NATIONAL ACADEMIES *Sciences Engineering Medicine*

TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar: Mechanically Stabilized Earth Wall Design Updates

December 11, 2024

12:00 – 1:30 PM

PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact Andie Pitchford at TRBwebinar@nas.edu

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Purpose Statement

This webinar will provide background and an overview of four design approaches for MSE walls: the coherent gravity method, the simplified method, the stiffness method, and the limit equilibrium method. Presenters will discuss how to select the appropriate parameters for the design of MSE walls based on geometry, facing, reinforcement, and backfill utilized.

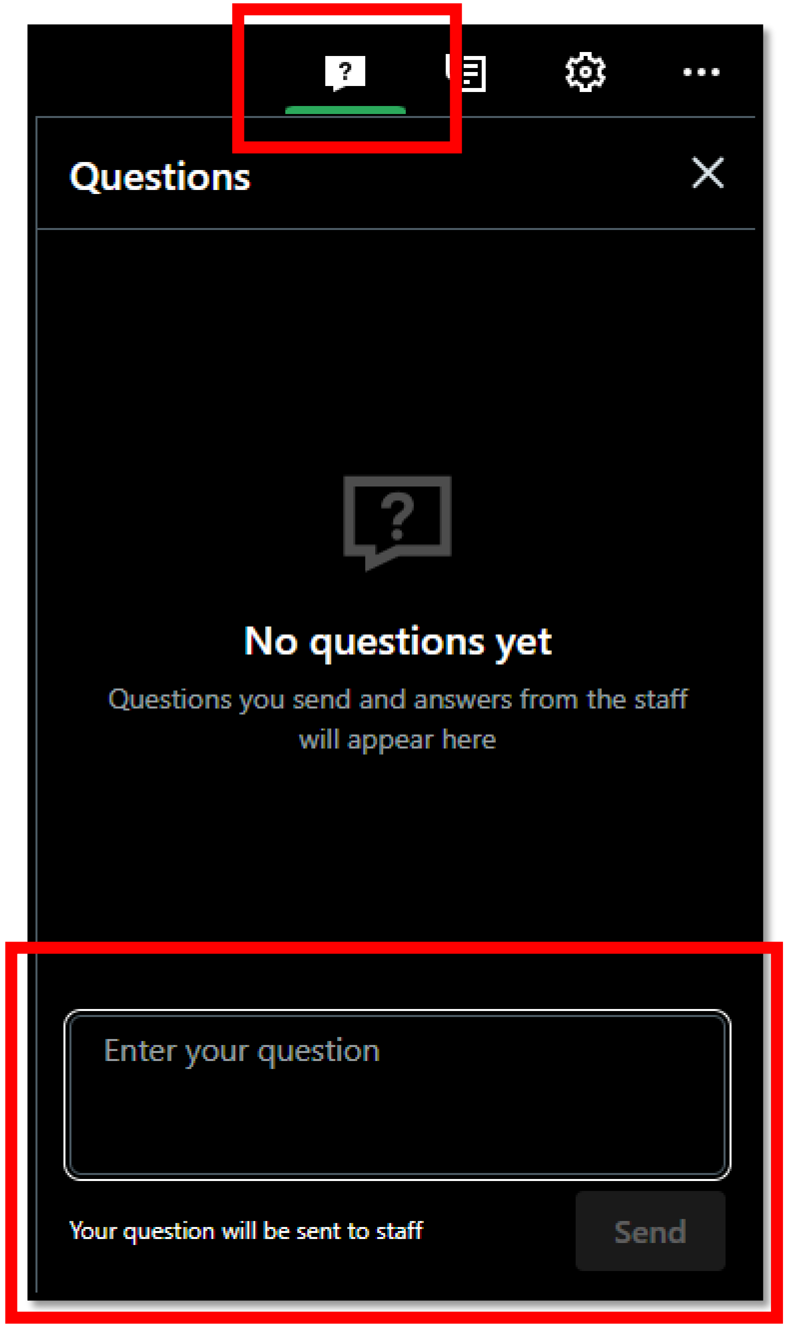
Learning Objectives

At the end of this webinar, you will be able to:

