THE ADVANTAGES OF REINFORCED EARTH STRUCTURES OVER OTHER RETAINAGE SYSTEMS

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OBJECTIVES

OBJECTIVES

- To Explain Differences Between RSS and MSE Systems
- To Explain the Applications of RSS Systems
- To Explain the Advantages and Disadvantages of RSS Systems
- To Explain the Design Approach for RSS Systems
- To Introduce New Reinforced Soil Technology

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REINFORCED SOIL

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Reinforced Soil

A composite Material Formed by the Association of Frictional Soil and Tension Resistant Elements in the Form of Sheets, Strips, or Nets of Metal, Synthetic Fabrics or Fiber Reinforced Plastics.

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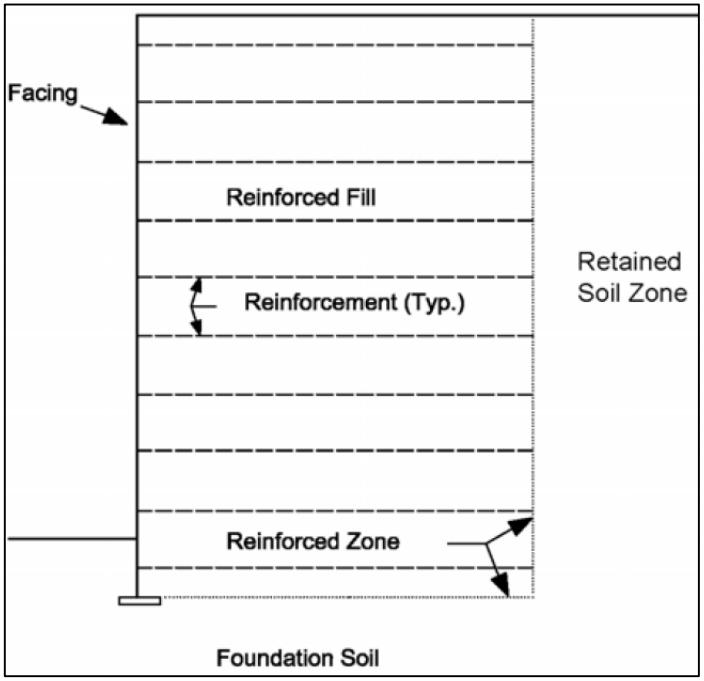
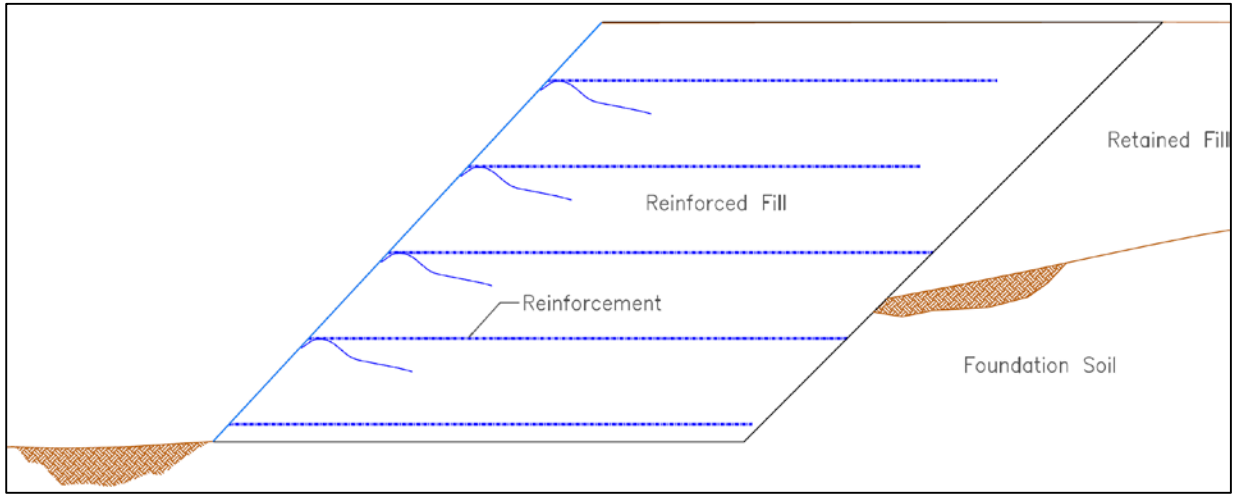
Reinforced Soil Structures

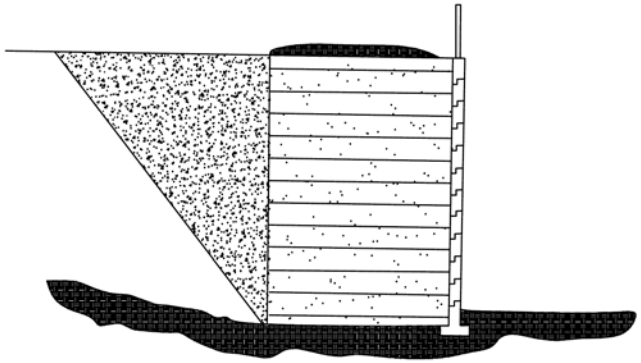
- Mechanically Stabilized Earth Walls (MSE)



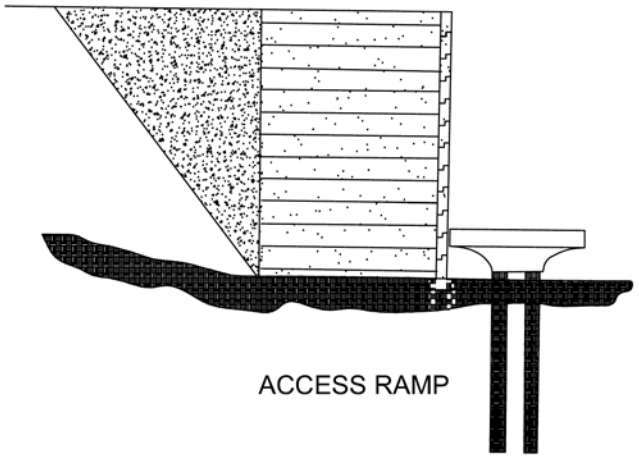
- Reinforced Soil Slope (RSS)



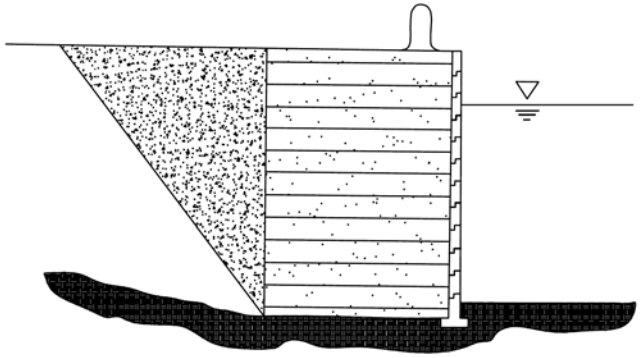
MSE Wall Applications



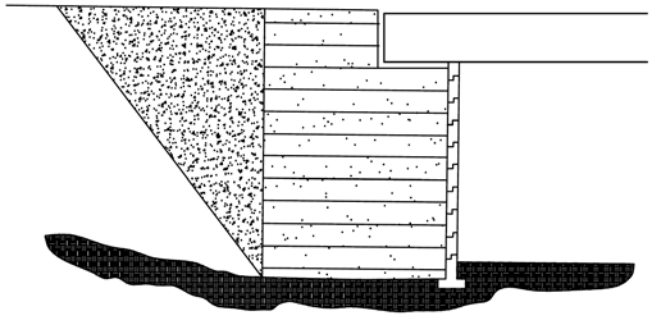
RETAINING WALL



ACCESS RAMP



WATERFRONT STRUCTURE



BRIDGE ABUTMENT

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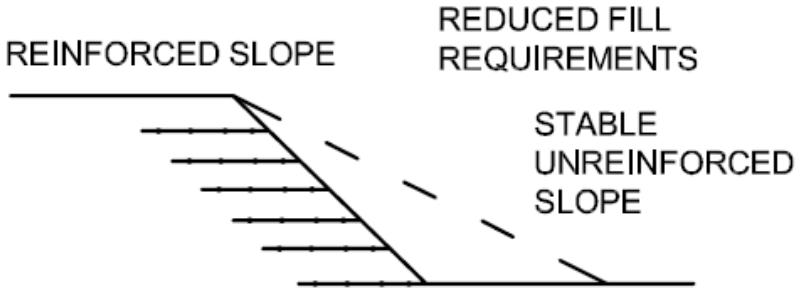
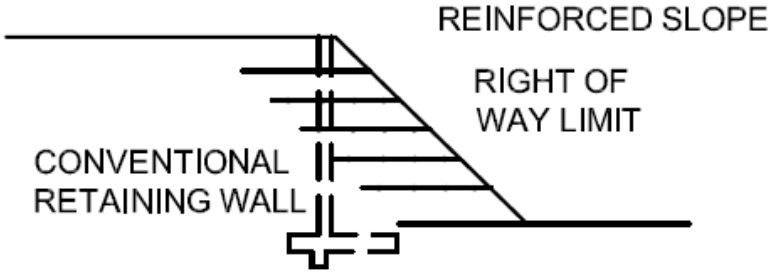
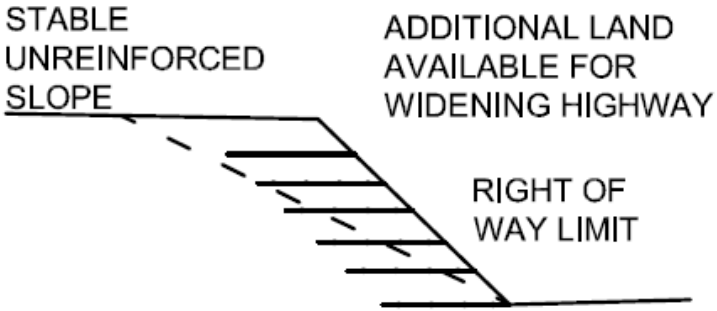


