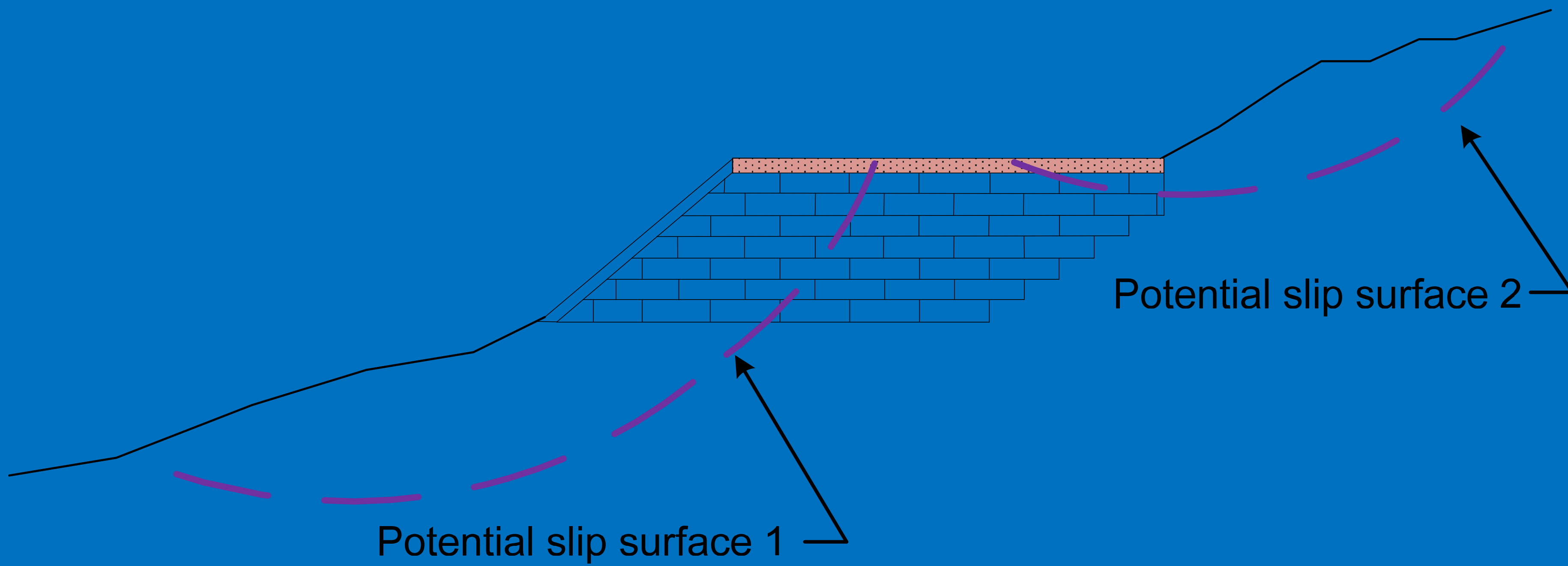
External Instability

Static and Seismic Slope Stability

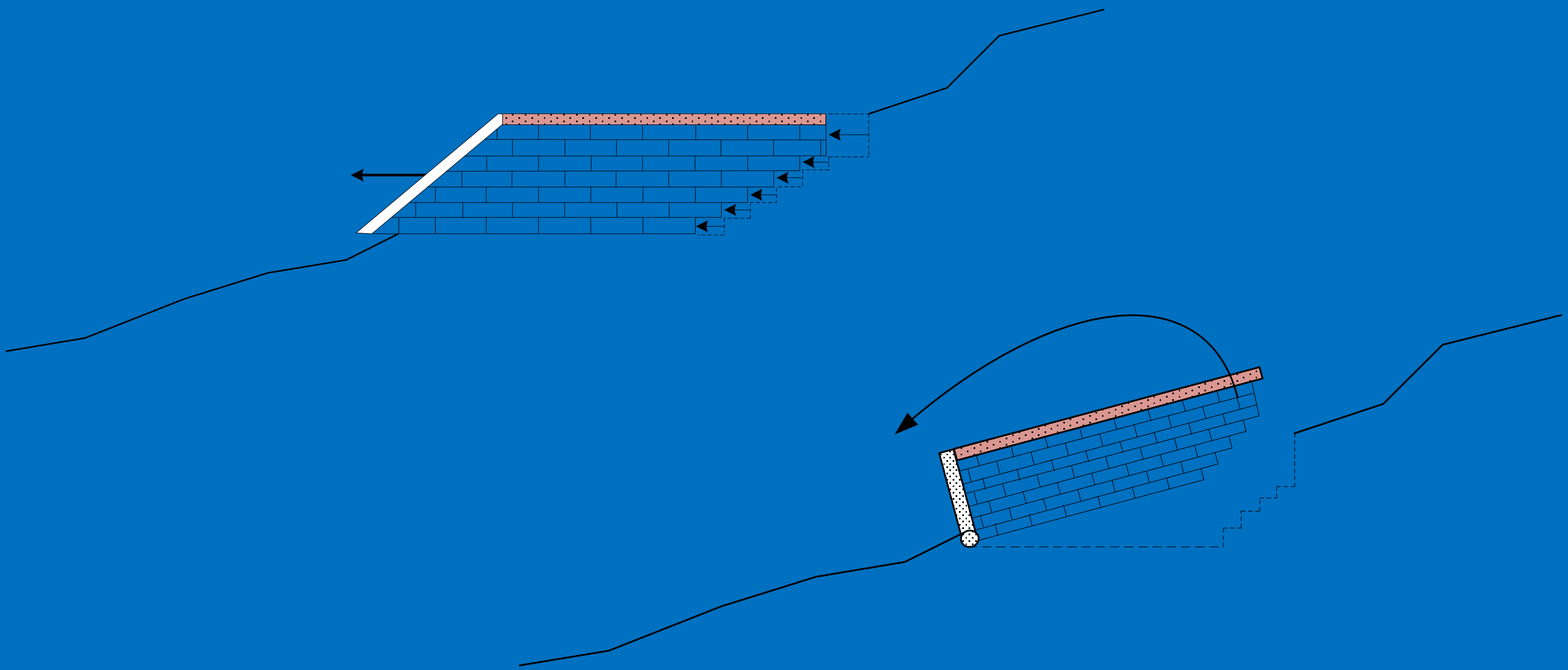
(Existing Soil Slope Material Only)



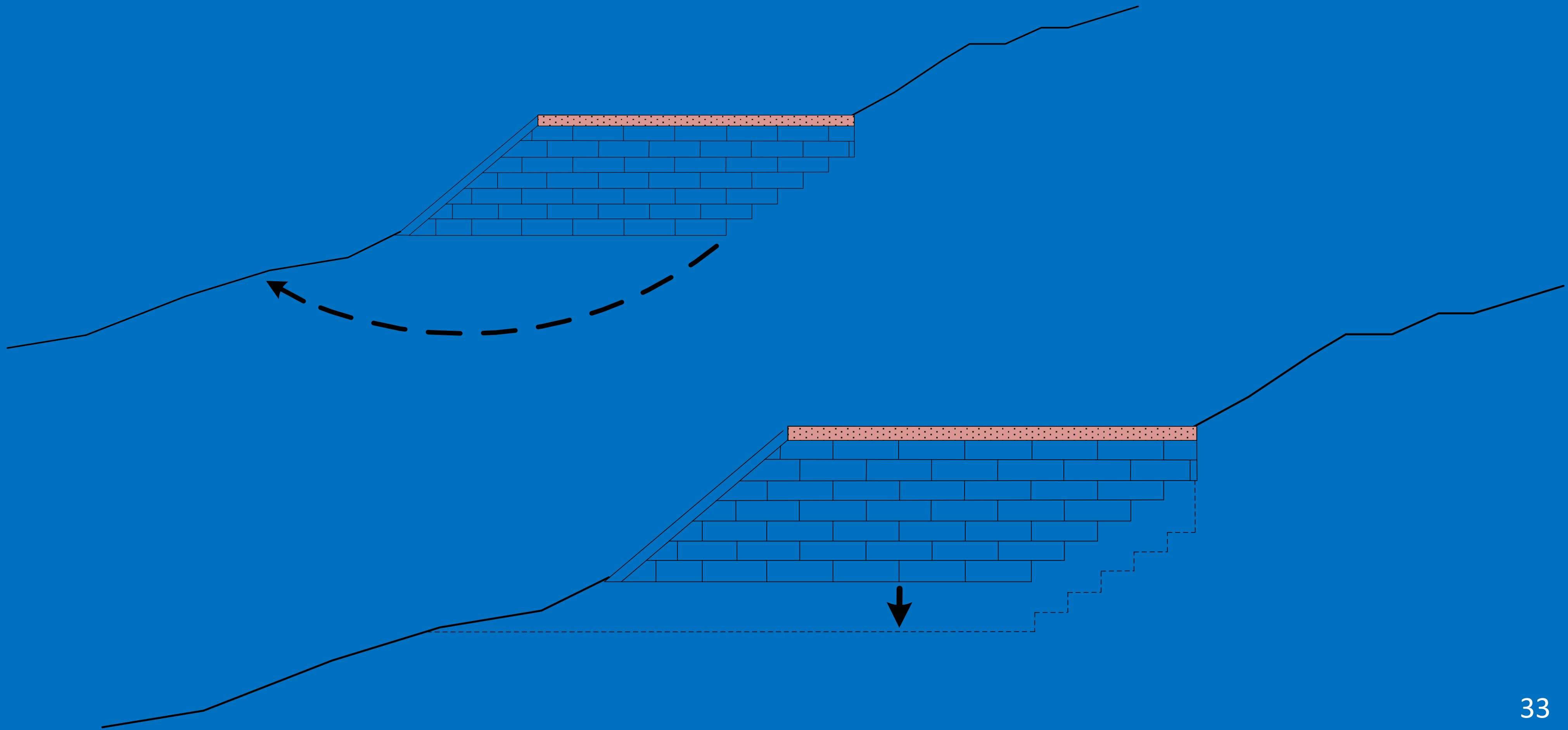
Static and Seismic Slope Stability
(Both Fill Mass and Existing Soil Slope Material)



External <u>Seismic </u>Stability Failure: Horizontal Sliding of the Entire Embankment & Overturning of an Entire Vertical Embankment about the Toe of the Embankment



Bearing Capacity Failure & Settlement



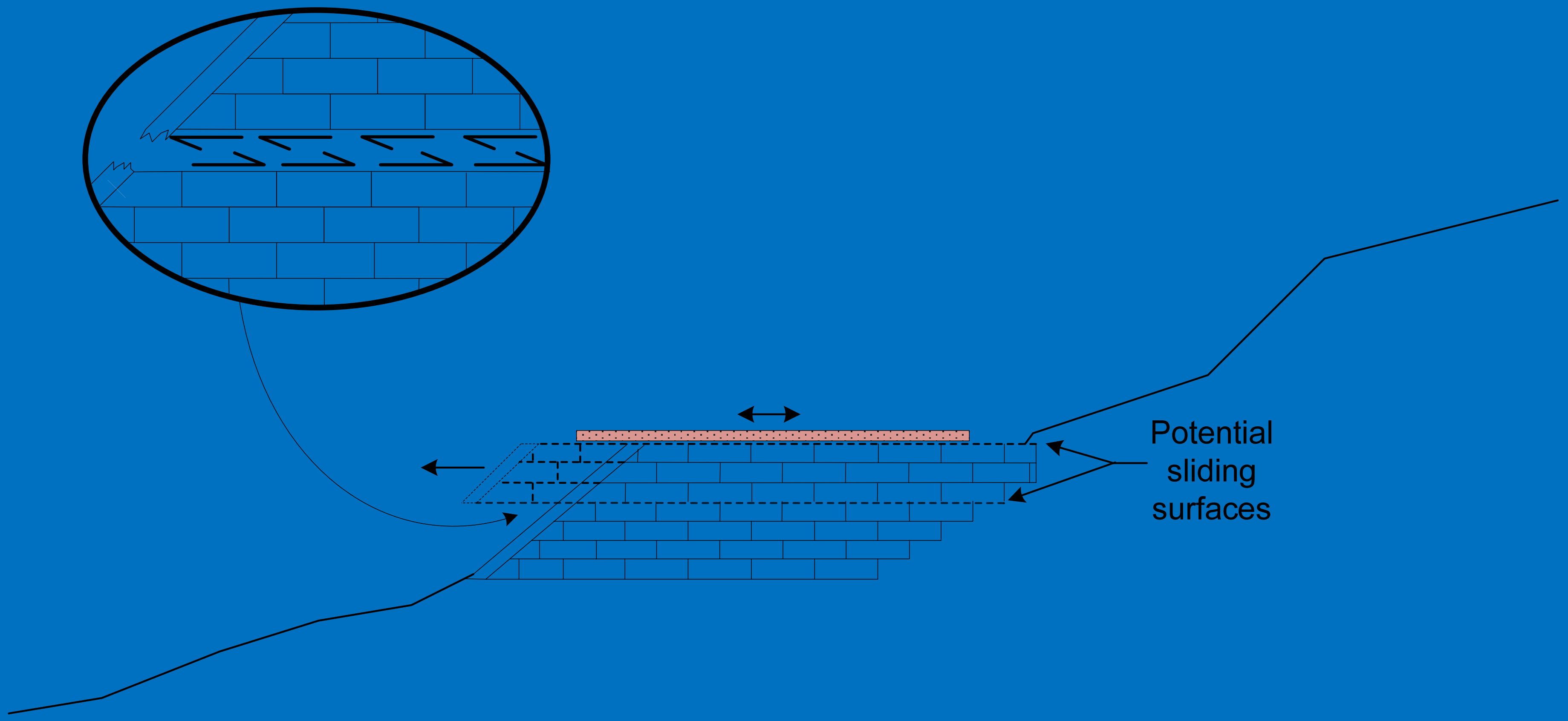
External Stability Summary of Failure Mechanisms