- Review contractor design submittals which incorporate the new MSE wall design methods
- Utilize GEC 011 to learn about the details and background related to the new MSE wall design methods
- Select appropriate parameters based on selected geometry, facing, reinforcement, and backfill utilized for the design of MSE walls

Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



Today's presenters

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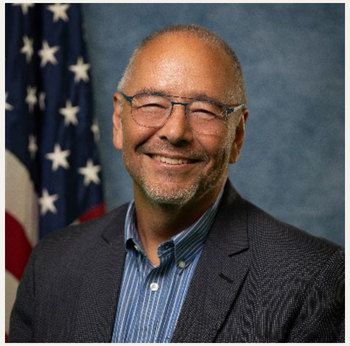

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TRB Webinar

MSE Wall Design Update

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Federal Highway Administration

December 2024

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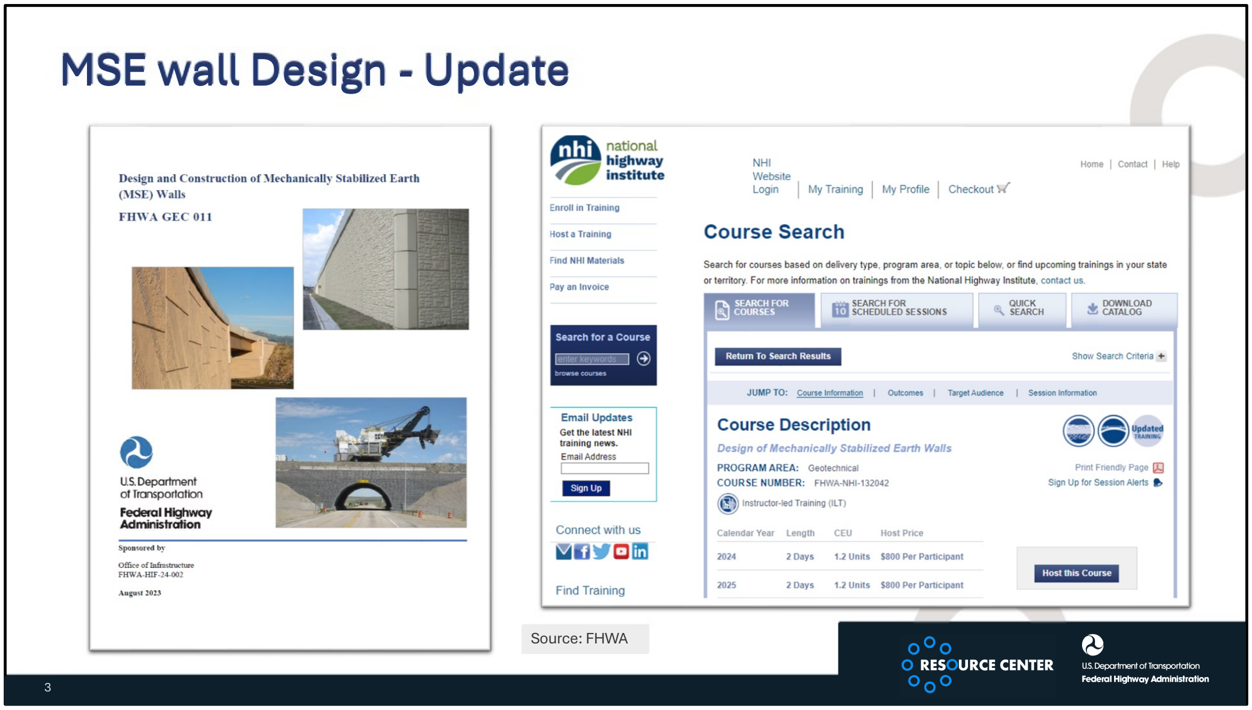
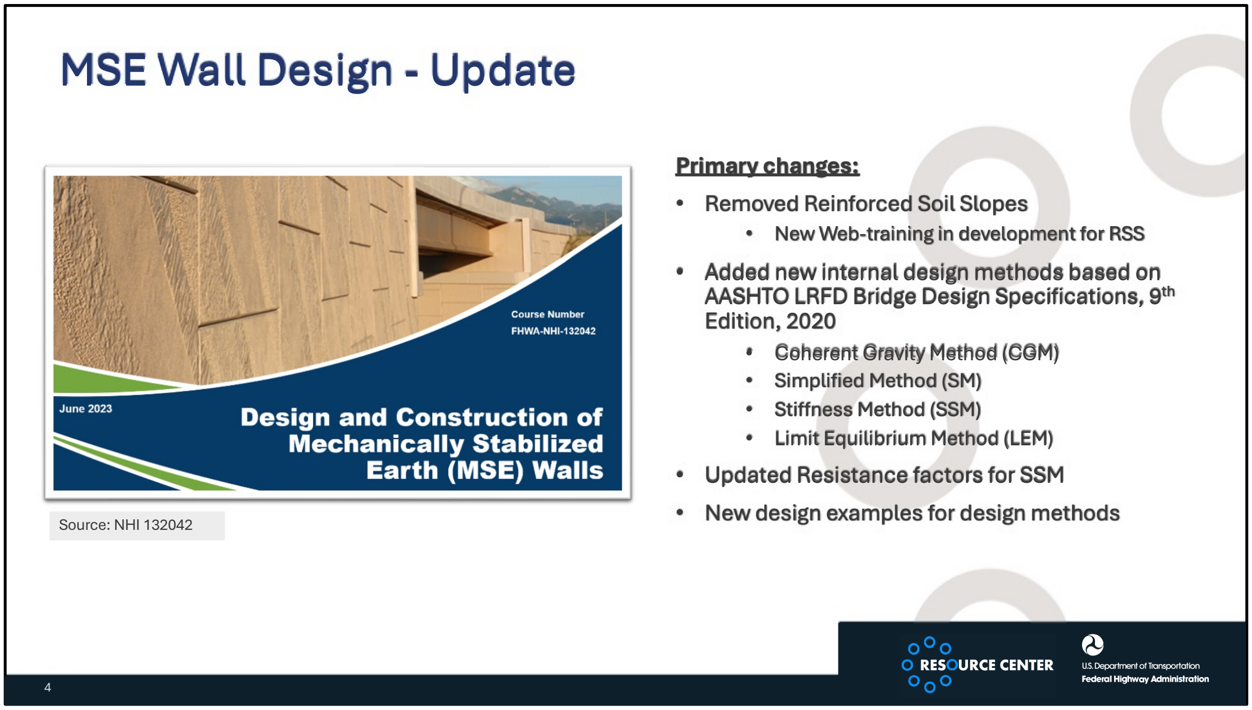