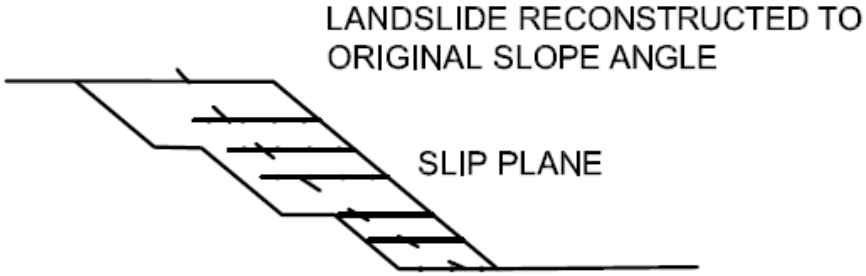
NEW CONSTRUCTION



WALL ALTERNATIVE



ROAD WIDENING



SLIDE REPAIR

Reinforced Soil Slope Applications

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Reinforcing Elements

- Metallic Reinforcements – Galvanized/Epoxy Coated
  - Smooth or Ribbed Strips
  - Grids or Bar Mats

- Geosynthetic Reinforcements – Polyethylene or Polyester
  - Geogrids
  - Geotextiles

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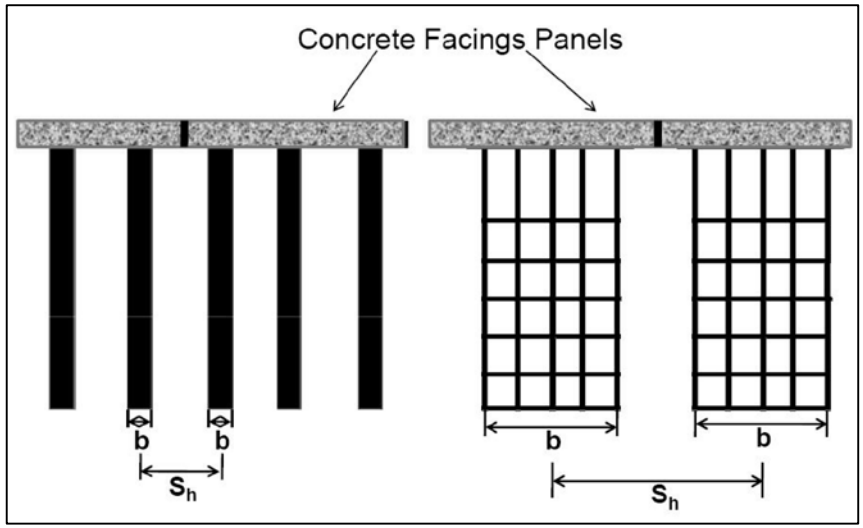
Concrete Facings Panels
b
b
S_h
b
b
S_h

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ADVANTAGES OF REINFORCED SOIL SLOPES AND COMPARISON WITH MSE SYSTEMS

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Advantages of Reinforced Soil Slopes

- Simple and Rapid Construction Procedures
- Not Requiring as Large of Construction Equipment
- Not Requiring Special Skills for Construction
- Needing Less Space in front of the Structure for Construction Operations
- Not Requiring Rigid, Unyielding Foundation Support
- Technically Feasible to Heights in Excess of 100 ft.

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Advantages of Reinforced Soil Slopes

- Material Saving
- Using Low Quality Material
- Economical Alternative to Retaining Wall
- Up to 50% or More, Less Expensive than MSE Walls
- Potential Aesthetic Advantage over Retaining Wall Structures (Vegetated-Faced)
- Safer than Flatter, Unreinforced Slopes Designed at the Same Factor of Safety
- Slope Drainage Element

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Advantages of Reinforced Soil Slopes

- No Rigid Facing and More Tolerable to Settlement as a Result
- More Tolerable to Minor Distortion Resulted From Freezing and Thawing, or Wetting-Drying of the Backfill

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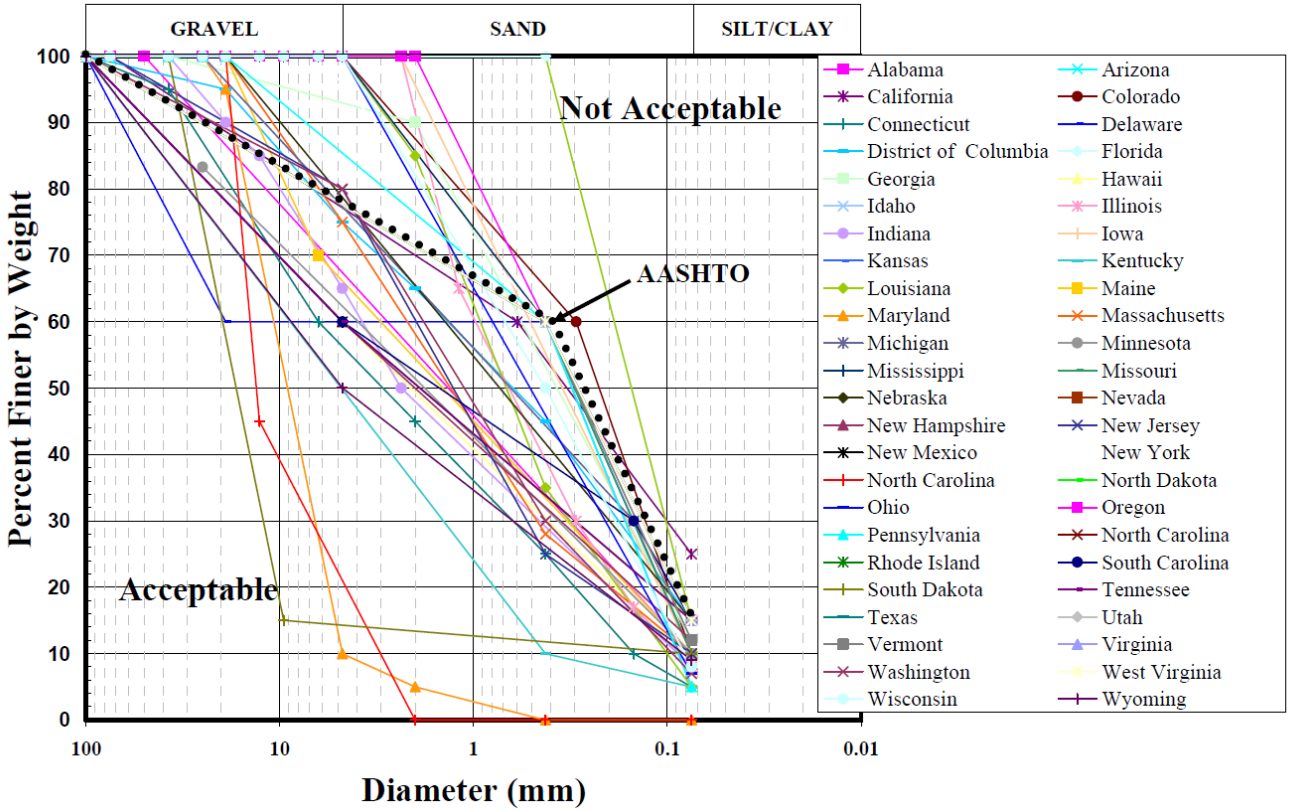
MSE Wall Select Granular Reinforced Fill Requirements

- Requiring the Use of Select Granular Fill

U.S. Sieve Size	Percent Passing
4-inch (102 mm)*	100
No. 40 (0.425 mm)	0 – 60
No. 200 (0.075 mm)	0 - 15
Plasticity Index (PI) shall not exceed 6 Soundness tests required	
* ≤ ¾ in. for geosynthetics & epoxy or PVC coated steel unless construction installation damage tests performed	

MSE Wall Select Granular Reinforced Fill Requirements

- NCHRP 24-22



Acceptable "Upper" Gradation Limit for Reinforced Fill from State Responses to the Survey