- Static slope stability
- Settlement
- Bearing capacity
- Seismic
  - seismic slope instability
  - seismic-induced settlement
  - seismic bearing capacity failure
  - seismic sliding
  - seismic overturning
-

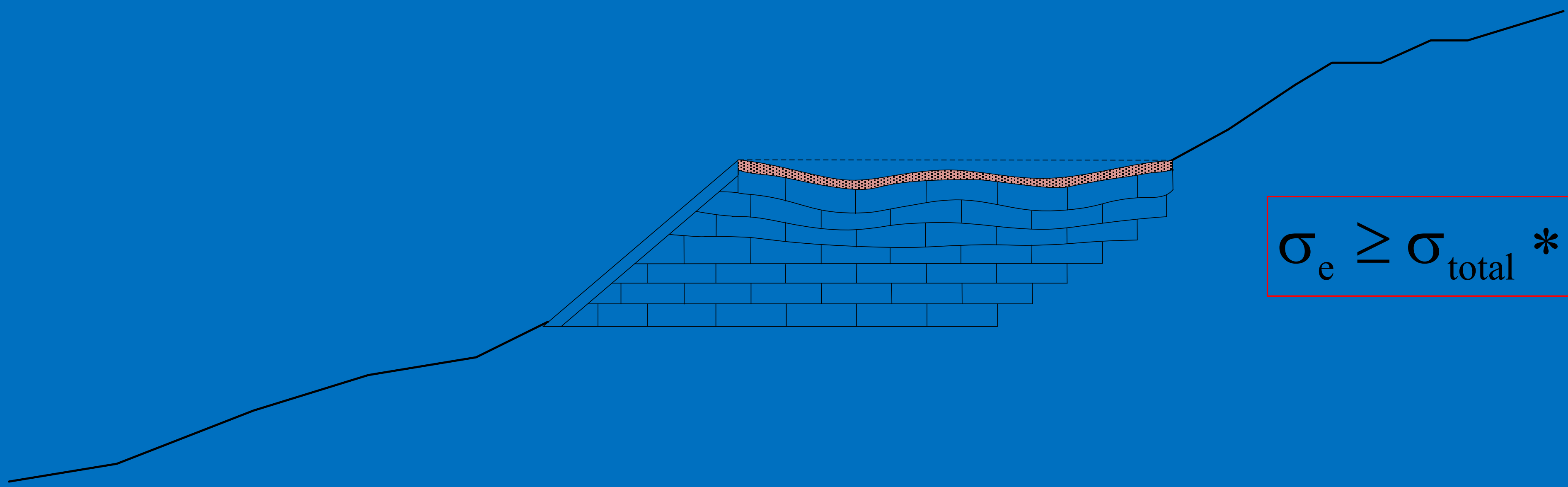
Internal Instability

Internal Seismic Stability Failure

Horizontal Sliding



Load Bearing Failure of the Blocks



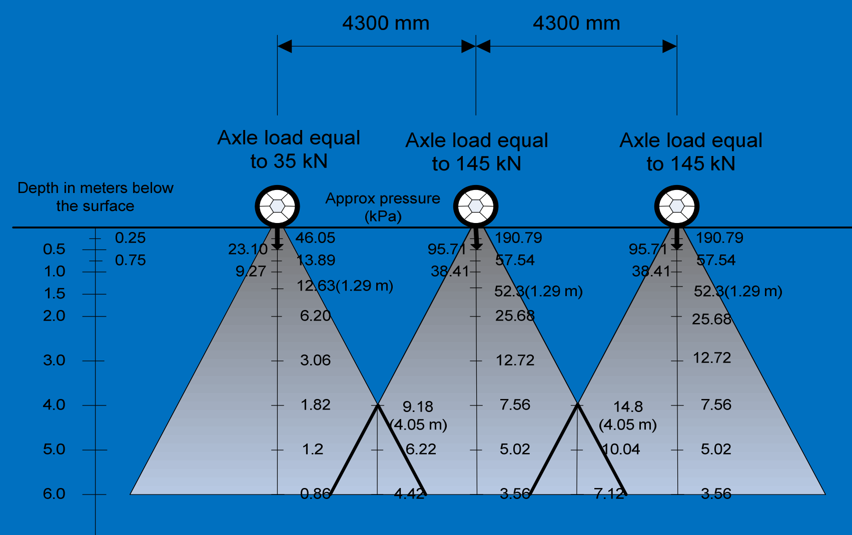
$$\sigma_e \geq \sigma_{total} * FS$$

1. Selection of EPS type directly below the pavement system
   - Traffic and gravity stresses on top of the geofoam.
2. Selection of EPS type at various depths within the EPS block fill mass.
   - Traffic and gravity load stresses at various depths within the geofoam.

EPS Geofoam Types (ASTM D 6817)

ASTM D6817 Physical Property Requirements of EPS Geofoam

Type	EPS12	EPS15	EPS19	EPS22	EPS29	EPS39	EPS46
Density, min., kg/m^3(lb/ft^3)	11.2 (0.70)	14.4 (0.90)	18.4 (1.15)	21.6 (1.35)	28.8 (1.80)	38.4 (2.40)	45.7 (2.85)
Compressive Resistance, min., kPa (psi) at 1 %	15 (2.2)	25 (3.6)	40 (5.8)	50 (7.3)	75 (10.9)	103 (15.0)	128 (18.6)
Compressive Resistance, min., kPa (psi) at 5 %	35 (5.1)	55 (8.0)	90 (13.1)	115 (16.7)	170 (24.7)	241 (35.0)	300 (43.5)
Compressive Resistance, min., kPa (psi) at 10 % ^{A}	40 (5.8)	70 (10.2)	110 (16.0)	135 (19.6)	200 (29.0)	276 (40.0)	345 (50.0)
Flexural Strength, min., kPa (psi)	69 (10.0)	172 (25.0)	207 (30.0)	240 (35.0)	345 (50.0)	414 (60.0)	517 (75.0)
Oxygen index, min., volume %	24.0	24.0	24.0	24.0	24.0	24.0	24.0



Depth (m)	**Estimated Largest Preliminary Stress (kPa)**	**Preliminary EPS Type**
0.5	96	***EPS39***
0.75	58	***EPS29***
1.0	38	***EPS19***
2	26	***EPS19***
3	13	***EPS19***
4	15	***EPS19***
5	10	***EPS19***