In April 2020, AASHTO released the updated LRFD Bridge Design Specifications, marking a significant milestone in bridge engineering standards. Later that year, in August, the Federal Highway Administration (FHWA) took a crucial step to align geotechnical practices with these new specifications. They awarded Dan Brown & Associates a contract to revise the FHWA Geotechnical Engineering Circular 11 (GEC 11), which focuses on designing and constructing Mechanically Stabilized Earth (MSE) walls and Reinforced Soil Slopes.

This comprehensive update project, overseen by project manager Robert Thompson from Dan Brown & Associates, brought together a team of distinguished subject matter experts. The team included Dr. Tom Taylor from Ground Improvement Systems, Dr Jim Collin from The Collin Group, Dr Stan Boyle from Shannon & Wilson, Dr. Ken Fishman from McMahon & Mann, and Dr. Jie Han from the University of Kansas. These experts collaborated to ensure the manual reflected the latest advancements in geotechnical engineering and the design of MSE.

The scope of the project extended beyond just updating the manual. It also involved revising the associated three-day National Highway Institute (NHI) course, ensuring that practitioners would have access to the most current knowledge and practices in MSE wall and reinforced soil slope design and construction

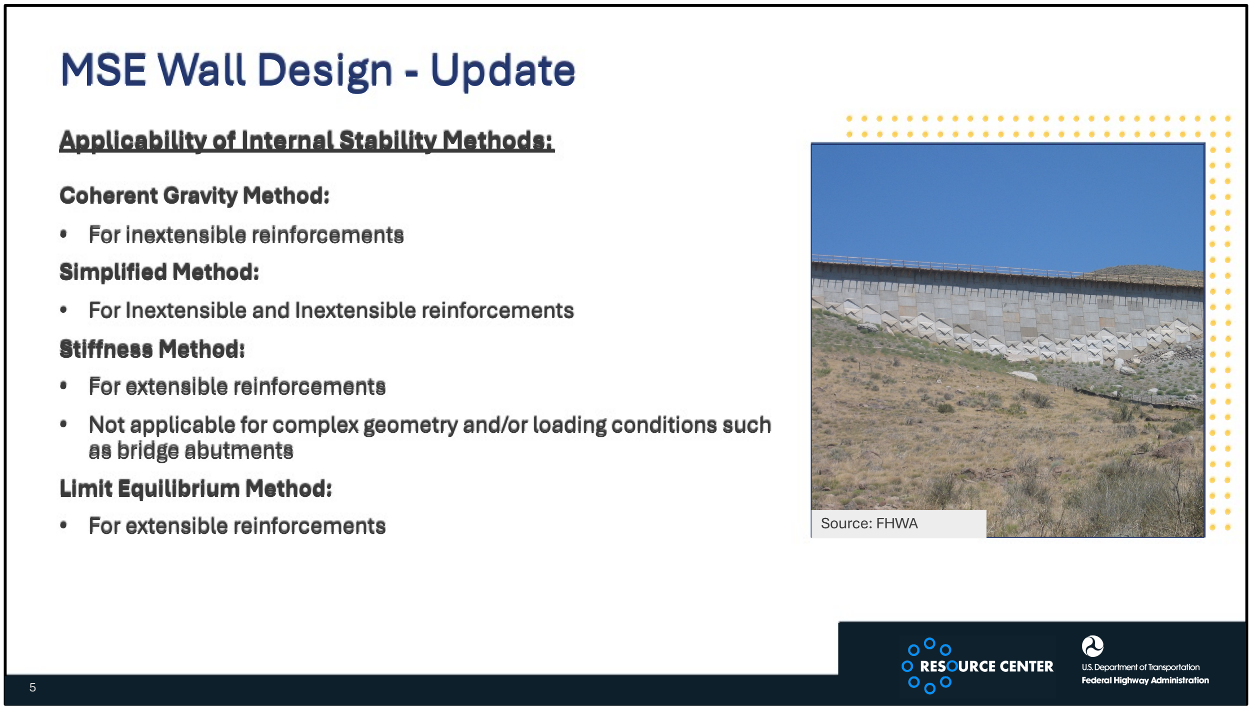


Key Message:
The design and construction guidelines for Mechanically Stabilized Earth (MSE) walls have undergone significant updates, including the introduction of multiple internal stability design methods and changes to course content.

Key Points:

1. Manual and Course Updates:
   - Reinforced Soil Slopes (RSS) content removed from the main manual and course
   - Course duration reduced from 3 days to 2 days
   - A separate web-based course for RSS to be available in spring of 2025
2. Internal Stability Design Methods:
   - Prior to 2020: Only the Simplified Method was used
   - Current update: Four design methods now available
3. Evolution of Design Methods:
   - Simplified Method (1995): Developed to unify design for steel and geosynthetic reinforcements
   - New methods added (2010-2020):
     a) Stiffness-based method by Allen and Bathurst
     b) Limit equilibrium method by FHWA
     c) Coherent Gravity Method (CGM) by Reinforced Earth Company
4. Rationale for Multiple Methods:
   - AASHTO T-15 Technical Committee's recommendations
   - Incorporation of different analytical approaches
   - Accommodation of established industry practices
5. Design Complexity:
   - Different resistance factors now apply to different design methods
   - Increased complexity in selecting and applying appropriate design approaches

These changes reflect the evolving understanding of MSE wall behavior and the industry's need for more diverse design options, while also presenting new challenges in method selection and application.