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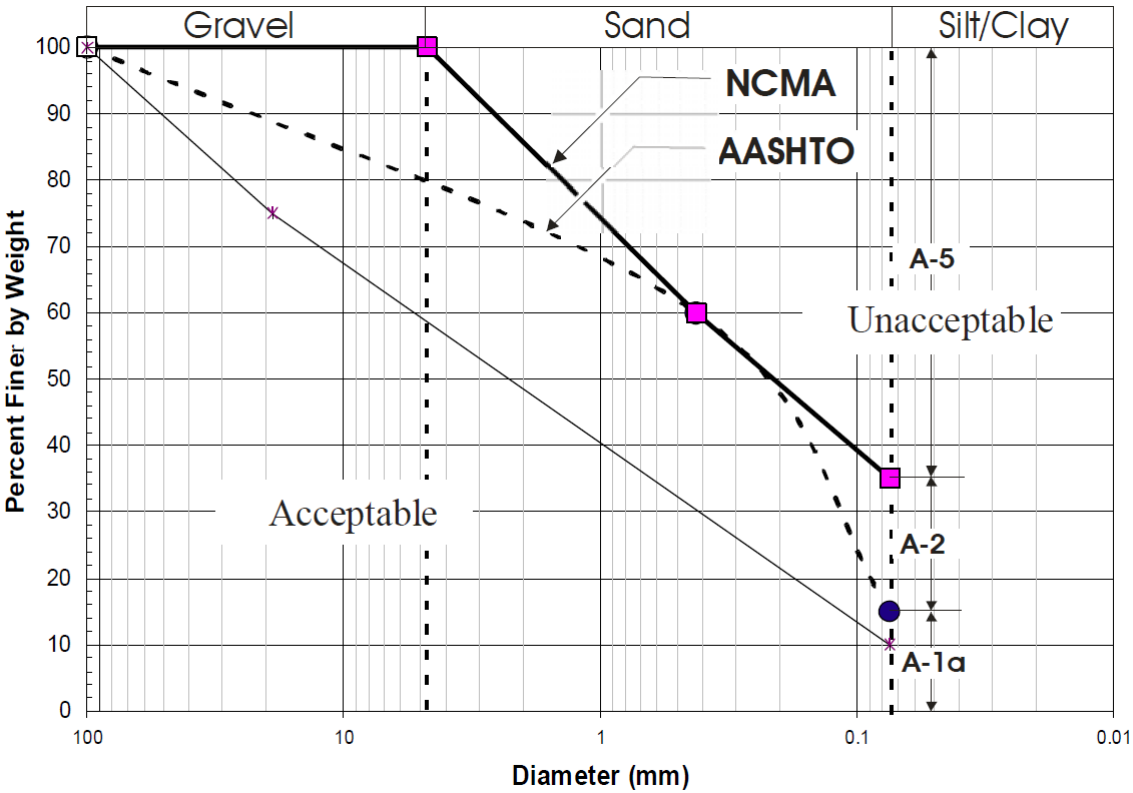
MSE Wall Select Granular Reinforced Fill Requirements

- NCHRP 24-22



Summary of Particle Size Distribution in the Reinforced Zone from Survey Responses

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MSE Wall Select Granular Reinforced Fill Requirements

- Reinforced Fill with up to 35% Passing a No. 200 (0.75 mm) Sieve Could be Safely Allowed in the Reinforced Fill
- Design Issues: Drainage, Corrosion, Deformations, Reinforcement Pullout, Constructability, and Performance Expectations
- Requiring the Evaluation of Total and Effective Shear Strength Parameters
- Requiring Both Long-Term and Short-Term Reinforcement Pullout Tests as well as Soil/Reinforcement Interface Friction Tests

MSE Wall Select Granular Reinforced Fill Requirements

- Drainage Requirements at the Back, Face, and Beneath the Reinforced Zone
- Geomembrane Recommended above the Wall to Preclude Infiltration of Seepage Water into the Fill
- Electrochemical tests on the Reinforced Fill to Evaluate Degradation
- Monitoring Deformation during Construction and Operation

RSS Select Granular Reinforced Fill Requirements

U.S. Sieve Size	Percent Passing
4-inch (102 mm)*	100
No. 4 (4.76 mm)	100-20
No. 40 (0.425 mm)	0-60
No. 200 (0.075 mm)	0 - 50
Plasticity Index (PI) shall not exceed 20	
Soundness tests required	
*<3/4 in. for geosynthetics & epoxy or PVC coated steel	
unless construction installation damage tests performed	

Lower Quality Material Could be Used in RSS

The Main Advantage of RSS Use of on-Site Soil

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Relative Costs

Function of Many Factors:

- Cut-Fill Requirements
- Slope Size
- Average Height of Slope Area
- Angle of Slope
- Available Backfill Materials
- Aesthetics
- Temporary or Permanent Application
- Need for Temporary Excavation Support Systems

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Relative Costs

- Reinforcement: 45-65% of Total Cost
- Reinforced Fill: 30-50% of Total Cost
- Face Treatment: 5-10% of Total Cost

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Limitations of MSE/RSS

- Requiring a Relatively Large Space (e.g., Excavation if in a Cut) Behind the Slope Face
- Future Utilities Must be Considered
- Metallic Reinforcements Exposed to Contaminated Corrosive Water (Low pH, High Chloride and Sulfate)
- Geosynthetics Damages: Abrasion, Wear, Punching, Tear, Scratching, Notching, Cracking, Creep Deformation, Ultraviolet Exposure Issues
- Erosion/Flooding Undermining Reinforced Soil

REINFORCED SOIL SLOPE DESIGN APPROACH

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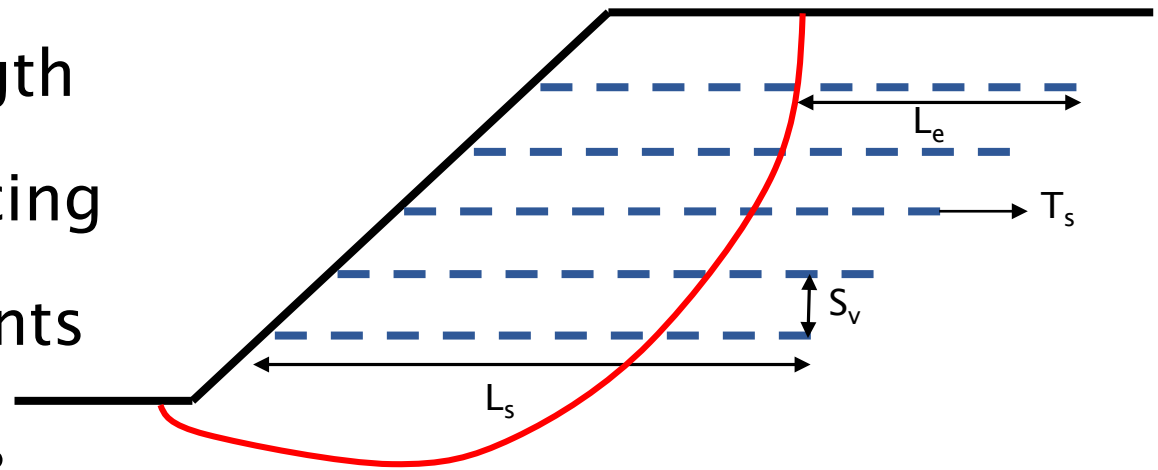
Design Approach

- Design Parameters:
  - Reinforcements Strength
  - Reinforcements Length
  - Reinforcements Spacing
  - Drainage Requirements
  - Facing Requirements



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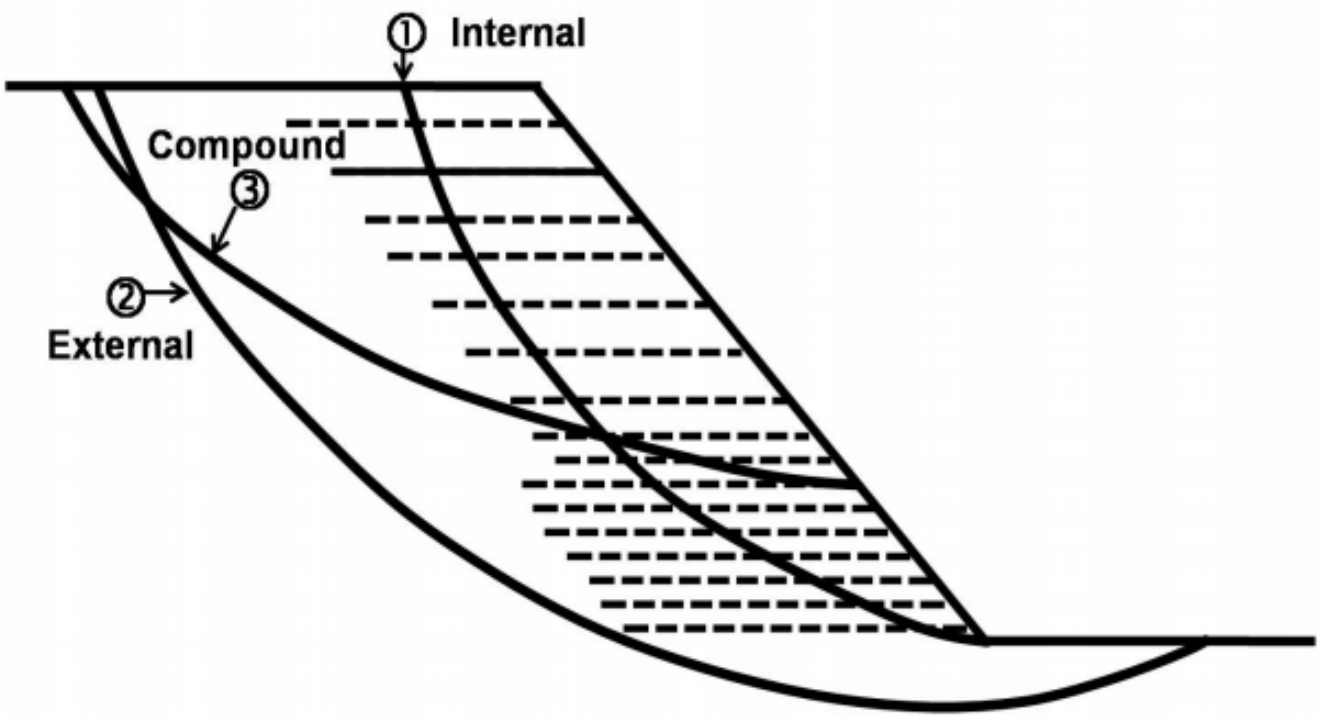
Design Approach