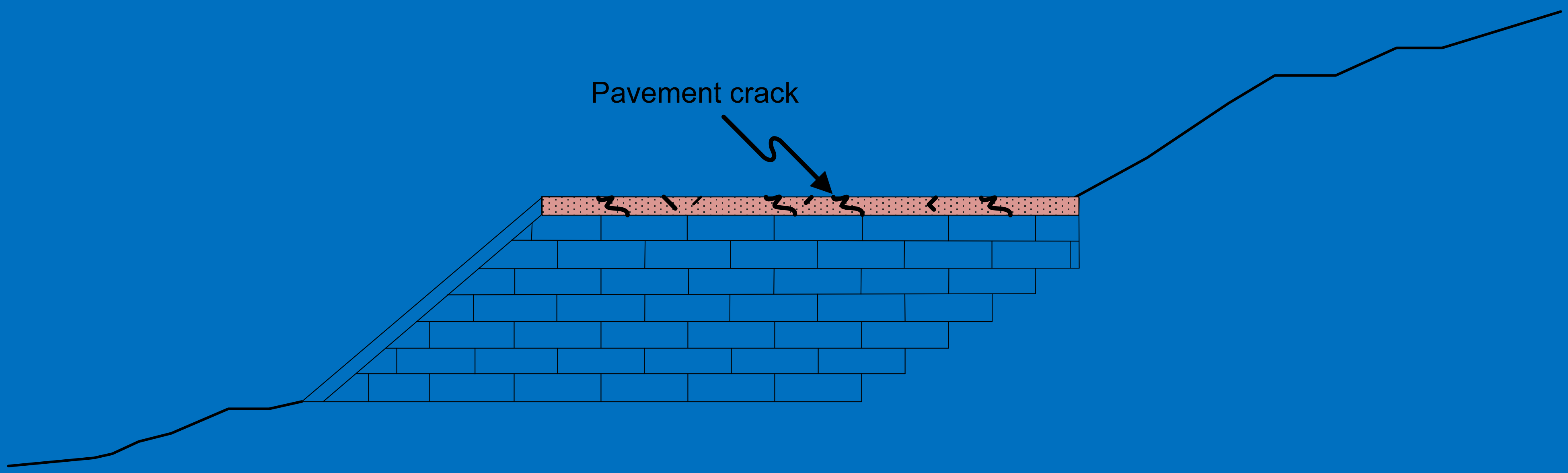
Load Distribution Slab

External Stability Summary of Failure Mechanisms

- Horizontal Sliding
- Load Bearing Failure

Pavement System Failure

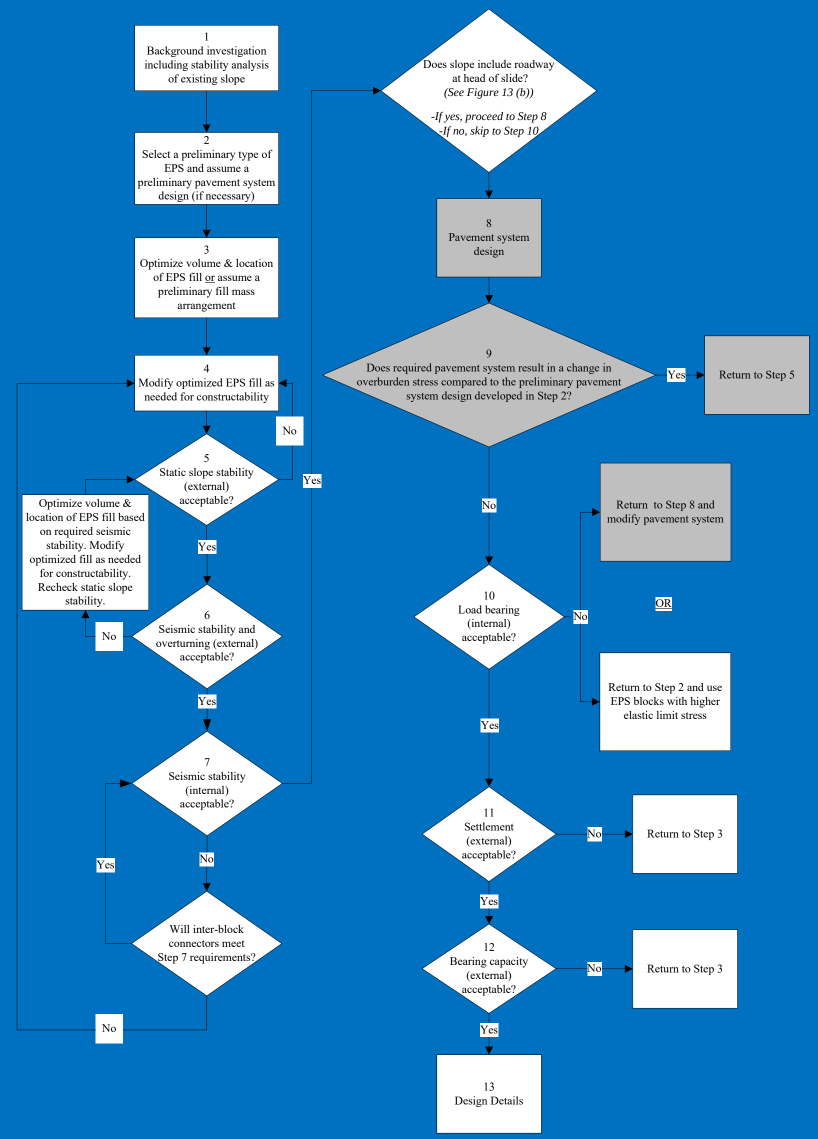
Pavement Design

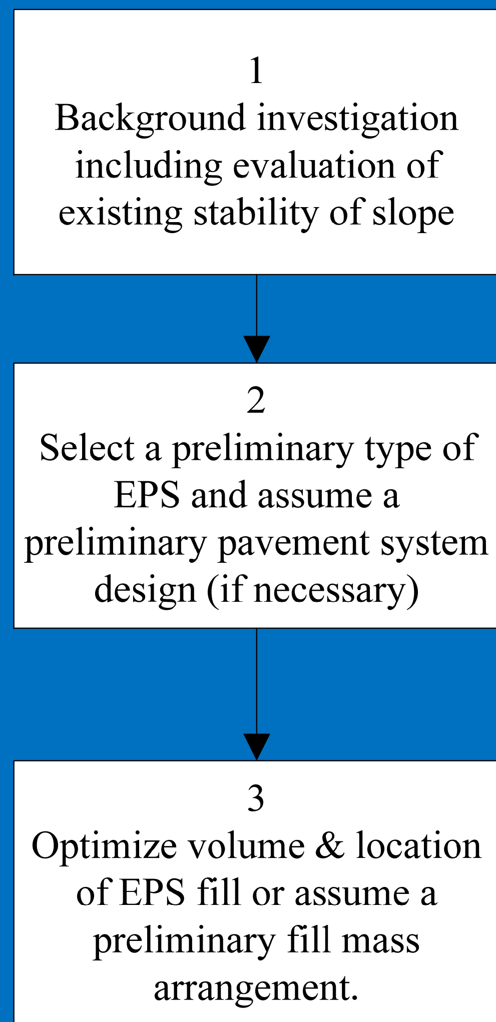


Overview of EPS Block Placement Configuration

Completed Road

Overall Design Procedure

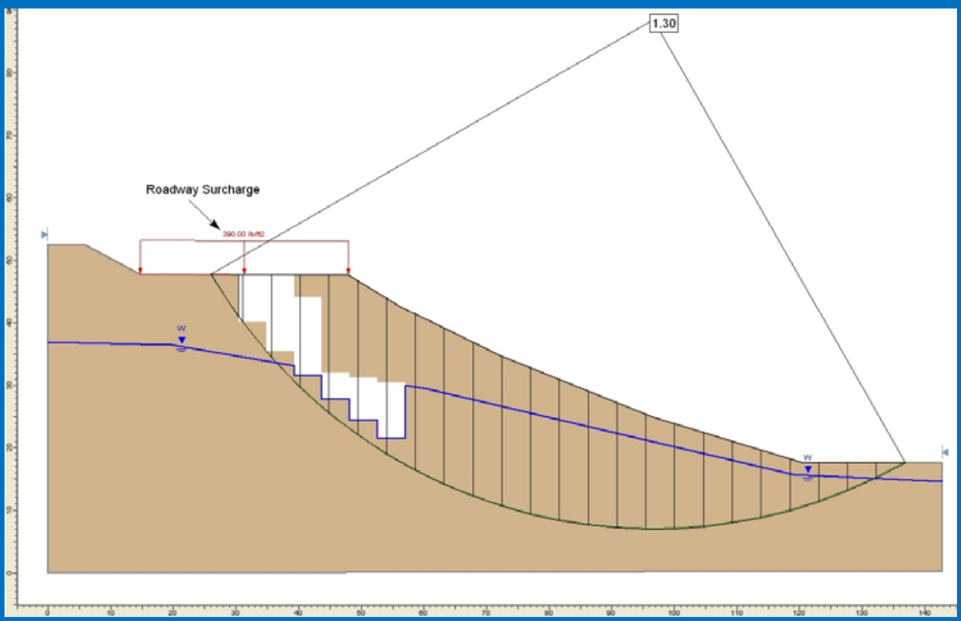



1
Background investigation including evaluation of existing stability of slope
2
Select a preliminary type of EPS and assume a preliminary pavement system design (if necessary)
3
Optimize volume & location of EPS fill or assume a preliminary fill mass arrangement.

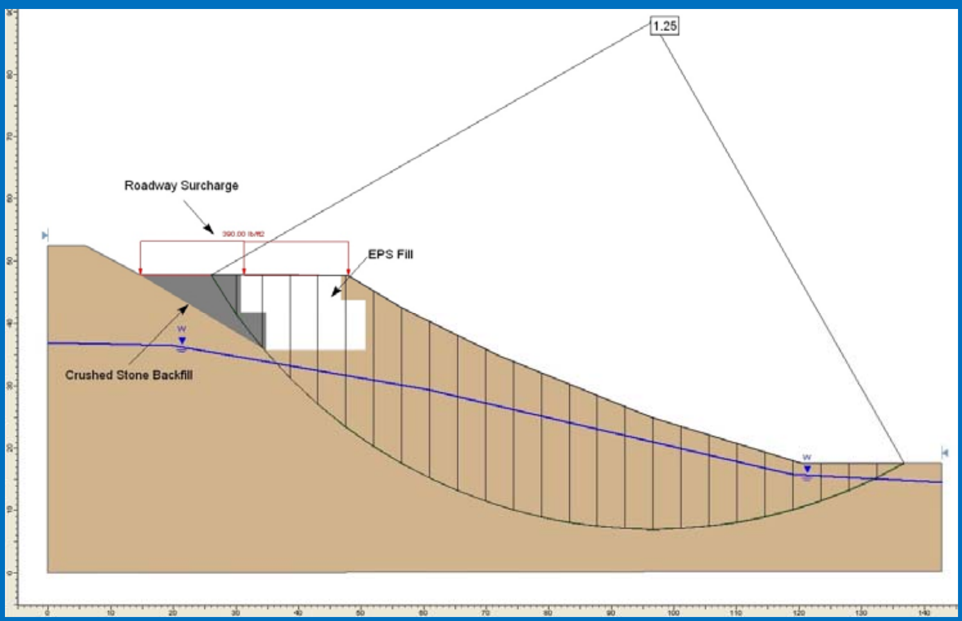
Optimization Procedure

- The optimal location of the EPS mass within the overall slope cross-section is not intuitively obvious.
  - Obtain results of preliminary slope stability analysis.
  - Copy or input stability analysis results into spreadsheet.
  - Set up optimization equations in spreadsheet.
  - Use Solver Add-In to perform optimization.

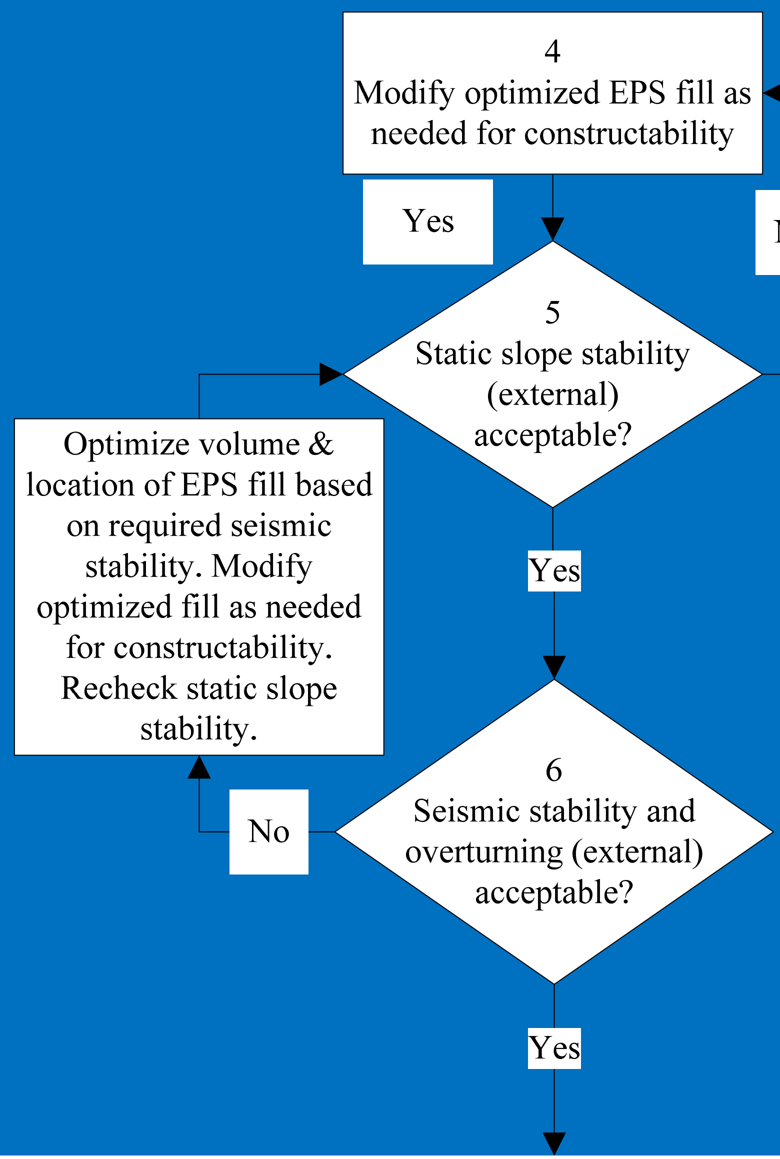
Optimization Procedure



Stability analysis results from optimization procedure



Stability analysis results of modified layout


4
Modify optimized EPS fill as needed for constructability
Yes
No
5
Static slope stability (external) acceptable?
Optimize volume & location of EPS fill based on required seismic stability. Modify optimized fill as needed for constructability. Recheck static slope stability.
Yes
6
Seismic stability and overturning (external) acceptable?
No
Yes

4
Modify optimized EPS fill as needed for constructability

No

Will the use of inter-block connectors meet Step 6 requirements?

-If Yes, Proceed to next step
-If No, Proceed to Step 4

No

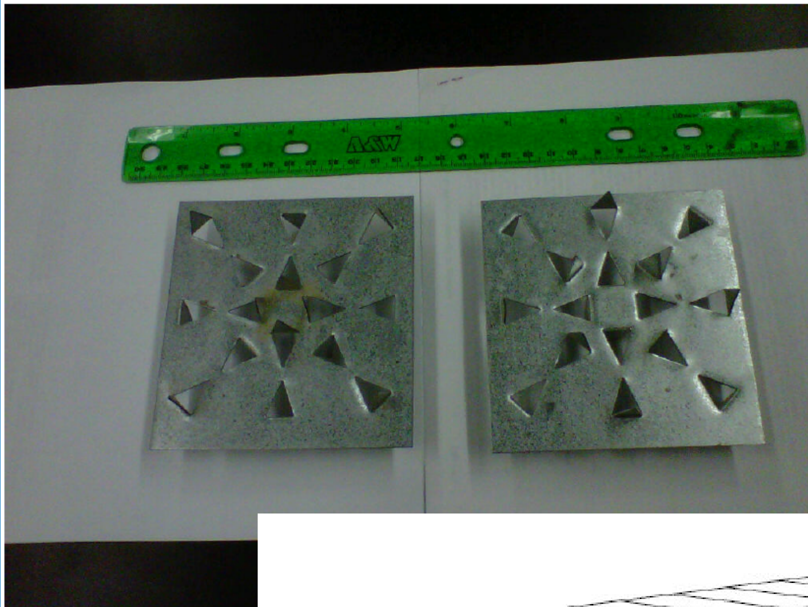
7
Seismic stability (internal) acceptable?