- The Overall Design Requirements Similar to Those for Unreinforced Slopes:
  - Limit Equilibrium Method to Calculate Factor of Safety
    - Internal
    - External
    - Compound



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Design Approach

- Design Steps

1. Establishing the Geometric, Loading, and Performance Requirements for Design:

- Slope Height and Angle
- External Loads
- Factor of Safeties (FS)

2. Determining the Engineering Properties of the in-Situ Soils and Backfill

- Shear Strength and Density
- Groundwater

Design Approach

- Design Steps

3. Evaluating Design Parameters for the Reinforcement

- Allowable Reinforcement Strength (T_{al})
- Factor of Safety Against Pullout Failure

4. Checking Unreinforced Stability

- Determining Unreinforced Slope Factor of Safety (FS_U)

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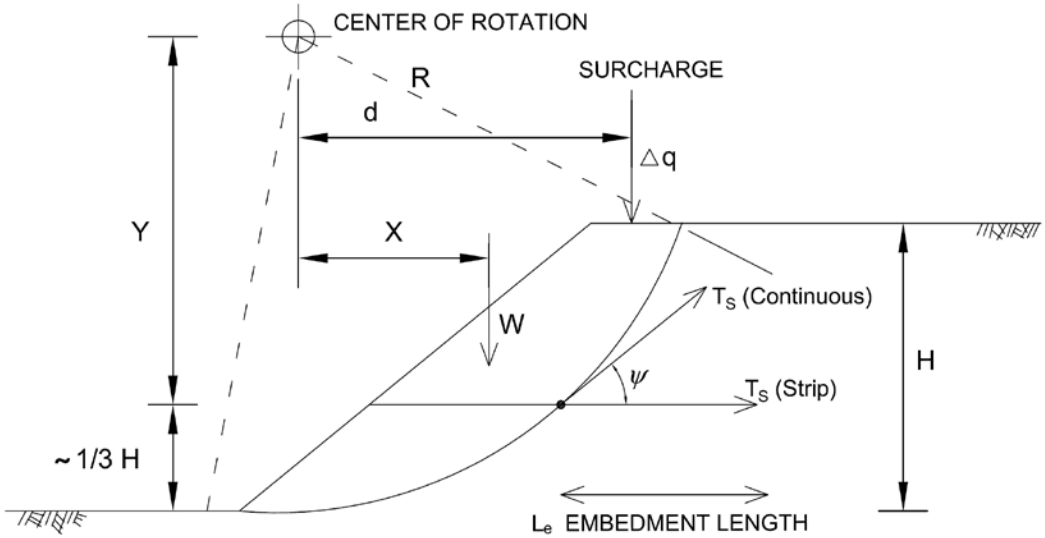
Design Approach

- Design Steps

5. Designing Reinforcement to Provide a Stable Slope

- Calculating the Required Total Reinforcement Tension Per Unit Width of Slope:

$$T_{S-MAX} = (FS_R - FS_U)\frac{M_D}{D}$$



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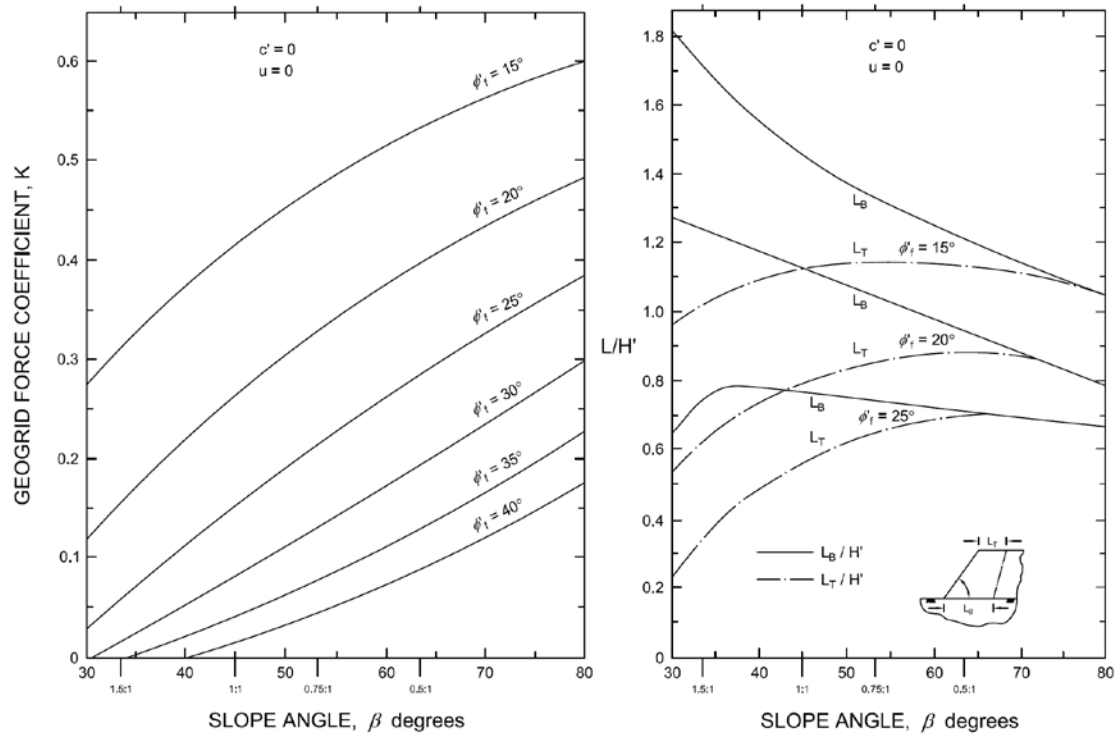
Design Approach

- Design Steps

6. T_{S-MAX} and Reinforcement Length Estimation Using Slope Angle and Backfill Friction Angle

$T_{S-MAX} = 0.5\ K\ \gamma_r\ (H')^2$

$H' = H + q/\gamma_r$



7. If H<20 ft.

- Uniform Reinforcement Distribution

Design Approach

- Design Steps

8. If H>20 ft.

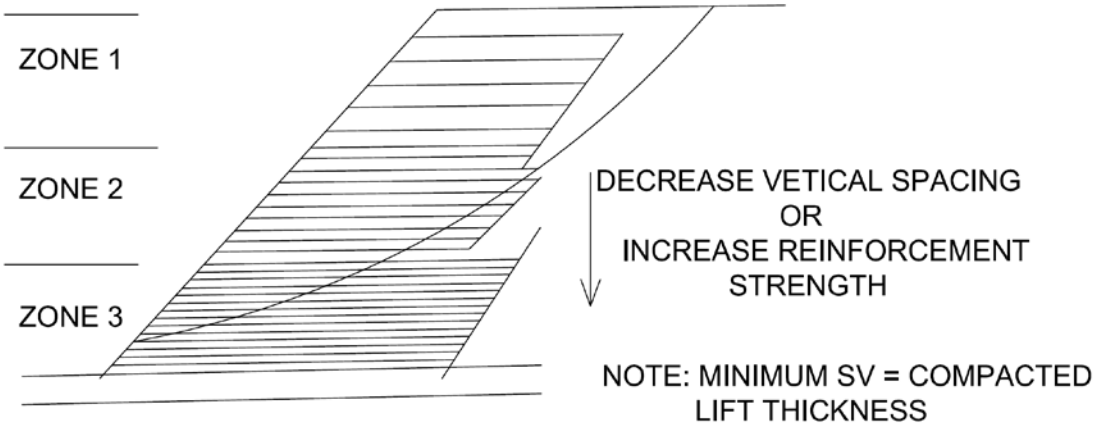
- For 1 Zone: Use T_{S-MAX}

- For 2 Zones:

- $T_{Bottom} = \frac{3}{4} T_{S-MAX}$
- $T_{Top} = \frac{1}{4} T_{S-MAX}$

- For 3 Zones:

- $T_{Bottom} = \frac{1}{2} T_{S-MAX}$
- $T_{Middle} = \frac{1}{3} T_{S-MAX}$
- $T_{Top} = \frac{1}{6} T_{S-MAX}$



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Design Approach

- Design Steps

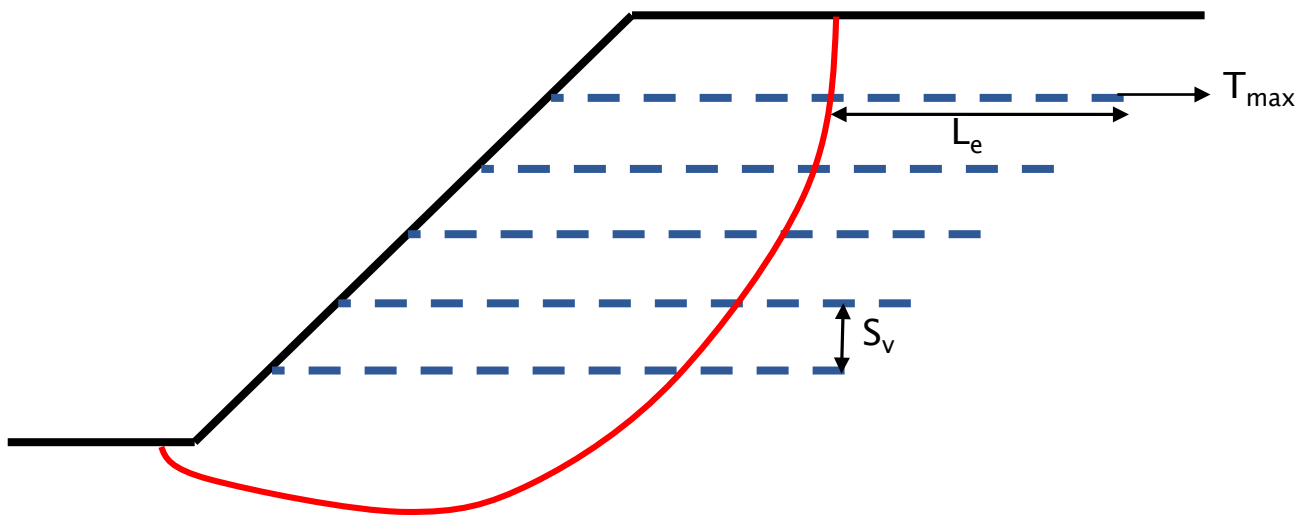
9. Determining the Required Reinforcement Strength

$$T_{max} = \frac{T_{zone} S_v}{H_{zone}}$$

$S_v < 32$ in.

10. Determining the Required Reinforcement Embedment Length (>3ft.)

$$L_e = \frac{T_{max}\, FS}{F^* \alpha \sigma_v' R_c C}$$



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Design Approach

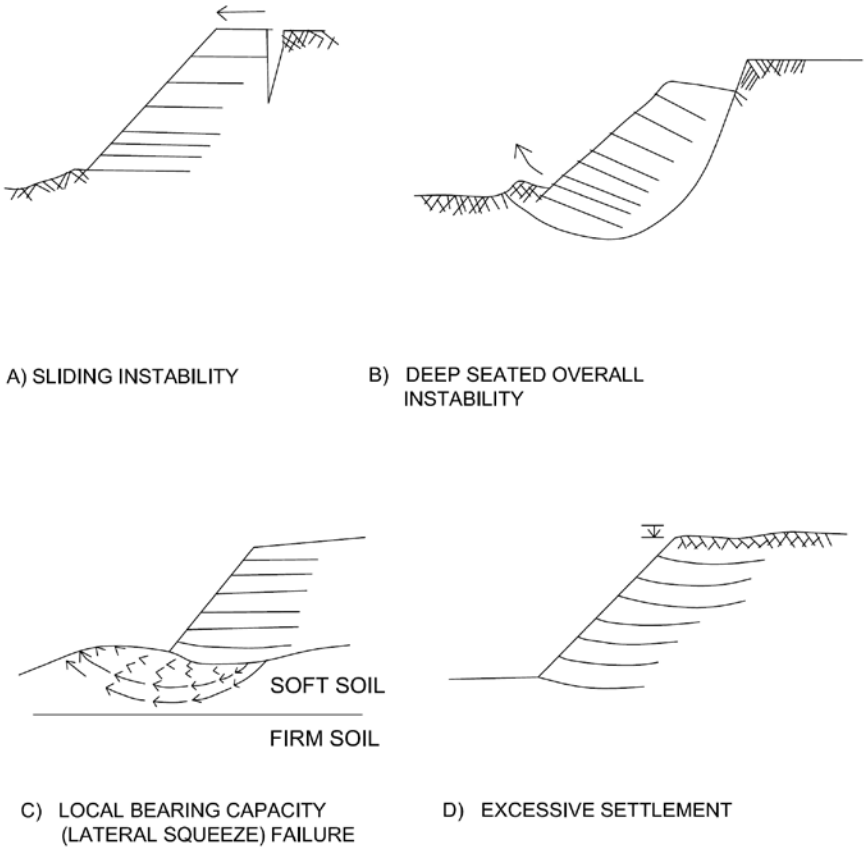
- External Stability
- Sliding:

Two-Part Wedge Type Failure Surface

- Global Stability:

Deep-Seated Failure Surface Behind the Reinforced Soil Zone

- Bearing Capacity: In Case a of a Weak Soil
- Excessive Settlement



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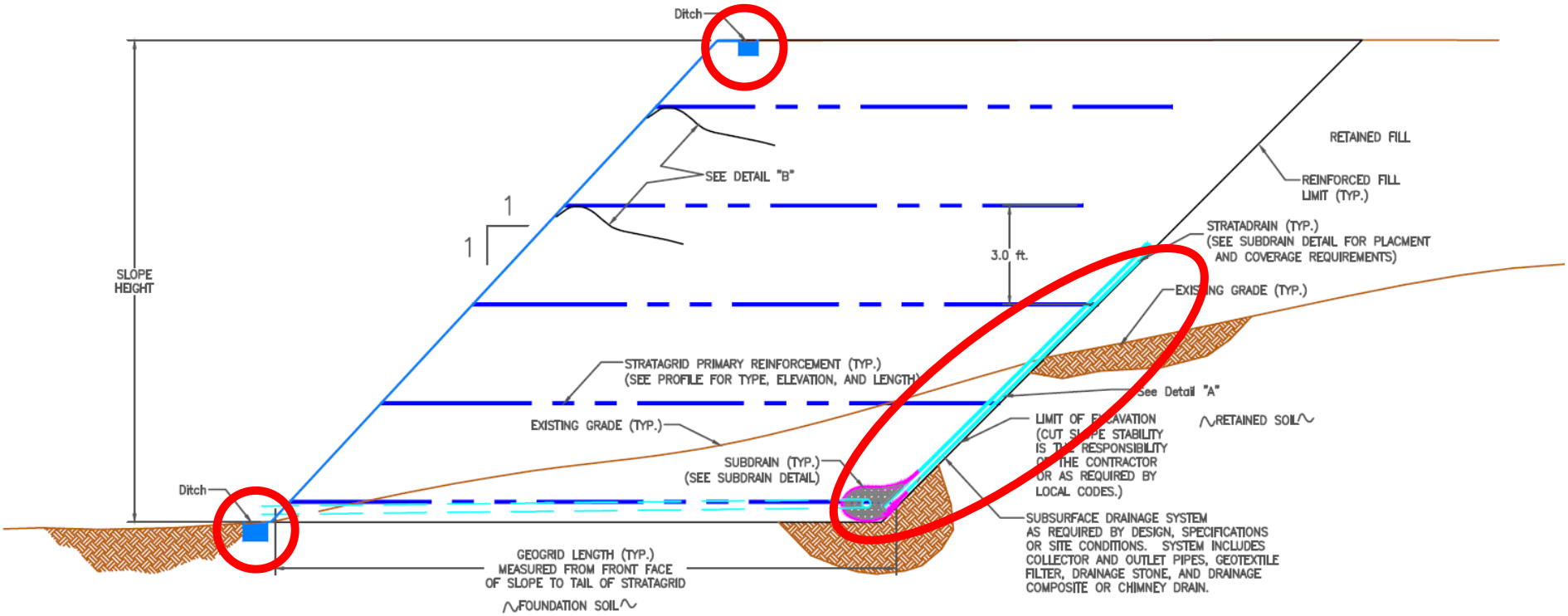
Design Approach