Yes

Proceed with next step

Yes

Increasing Block Resistance



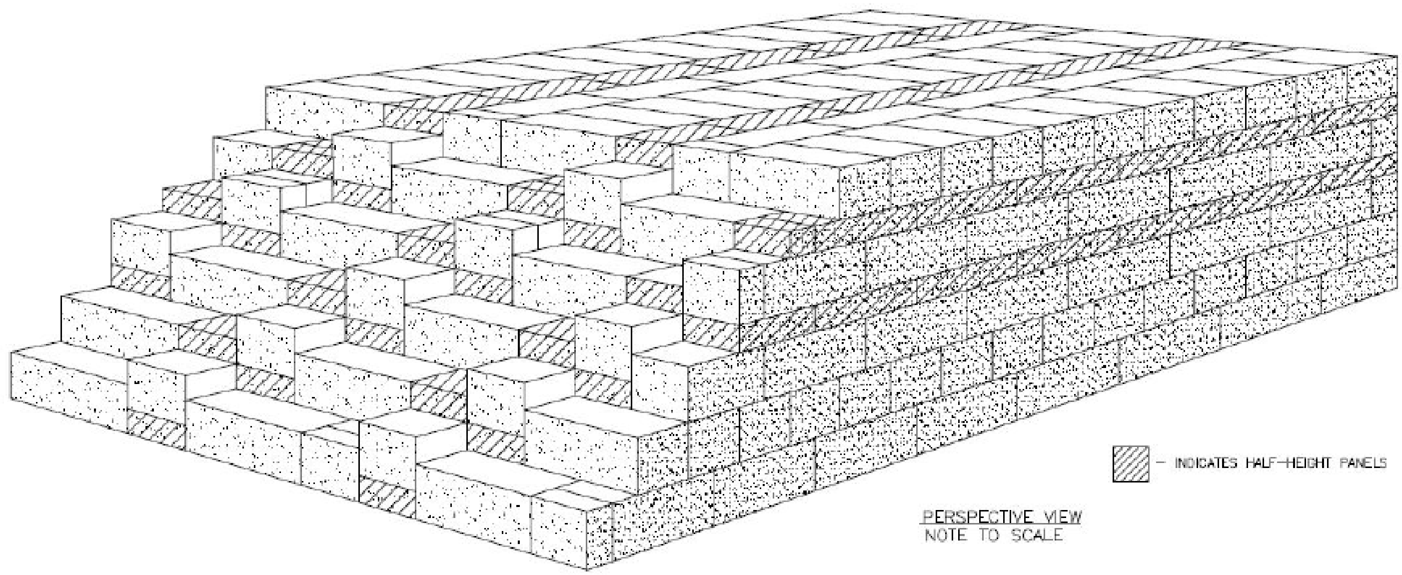
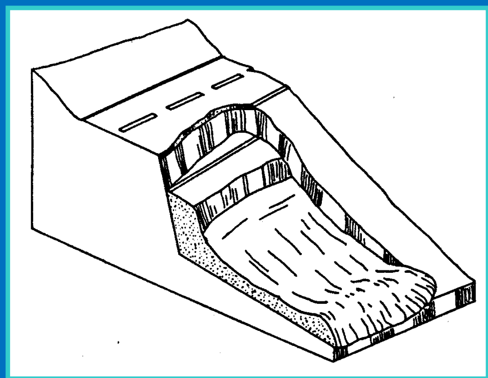
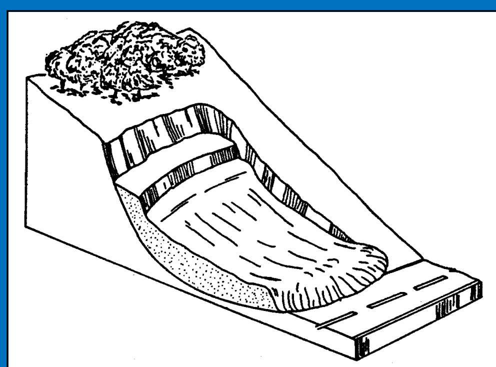
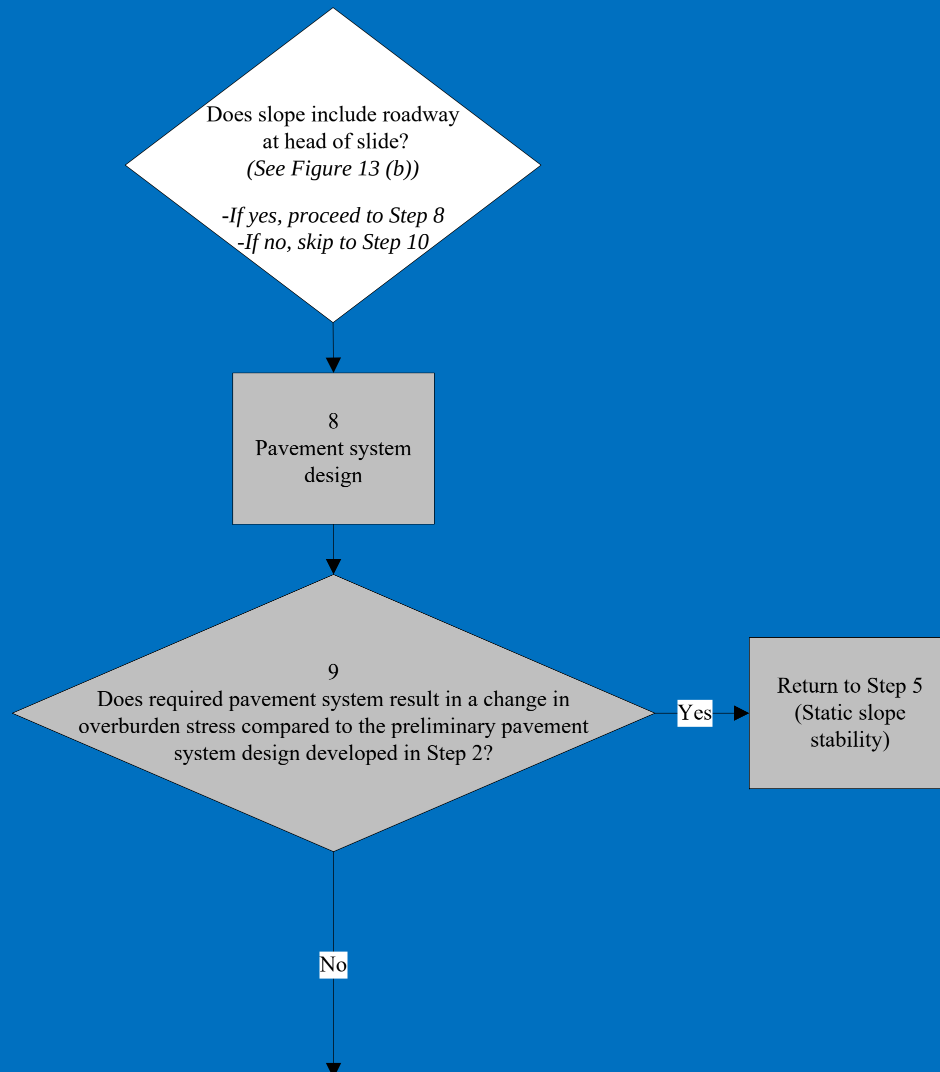
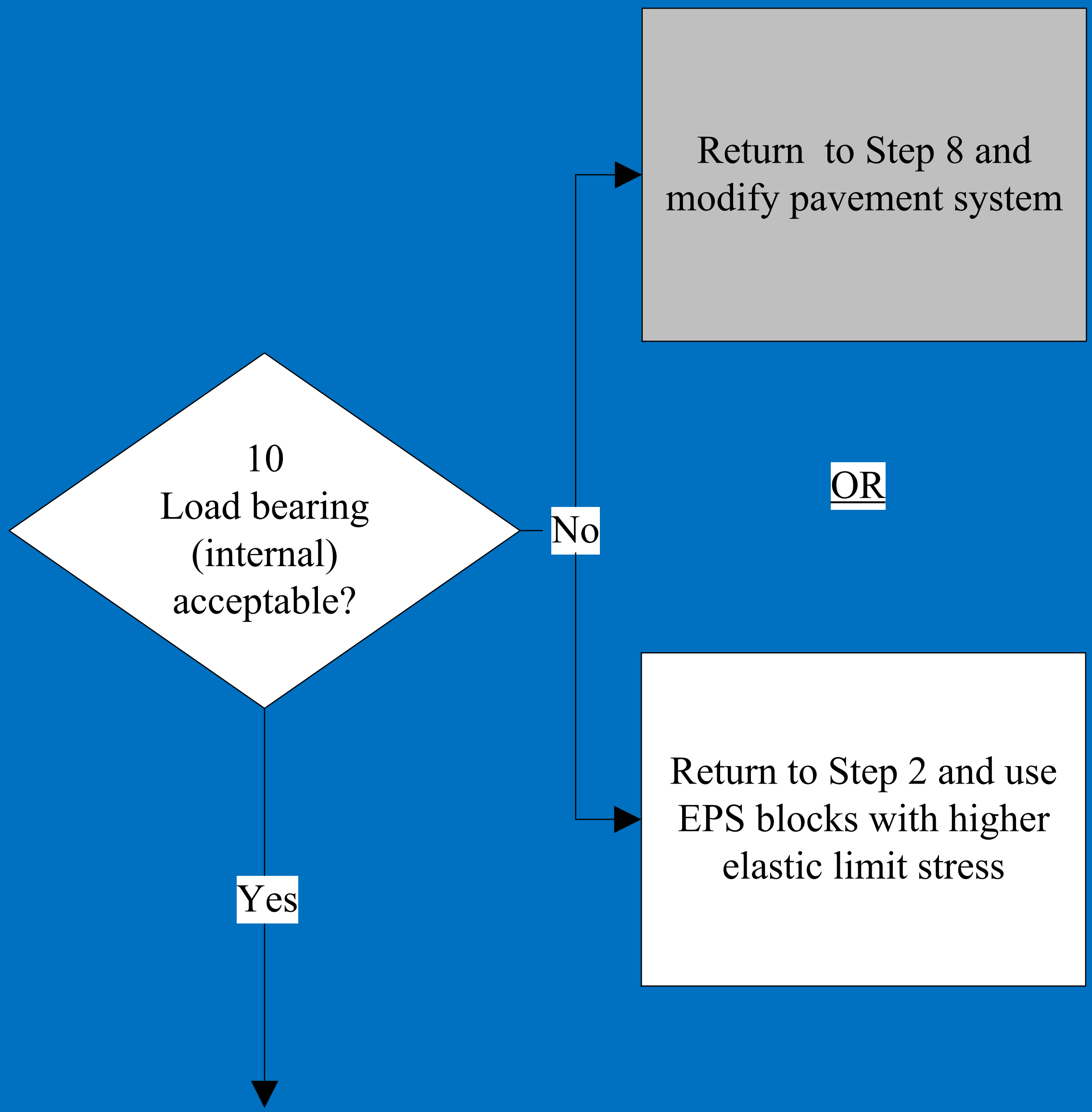


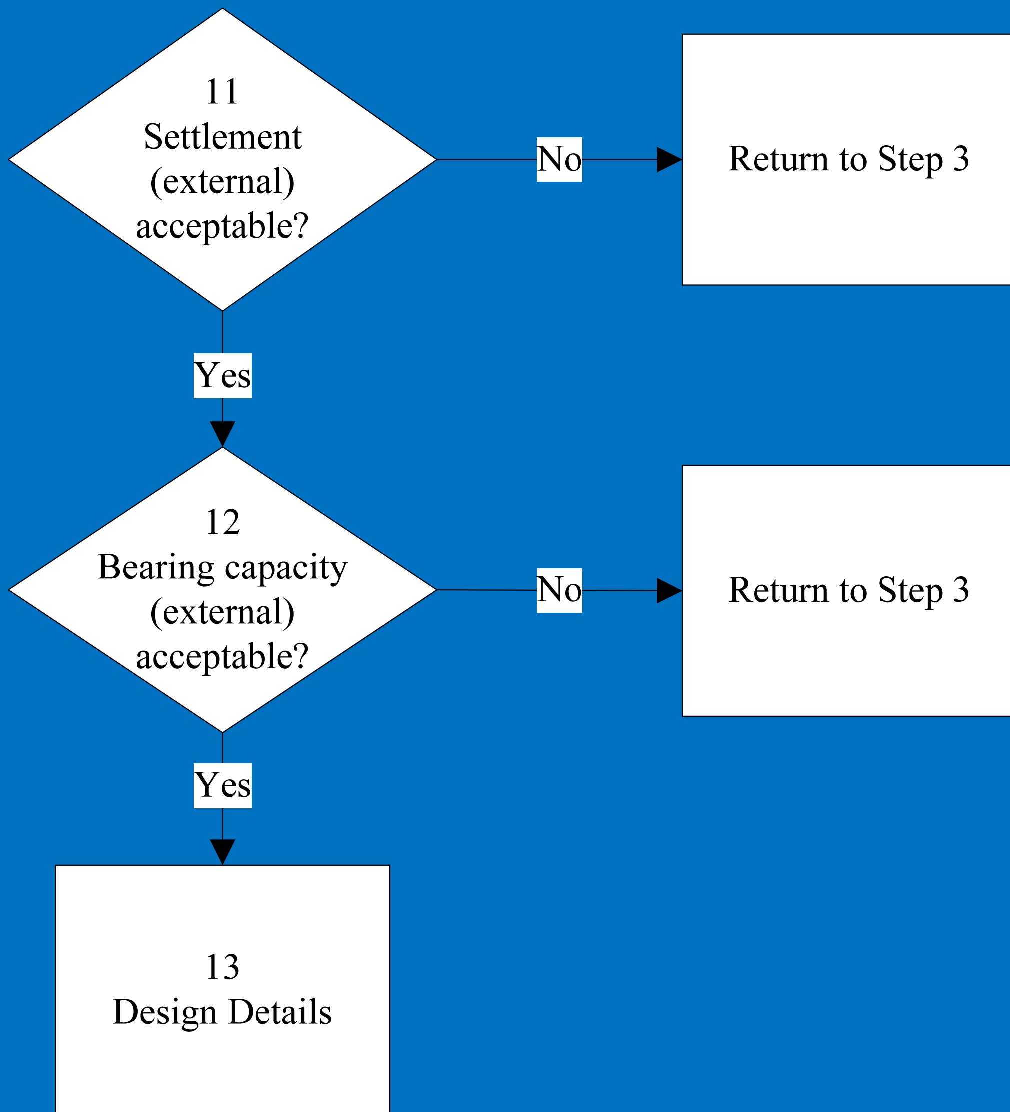
Figure 3.6. Geofoam shear key illustration (Insulfoam).