- Drainage System Details



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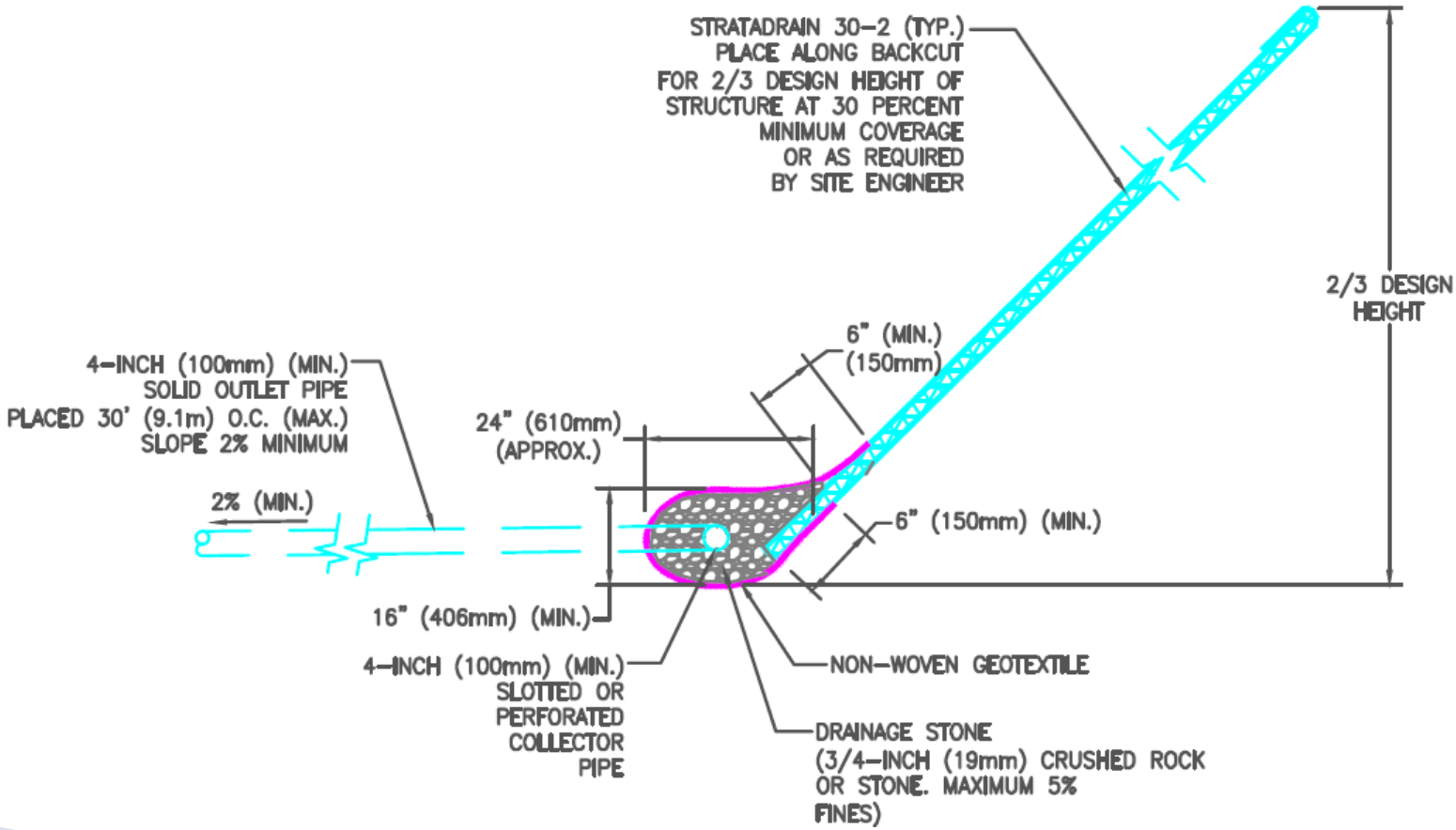
Design Approach

- Drainage System Details



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Design Approach

- Facing Types
  - Vegetated
    - SOD
    - Wrapped Geosynthetics
    - Soil Bio Reinforcement
    - Erosion Blanket
  - Hard
    - Gabion
    - Soil-Cement
    - Stone Veneer
    - Wire Baskets
    - Shotcrete

Slope Face Angle and Soil Type	Type of Facing			
	When Geosynthetic is not Wrapped at Face		When Geosynthetic is Wrapped at Face	
	Vegetated Face[1]	Hard Facing[2]	Vegetated Face[1]	Hard Facing[2]
> 50° (> ~0.9H:1V) All Soil Types	Not Recommended	Gabions	Sod, Permanent Erosion Blanket w/ seed	Wire Baskets,[3] Stone, Shotcrete
35° to 50° (~ 1.4H:1V to 0.9H:1V) Clean Sands (SP)[4] Rounded Gravel (GP)	Not Recommended	Gabions, Soil-Cement	Sod, Permanent Erosion Blanket w/ seed	Wire Baskets,[3] Stone, Shotcrete
35° to 50° (~ 1.4H:1V to 0.9H:1V) Silts (ML) Sandy Silts (ML)	Soil Bio reinforcement, Drainage Composites[5]	Gabions, Soil-Cement, Stone Veneer	Sod, Permanent Erosion Blanket w/ seed	Wire Baskets,[3] Stone, Shotcrete
35° to 50° (~ 1.4H:1V to 0.9H:1V) Silty Sands (SM) Clayey Sands (SC) Well graded sands and gravels (SW & GW)	Temporary Erosion Blanket w/ Seed or Sod, Permanent Erosion Mat w/ Seed or Sod	Hard Facing, Not Needed	Geosynthetic Wrap Not Needed	Geosynthetic Wrap Not Needed
25° to 35° (~ 2H:1V to 1.4H:1V) All Soil Types	Temporary Erosion Blanket w/ Seed or Sod, Permanent Erosion Mat w/ Seed or Sod	Hard Facing Not Needed	Geosynthetic Wrap Not Needed	Geosynthetic Wrap Not Needed

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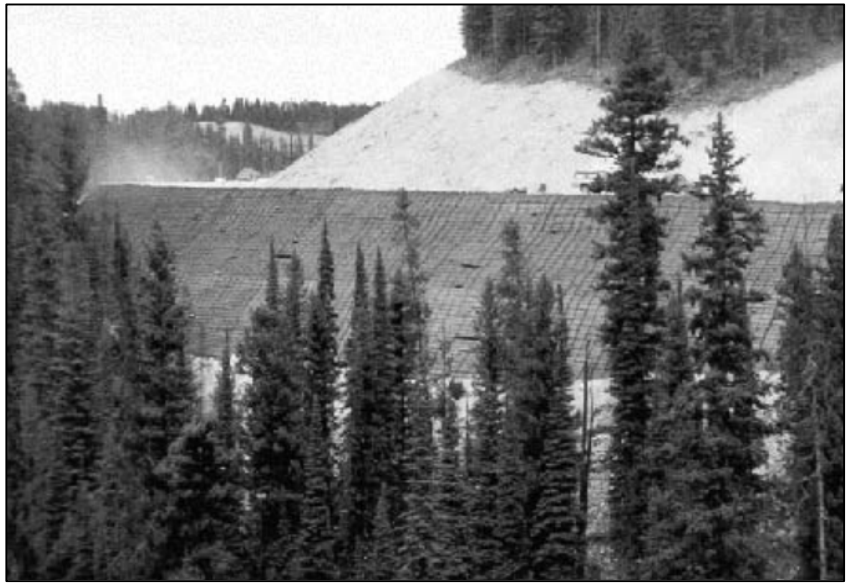
EXAMPLES

Examples

- **Dickey Lake Roadway Improvement**
  - Montana
  - Reconstruction of I-93 Around the Shore of Dickey Lake
  - 30 ft. to 60 ft. Height
  - 1H:1V (1.5H:1V to 0.84H:1V)
  - Geogrid Reinforcement
  - 15 ft. to 60 ft. Length
  - 2 ft. to 4 ft. Spacing
  - 6850 lb/ft Strength
  - Intermediate Reinforcement for 1H:1V or Flatter
  - Welded Wire Mesh on Steeper than 1H:1V Slope