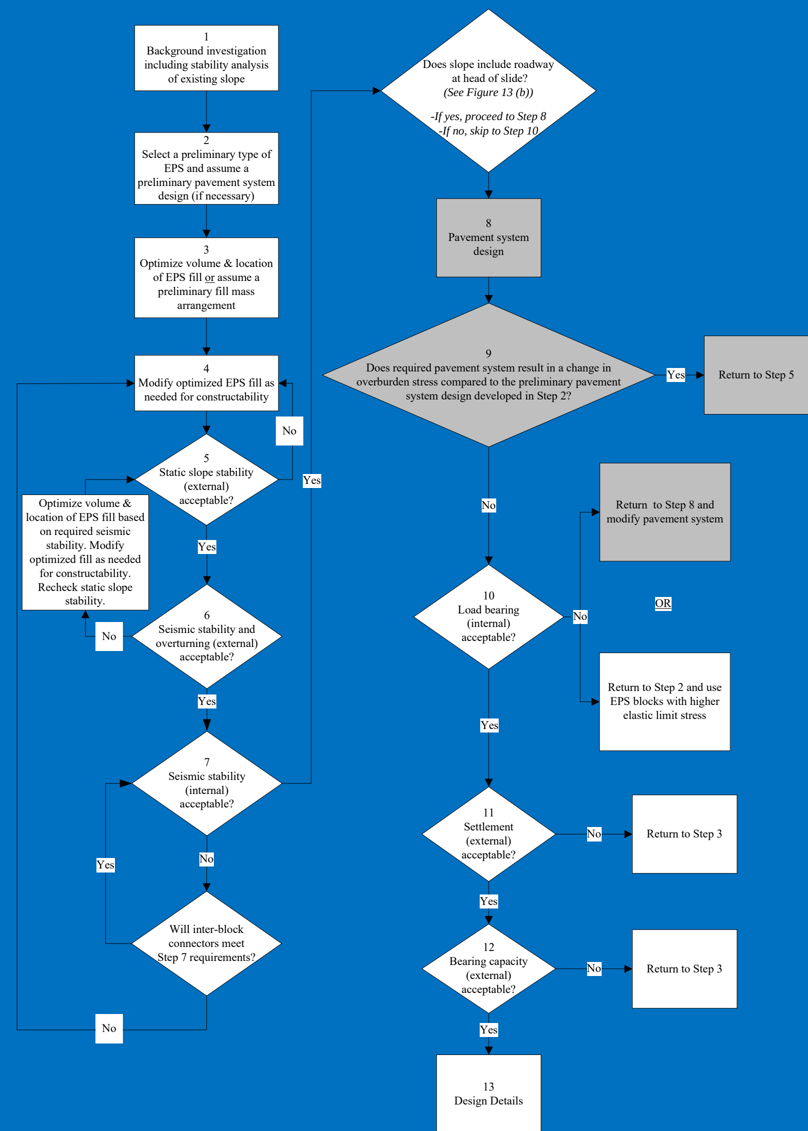



Does slope include roadway at head of slide?
(See Figure 13 (b))
-If yes, proceed to Step 8
-If no, skip to Step 10
8
Pavement system design
9
Does required pavement system result in a change in overburden stress compared to the preliminary pavement system design developed in Step 2?
Yes
Return to Step 5 (Static slope stability)
No


Return to Step 8 and modify pavement system
10
Load bearing (internal) acceptable?
No
OR
Return to Step 2 and use EPS blocks with higher elastic limit stress
Yes


11
Settlement
(external)
acceptable?
No
Return to Step 3
Yes
12
Bearing capacity
(external)
acceptable?
No
Return to Step 3
Yes
13
Design Details

Overall Design Procedure



Additional Design Considerations

Overview of EPS Block Placement Configuration

Long-Term Durability

Figure 4. Excavation of a 24 years old EPS block from the first EPS embankment at Flom bridge.

- 1972 Norway Flom Bridge
- First major lightweight fill project.
- Over 40 years of extensive worldwide use.

Aaboe & Frydenlund (2011)

Design Considerations: Ultraviolet Radiation

Photo: Sutmoller

Design Considerations: Flammability

- Two known fires worldwide – both in Norway
- Geofoam can be manufactured with flame retardant additives.
- Storage and handling of geofoam blocks should be done with attention to fire safety.

Frydenlund and Aabøe (1996)

Design Considerations: Liquid Petroleum Hydrocarbons

Photos: Sutmoller

Groundwater Control During Construction

- "Site flooding as a result of a heavy rain that caused previously placed blocks to float and move out of position was the underlying cause in all cases."

(Horvath 2010)

Key Assumptions of Design Procedure

- Based on a self-stable adjacent upper slope to prevent earth pressures on the EPS fill mass that can result in horizontal sliding between blocks.
- Based on the installation of a permanent drainage system.

Overview of Slope Excavation

Water at Bottom of Cut

Placement of Subsurface Drainage

Subsurface Drainage System & Drainage Channel

Drainage Channel Diverts Water Away From Slope

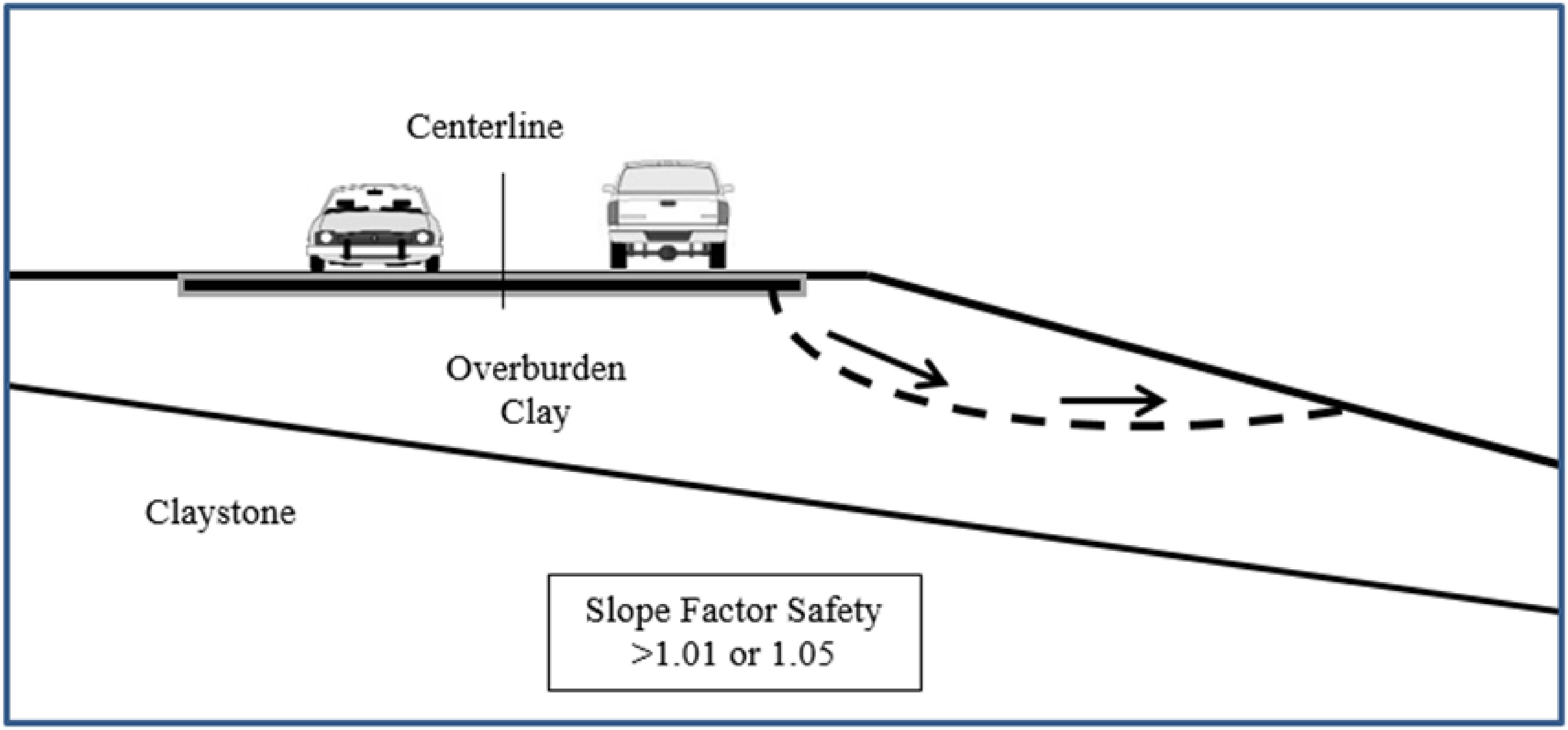
Construction practices & cost considerations

Ben Arndt, Yeh & Associates, Inc.

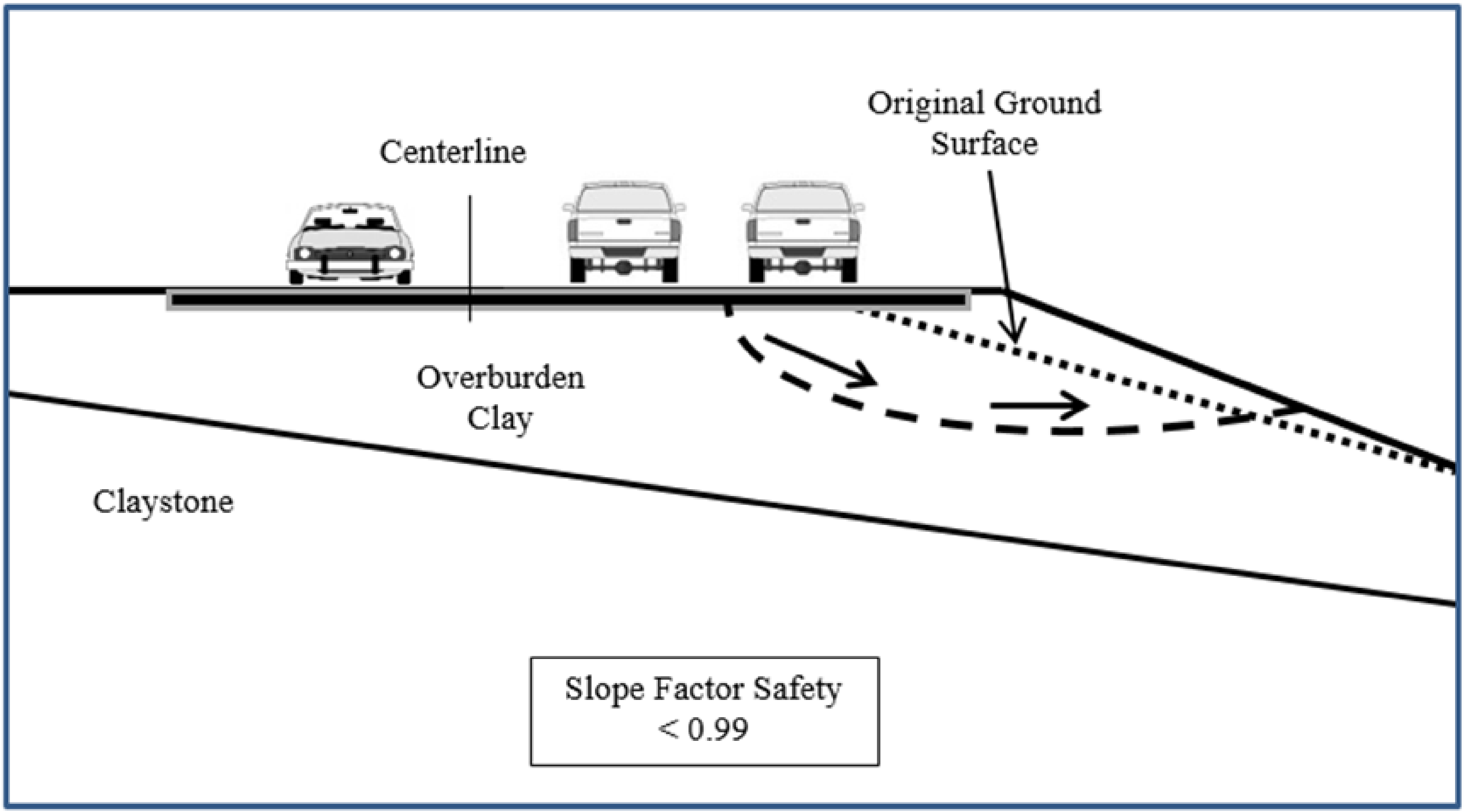
Using Geofoam for Embankment Failures

Using Geofoam for Embankment Failures

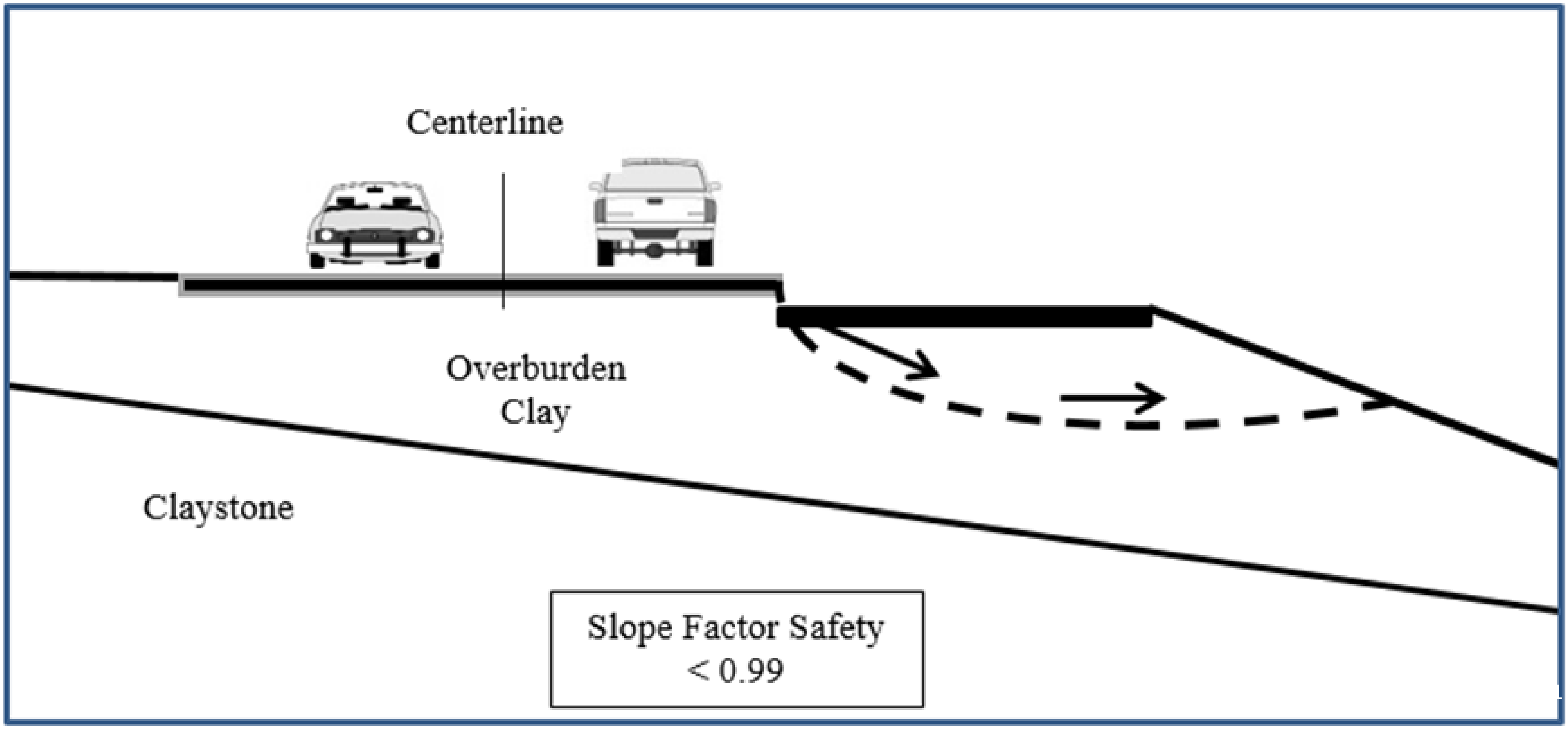
Existing Roadway with low strength embankments.