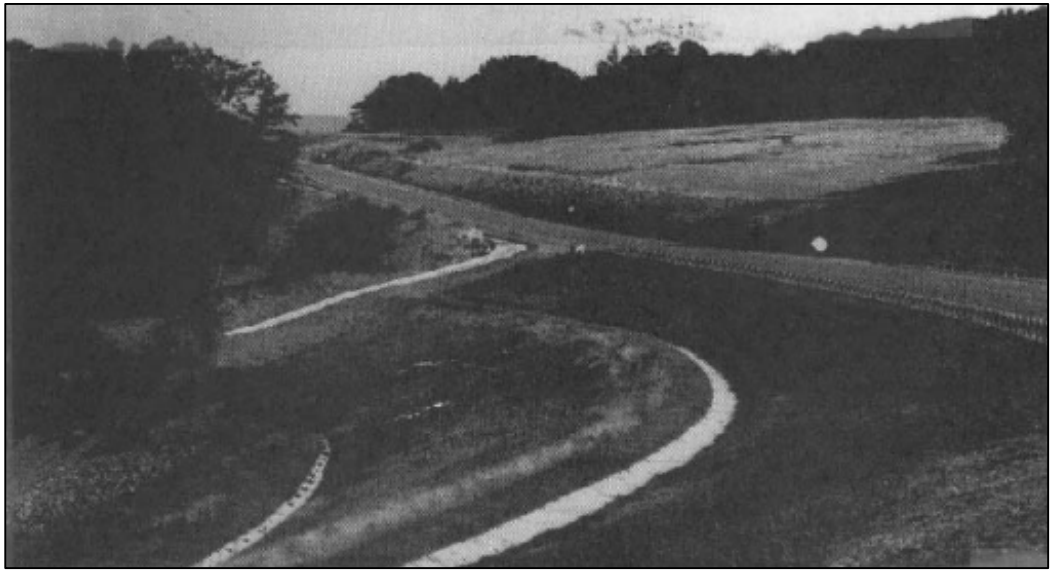
Examples

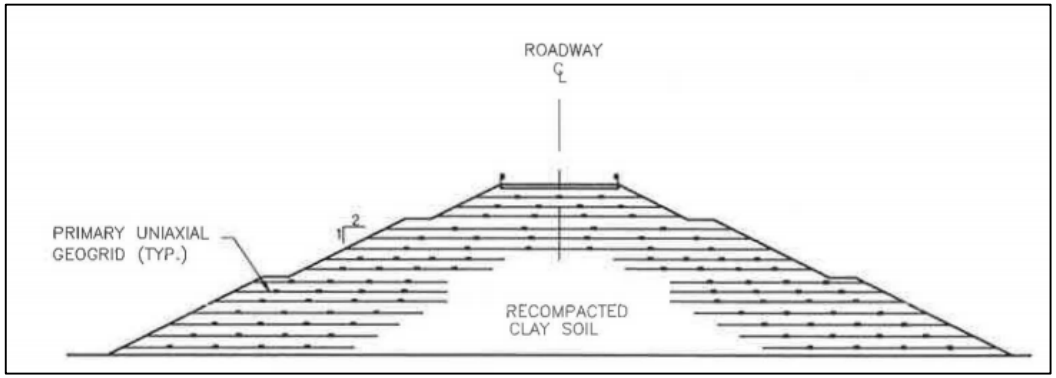
- **Salmon-Lost Trail Roadway**
  - Idaho
  - Widening Project
  - 50 ft. Height
  - 565 ft. Length
  - 2H:1V to 1H: 1V
  - Geotextile Reinforcement
  - 1 ft. Spacing
  - 6850 lb/ft Strength in Lower Zone
  - 1370 lb/ft Strength in Upper Zone
  - Vegetated Facing



Examples

- **Cannon Creek Embankment Construction**
- Arkansas
  - State Highway 16
  - 75 ft. Height
  - 2H:1V
  - Geogrid Reinforcement
  - 6850 lb/ft Strength
  - Vegetated Facing
  - Alternative Option: Gravelly Soil Embankment Fill
  - Alternative Option was $200,000 More Expensive





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Examples

- **Pennsylvania SR 54 Roadway Repair**
- Pennsylvania
  - Sinkhole
  - State Route 54
  - 50 ft. Height
  - 1.5H:1V
  - Geotextile Reinforcement also Drainage
  - 1100 lb/ft Strength
  - 1 ft. Spacing
  - Native Soil Used Resulted in Significant Savings of $200,000

Examples

- **Road Embankment Slope Failure Repair**
- Thailand
  - 30 ft. Height
  - 70 Degrees Slope
  - Geogrid
  - 4000 lb/ft, 9000 lb/ft and 11000 lb/ft Strength
  - 2 ft. Spacing

NEW ADVANCEMENT IN REINFORCED SOIL STRUCTURES: GRS-IBS

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Problem

<u>According to FHWA (2015):</u>

In the US:

- 611,845 bridges
- 142,915 are deficient (23%)

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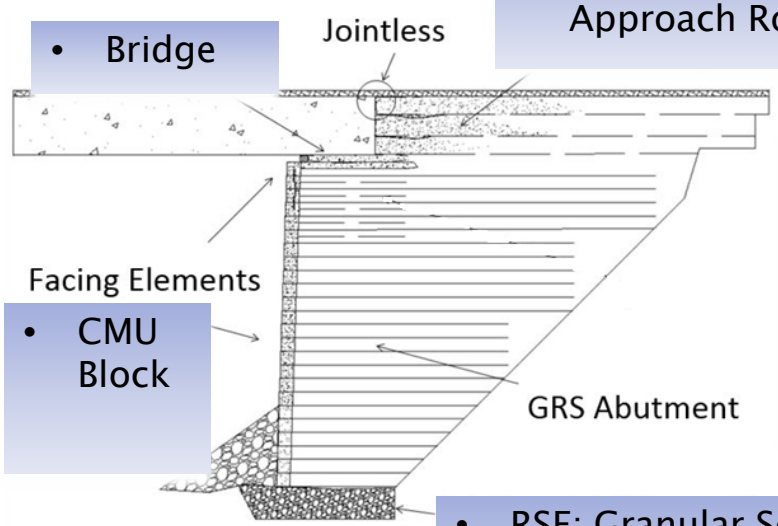
Problem

- Not Enough Financial Resources to Repair/Replace Deficient Bridges
- Expensive and Long to Construct/Repair Conventional Bridge
- A Rapidly Emerging Bridge System Could Solve This Problem – The Geosynthetic Reinforced Soil Integrated Bridge System (GRS-IBS)

What is GRS-IBS?

- Reinforced Integrated Approach Road

- Bridge



- CMU Block

- # 89 AASHTO or # 8 Stone in Abutments
- High Strength Geotextile
- Very Close Reinforcement Spacing (i.e., About 8 in.)

- RSF: Granular Soil Material Encapsulated by Geotextile

IBS (Integrated Bridge System)

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Geosynthetics

- Geogrids

- Geotextiles

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Facing Elements

Difference Between GRS and MSE Structures

- The Reinforcement Spacing
  - GRS: <12 in.
  - MSE: < 32 in.

- The Reinforcement Strength
  - GRS: Ultimate Strength>4800 lb/ft
  - MSE: Based on Design Requirement

- The Fill Material:
  - GRS: No. 200 sieve <5%-12%, No. 40 Sieve <5%-24%
  - MSE: No. 200 sieve <15%, No. 40 Sieve <60%

MSE

GRS

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Difference Between GRS and MSE Structures

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Difference Between GRS and MSE Structures

→ Composite Behavior in GRS

- Applied Surcharges to GRS-IBS Several Times Greater Than Those Applied to MSE Because of Composite Behavior
- Very Limited Lateral Strain in the Abutment (Usually less than 0.5%)
- Very Limited Facing Lateral Displacement

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Geometry and Loading Limitations of GRS

- Maximum Height 30 ft.
  - Maximum Span 140 ft.
  - Maximum Pressure 4000 psf

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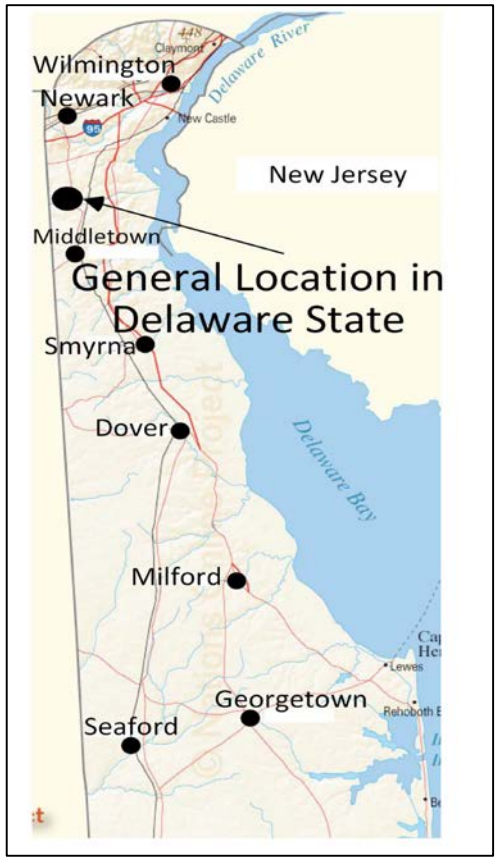
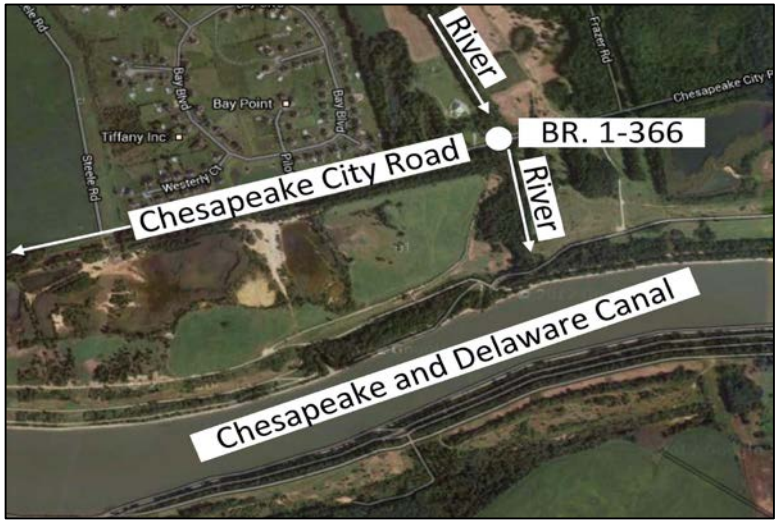
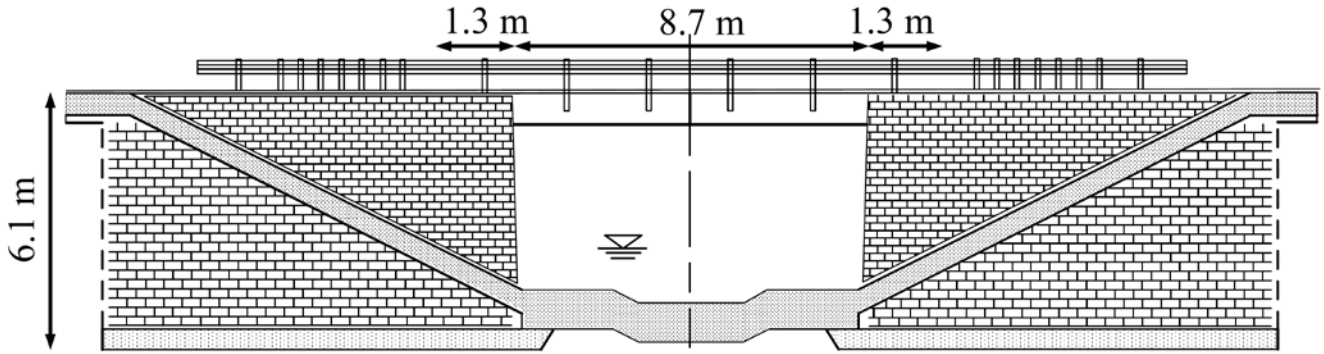
Example