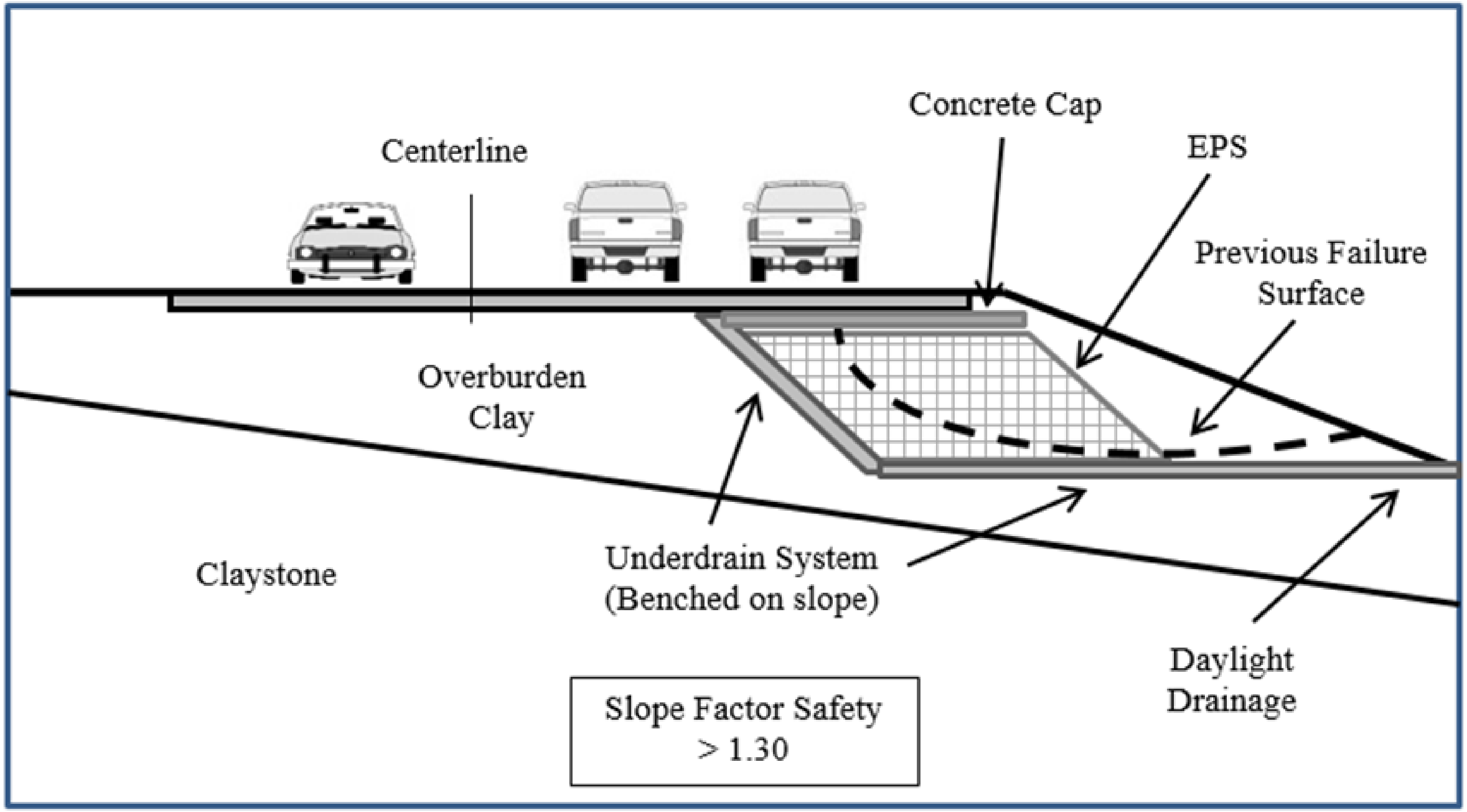
Roadway Widening Project



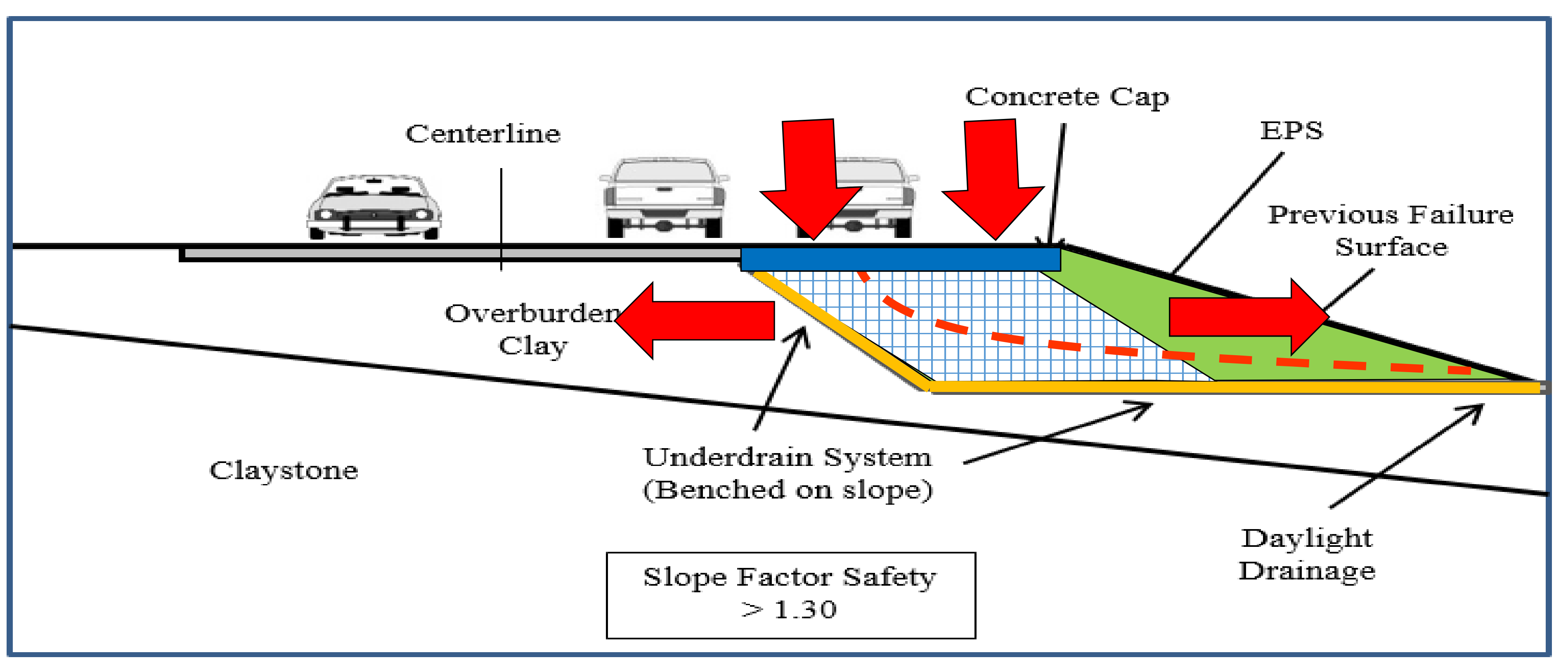
Creates an unstable roadway template



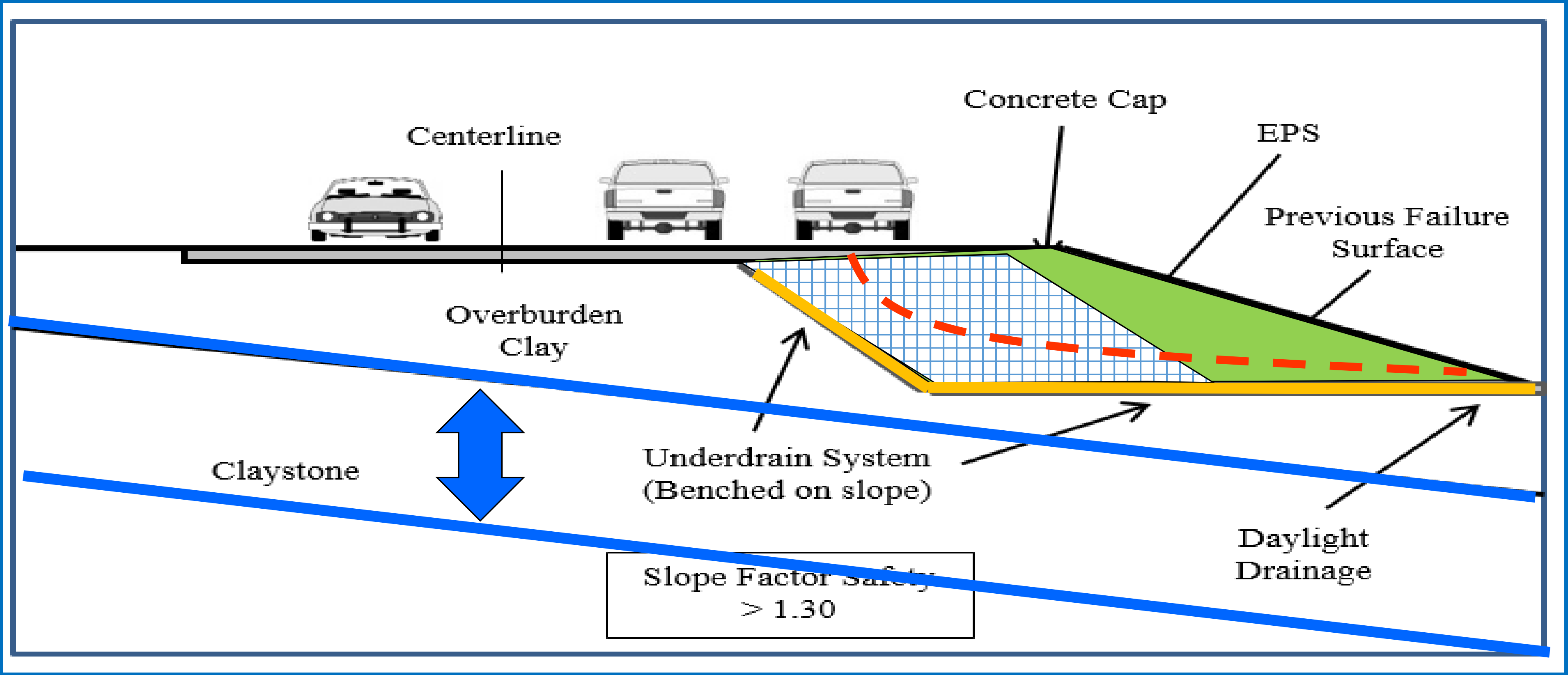
Mitigating the failure



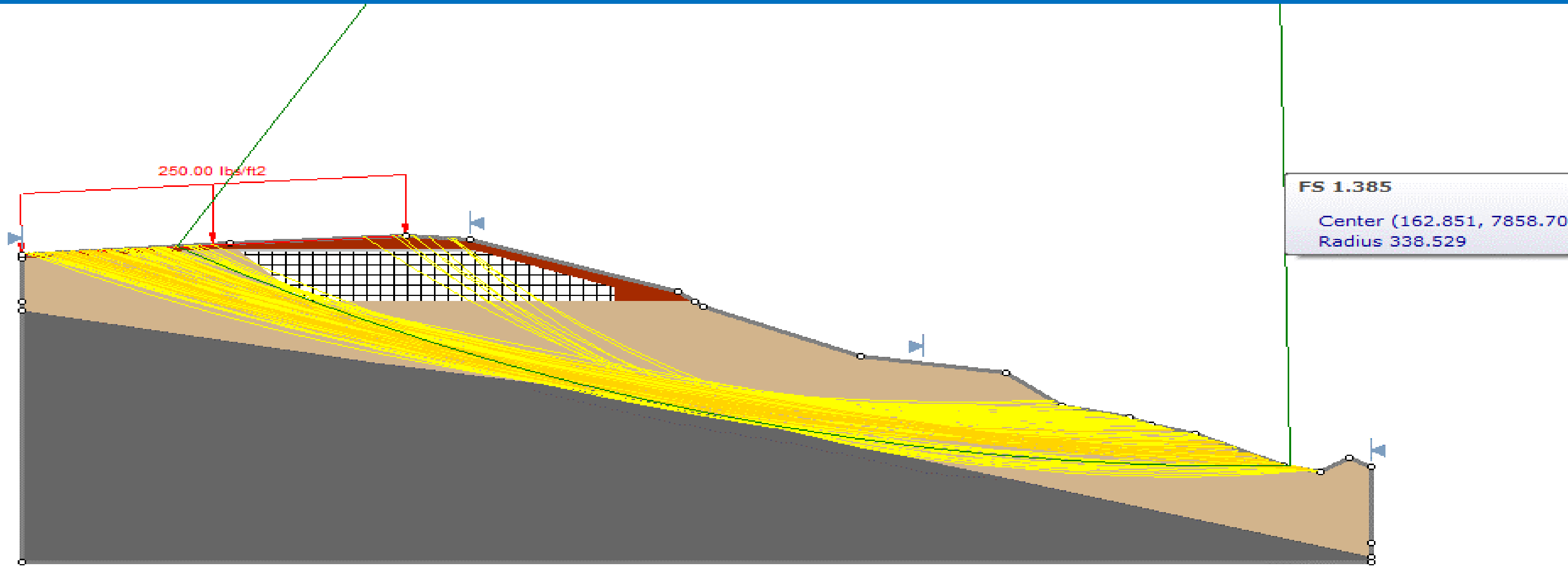
Mitigating the failure?



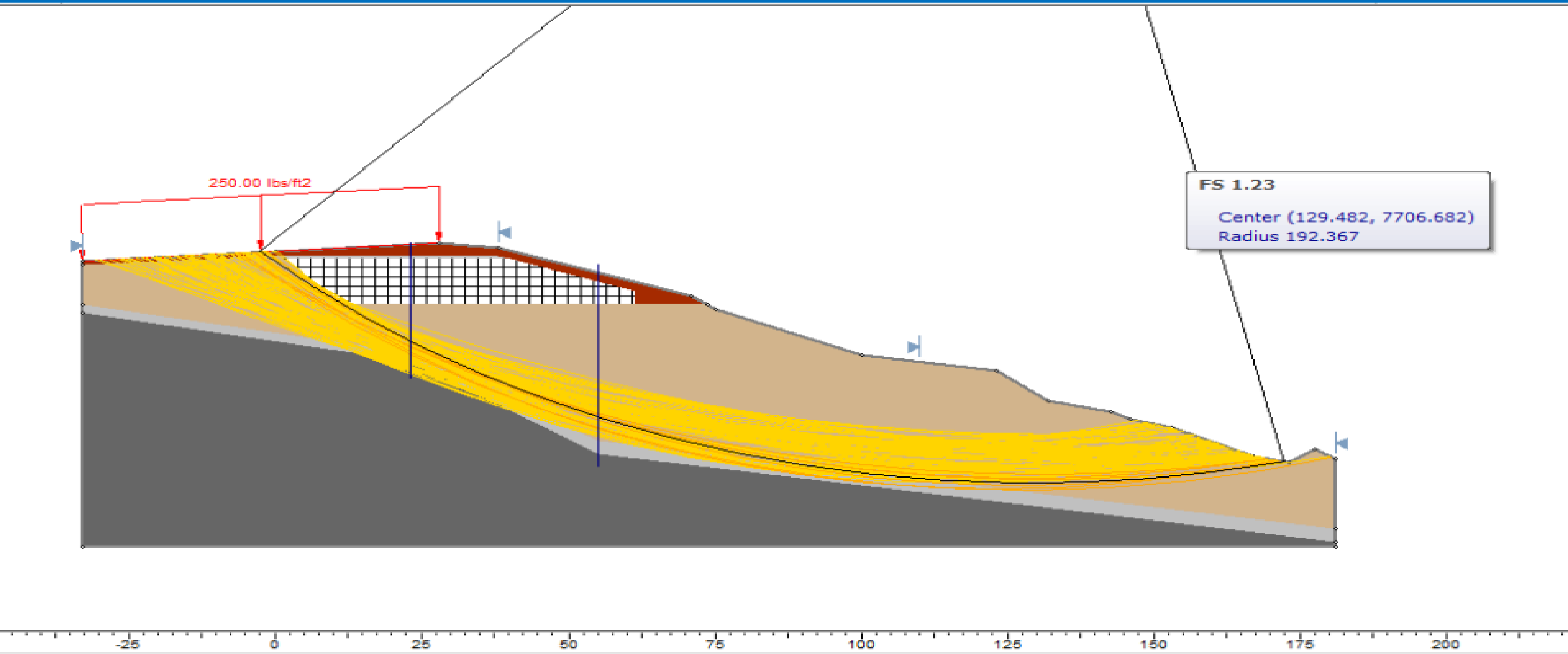
Mitigating the failure?



Depth of Bedrock
FOS = 1.38



Depth of Bedrock
FOS = 1.23



Case Histories Examples Corridors Yeh and Associates, Inc. have designed Geofoam Applications:

- US 50 – Montrose, CO
- US 160 – Durango, CO
- SH 13 – Rifle, CO
- US 26/89 – Jackson, WY

Site Conditions Colorado

- Sandstones and shales of the Mesaverde Group and Mancos Shale
- Highway embankments and fills exhibit low shear-strength properties when wetted and are prone to landslides and embankment failures.
- Overall the subject sites consisted of approximately 15 to 25 feet of low to medium plasticity clays underlain by weathered to unweathered shale/claystone bedrock.


Colorado US 50
Roadway Pavement Distress


Colorado US 50
MSE Walls Not Effective


Colorado US 50
KOMATSU
Geofoam Systems


Colorado US 50
1:1 Backslope or Flatter


Colorado US 50
Load Transfer Slab


Colorado US 50
Bobcat
Underdrain System


Colorado US 50
Well Aligned Block Interlock
System


Colorado US 50
Damaged Blocks to Outside

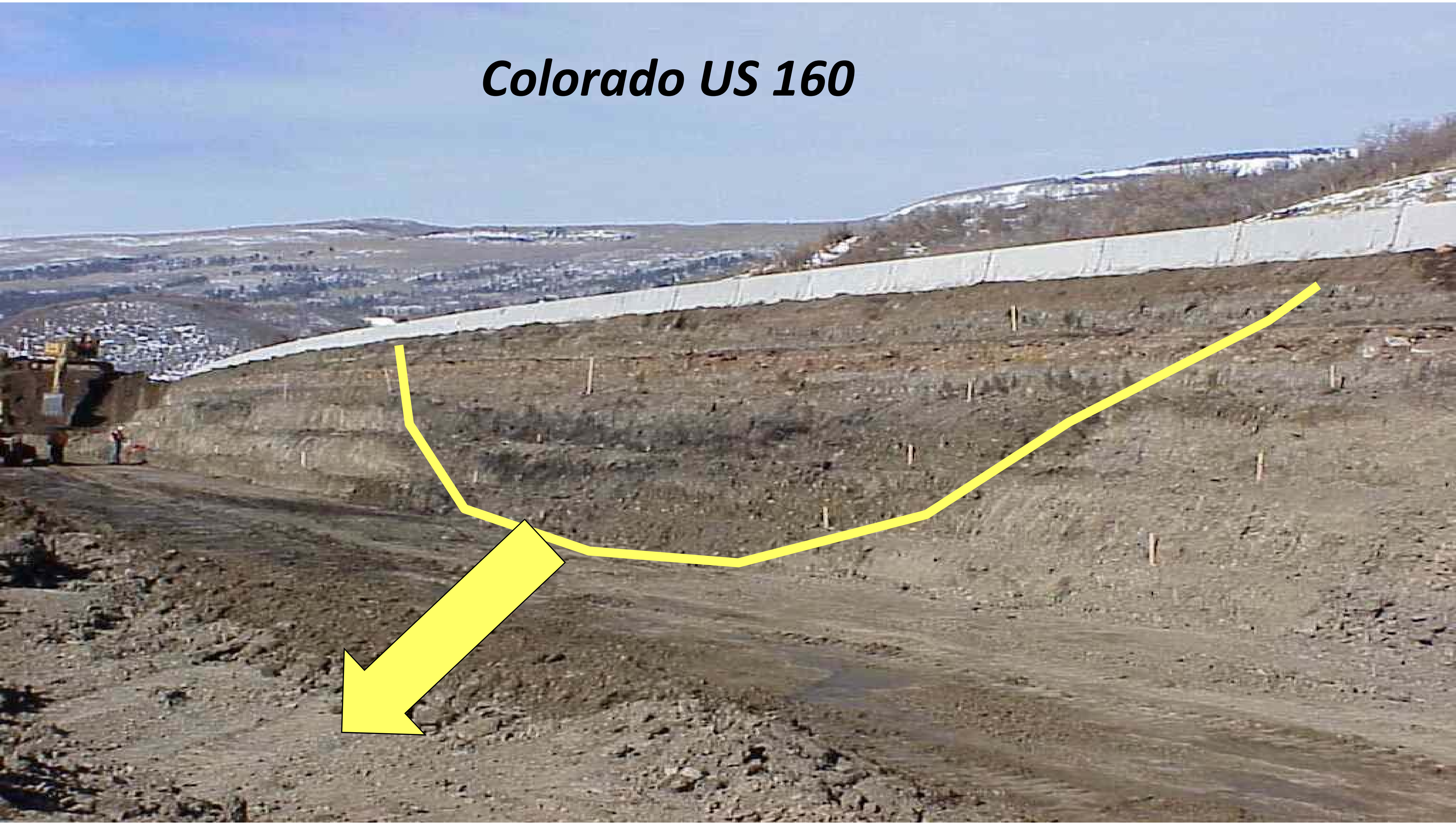

Colorado US 50
Cut with Hot Wire (No Chainsaws)

Project

- ***$3.9 Million Overall Project - 3 sites***
- ***$56/CY Geofoam Placement (26,000 CY)***
- ***2 Season Construction***

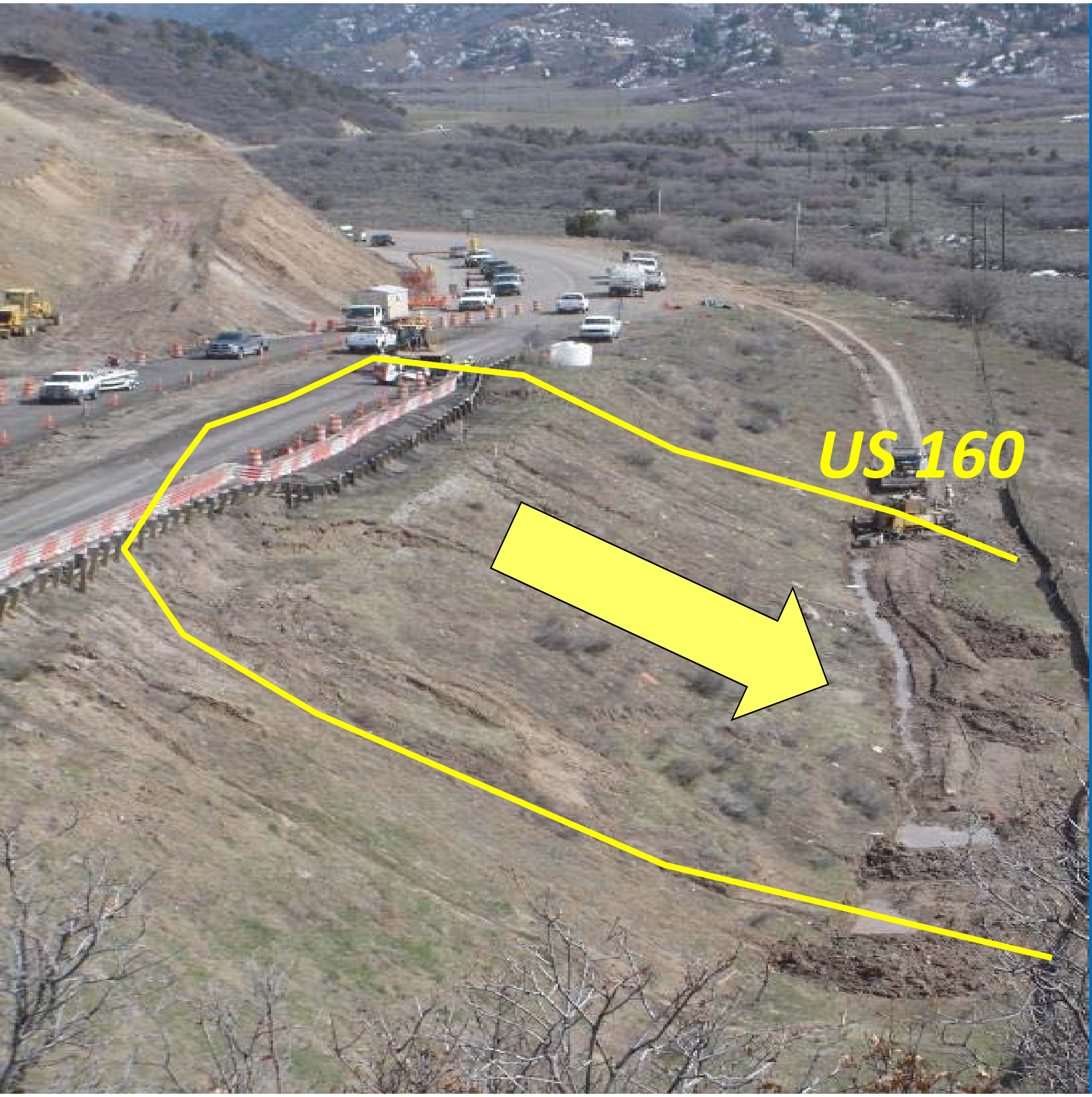
Colorado US 160

Colorado US 160


Colorado US 160


Colorado US 160
Winter Construction Fine


Colorado SH 13
Pavement Distress!