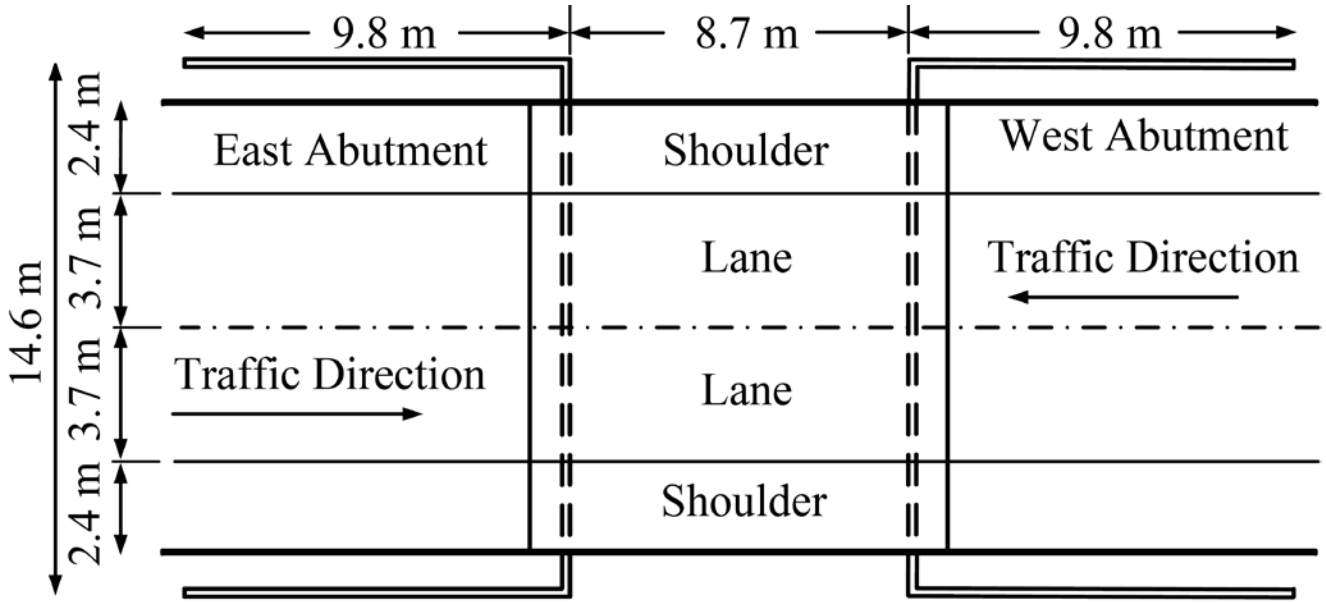
- First GRS-IBS Constructed in Delaware (2013)





Example





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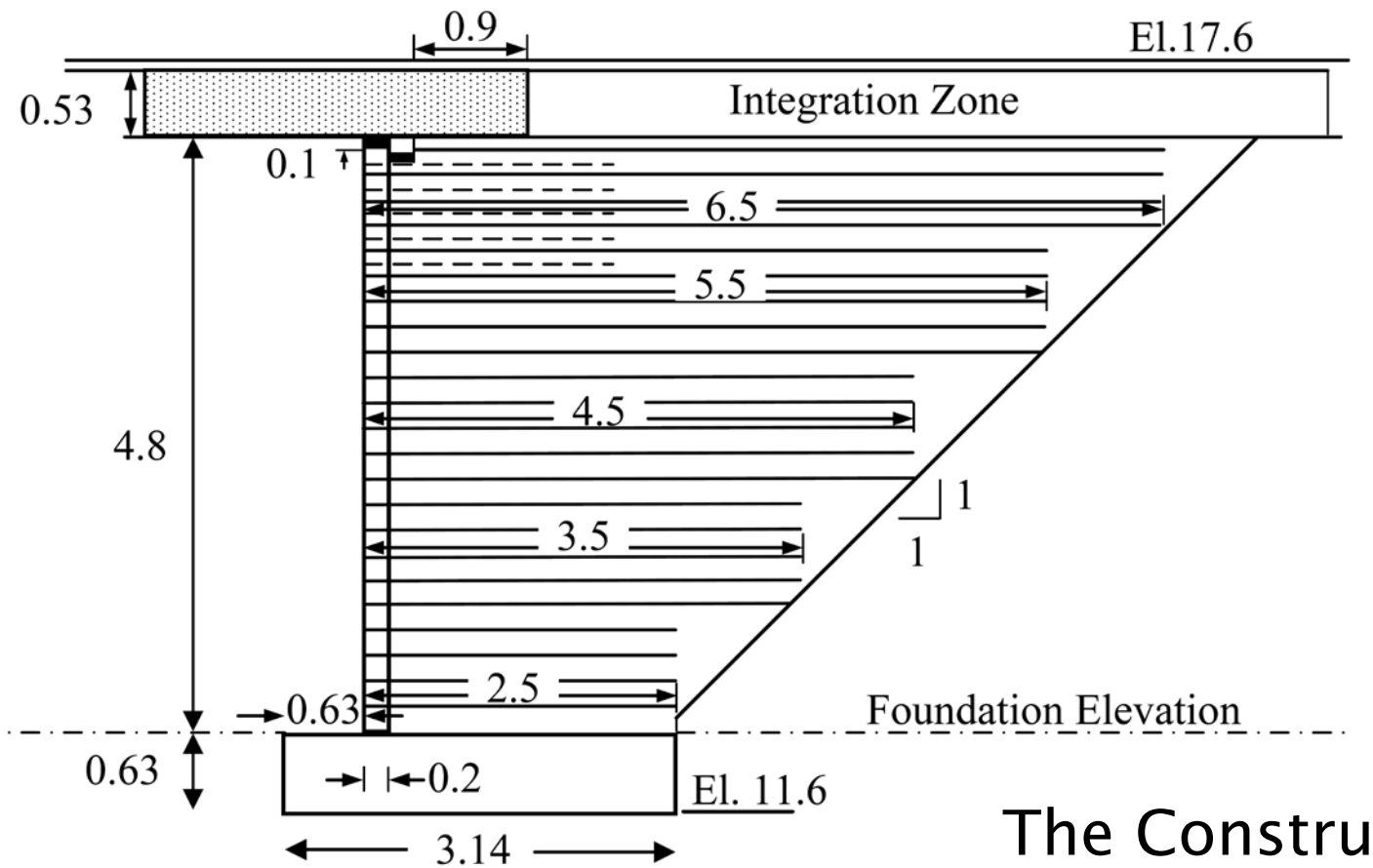
Example



The Construction Duration was About Less Than Two Months

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Example

CONCLUSIONS

CONCLUSIONS

- **Advantages of Reinforced Structures**
  - Cost-Effective
  - Less ROW
  - Rapid Construction
  - Not Very Affected by the Foundation Compressibility

- **Limitations of Reinforced Structures**
  - Corrosion in Steel Strip and Creep and Construction Damages in Geosynthetics
  - Requiring Large Space Behind the Wall
  - Requiring Select Granular Fill

- Using GRS as a New Technology to Build Stronger Structures in a Shorter Time and Lower Cost

THANK YOU

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