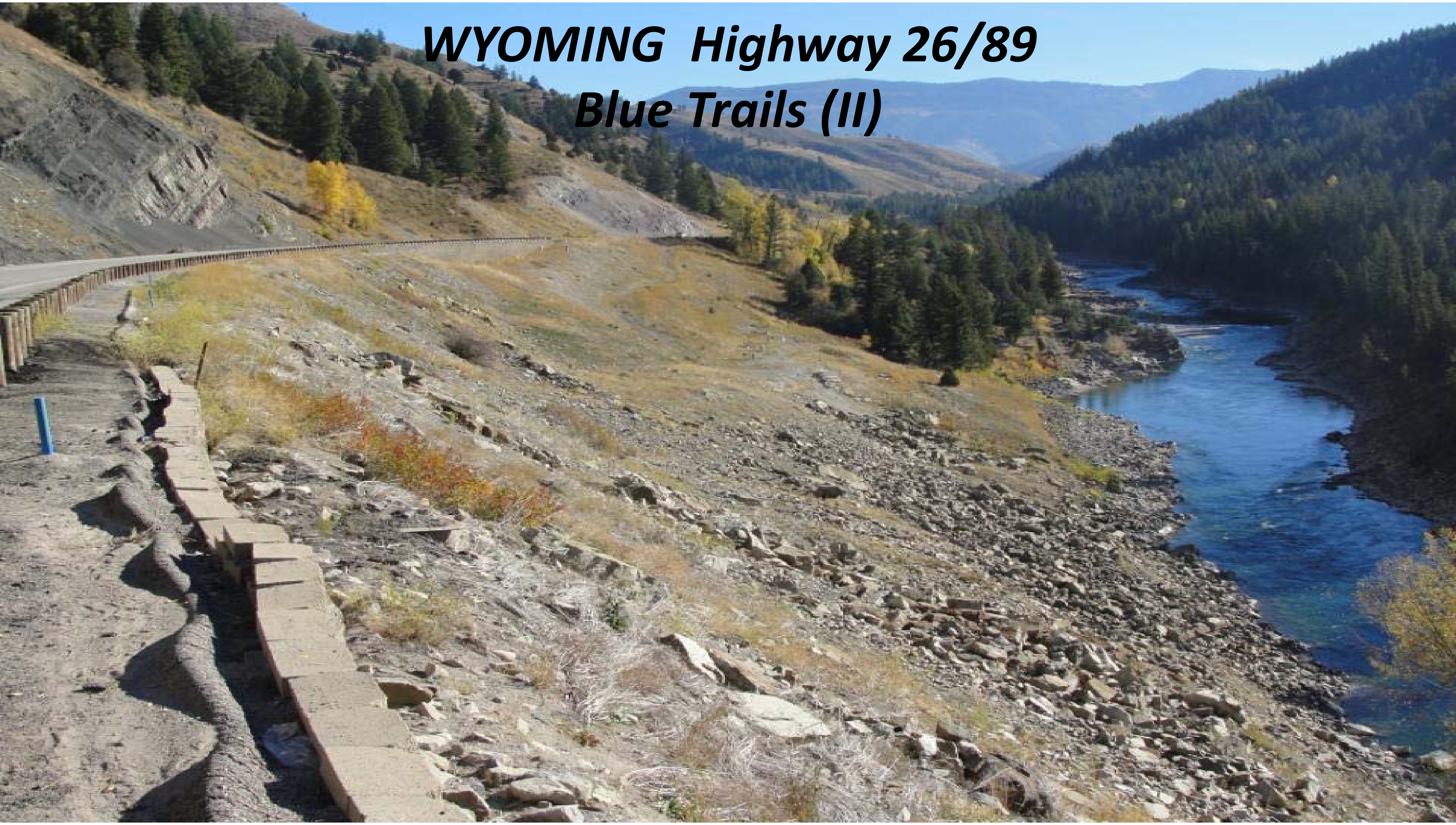
Colorado SH 13


Colorado SH 13


Colorado SH 13


Colorado SH 13


Colorado SH 13


WYOMING Highway 26/89
Blue Trails (II)

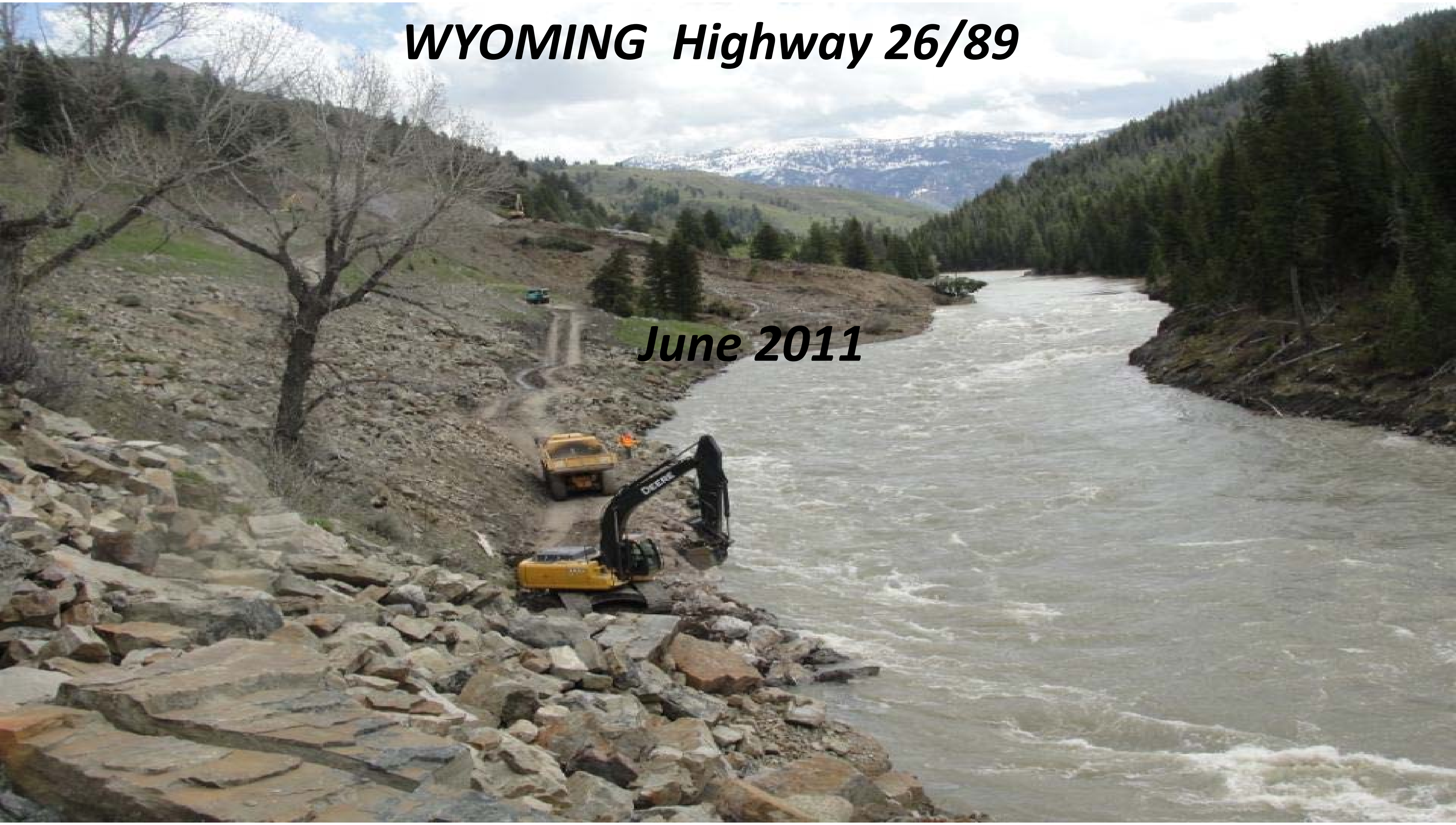

WYOMING Highway 26/89
June 2010
Pavement Distress!

Record Snow Winter
2011 to 2012


June 2011 – Double Draw


October 2010
June 2011


WYOMING Highway 26/89
June 2011


WYOMING Highway 26/89
June 2011
DEERE


WYOMING Highway 26/89
SPEED LIMIT 30
June 2011


WYOMING Highway 26/89
August 2011 - Construction
DEERE


WYOMING Highway 26/89
August 2011 - Construction
CAT

WYOMING Highway 26/89


WYOMING Highway 26/89
GF
Geofoam
09/28/2011 AM 10:41


WYOMING Highway 26/89
Project
• $2.2 Million Overall Project
• $90/CY Geofoam Placement (2,500 CY)
• 3 Month Construction

Geofoam Lightweight Fill

Reoccurring Construction Issues:

1. ***Handling of blocks to avoid damage***
2. ***Layout…….layout………layout.***
3. ***Acceptable gaps between blocks (1/4 inch -1 inch)?***
4. ***Accommodating short term settlement prior to paving.***

Update on previous standard for slope stability applications

David Arellano, University of Memphis

Availability of Standards

- ASTM Standards
  - D6817 Standard Specification for Rigid Cellular Polystyrene Geofoam
  - D7180 Standard Guide for Use of Expanded Polystyrene (EPS) Geofoam in Geotechnical Projects
  - D7557 Standard Practice for Sampling of Expanded Polystyrene Geofoam Specimens

ASTM D6817 Physical Property Requirements of EPS Geofoam

Type	EPS12	EPS15	EPS19	EPS22	EPS29	EPS39	EPS46
Density, min., kg/m³(lb/ft³)	11.2 (0.70)	14.4 (0.90)	18.4 (1.15)	21.6 (1.35)	28.8 (1.80)	38.4 (2.40)	45.7 (2.85)
Compressive Resistance, min., kPa (psi) at 1 %	15 (2.2)	25 (3.6)	40 (5.8)	50 (7.3)	75 (10.9)	103 (15.0)	128 (18.6)
Compressive Resistance, min., kPa (psi) at 5 %	35 (5.1)	55 (8.0)	90 (13.1)	115 (16.7)	170 (24.7)	241 (35.0)	300 (43.5)
Compressive Resistance, min., kPa (psi) at 10 % [A]	40 (5.8)	70 (10.2)	110 (16.0)	135 (19.6)	200 (29.0)	276 (40.0)	345 (50.0)
Flexural Strength, min., kPa (psi)	69 (10.0)	172 (25.0)	207 (30.0)	240 (35.0)	345 (50.0)	414 (60.0)	517 (75.0)
Oxygen index, min., volume %	24.0	24.0	24.0	24.0	24.0	24.0	24.0

EPSIA: EPS Geofoam Applications & Technical Data

Proven Technology

- Has been used in roads since 1972.
  - Proven durability
- Proven technology in various transportation applications.
- Design guidelines are available.
- Construction quality control and assurance standards available.
- FHWA designated priority, market-ready technology.
  - FHWA Resource Center serves as a resource for State DOTs.
  - GeoTechTools: Web-based geotechnical solutions for soil improvement, rapid embankment construction, and stabilization of the pavement platform.

Technology Information

Lightweight Fill

A lower unit weight of fill is used for roadway embankment construction and for other applications in combination with other technologies to reduce the magnitude of applied load and seismic horizontal forces so that the total embankment settlement can be reduced and stability can be increased. Advantages include accelerated construction, reduced structural requirements for resisting lateral loads, reduced settlement and stability problems, and suitability for wide variety of projects. This technique is applicable to embankments on soft soils and embankment widening.

Lightweight fill technology refers to six different categories of lightweight fill materials:

- Aggregate (includes pumice, scoria, Expanded Shale, Clay & Slate (ESCS), and slag)
- Cellular concrete (something referred to as foamed concrete)
- Fly ash
- Geofoam
- Shredded tire (sometimes referred to as Tire Derived Aggregate (TDA))
- Wood fiber

- ☐ Technology Fact Sheet
- ☐ Photos
- Case Histories
  - ☐ Boston Central Artery/Tunnel, Boston, Massachusetts
  - ☐ I-15 Reconstruction, Salt Lake City, Utah
- ☐ Design Guidance
- ☐ Quality Control/Quality Assurance
- ☐ Cost Information
- ☐ Specifications
- ☐ Bibliography

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SHRP 2 ratings for Lightweight Fill

	Potential Contribution to SHRP 2 Renewal Objectives		
Degree of Technology Establishment	Rapid Renewal of Transp. Facilities	Minimal Disruption of Traffic	Production of Long-Lived Facilities
5	5	3	3

(Rating Scale: 1 = not established or low applicability, 5 = well established or high applicability)

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

Summary of Applications

- Road construction over poor soils
- Road widening
- Bridge abutment
- Bridge under fill
- Culverts, pipelines & buried structures
- Rail embankment
- Slope stabilization
- Airport taxiway
- Retaining and buried wall backfill
- Compensating foundations
- Landscaping & vegetative green roofs
- Stadium & theater seating
- Levees
- Foundations for lightweight structures
- Noise and vibration damping
- Compressible application
- Seismic application
- Permafrost embankments
- Rock fall/impact protection

Question & answer session