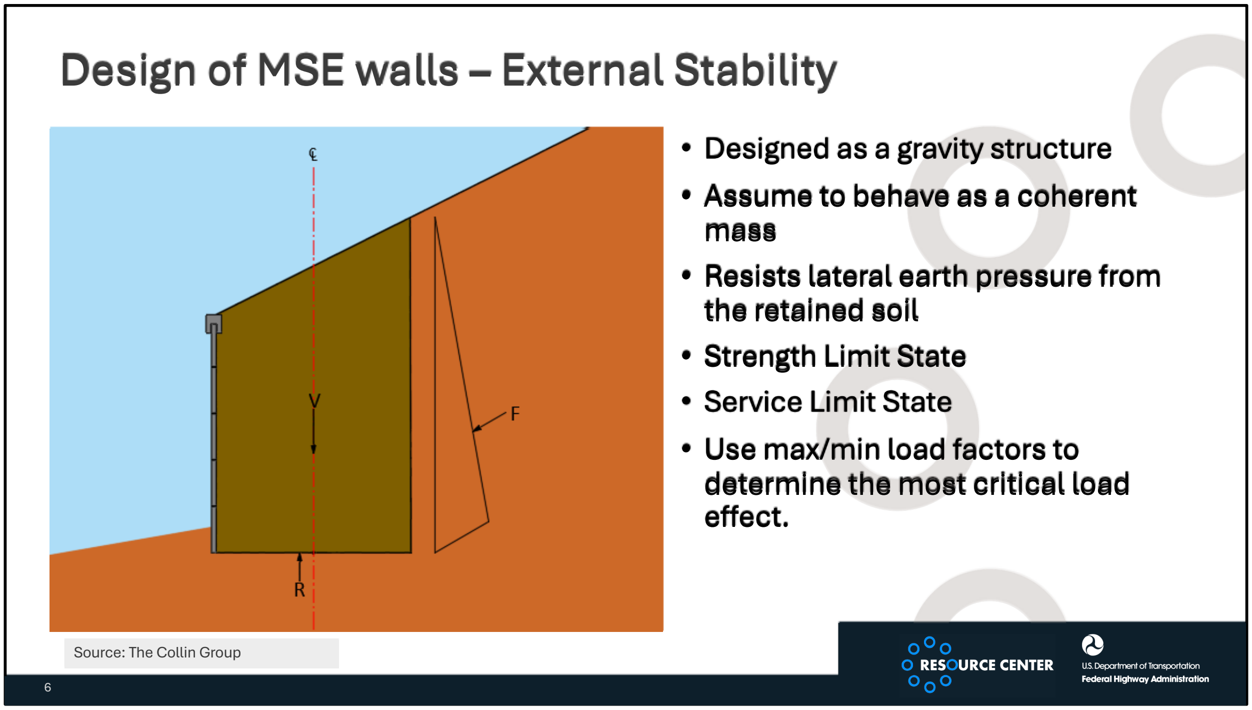
Key Message:
The internal stability analysis of mechanically stabilized earth (MSE) structures now employs four different internal design methods based on the type of reinforcement and structural complexity.

Key Points:

Applicability of Internal Stability Methods:

1. Coherent Gravity Method:
   - Applicable for: Inextensible reinforcements only
   - Examples: Steel strips, steel grids
2. Simplified Method:
   - Applicable for: Both inextensible and extensible reinforcements
   - Versatile method suitable for various reinforcement types
3. Stiffness Method:
   - Applicable for: Extensible reinforcements
   - Limitations: Not suitable for complex geometry or loading conditions (e.g., bridge abutments)
   - Examples: Geotextiles, geogrids
4. Limit Equilibrium Method:
   - Applicable for: Extensible reinforcements
   - Provides comprehensive analysis for geosynthetic-reinforced structures

This breakdown highlights the importance of selecting the appropriate method based on reinforcement type and application.



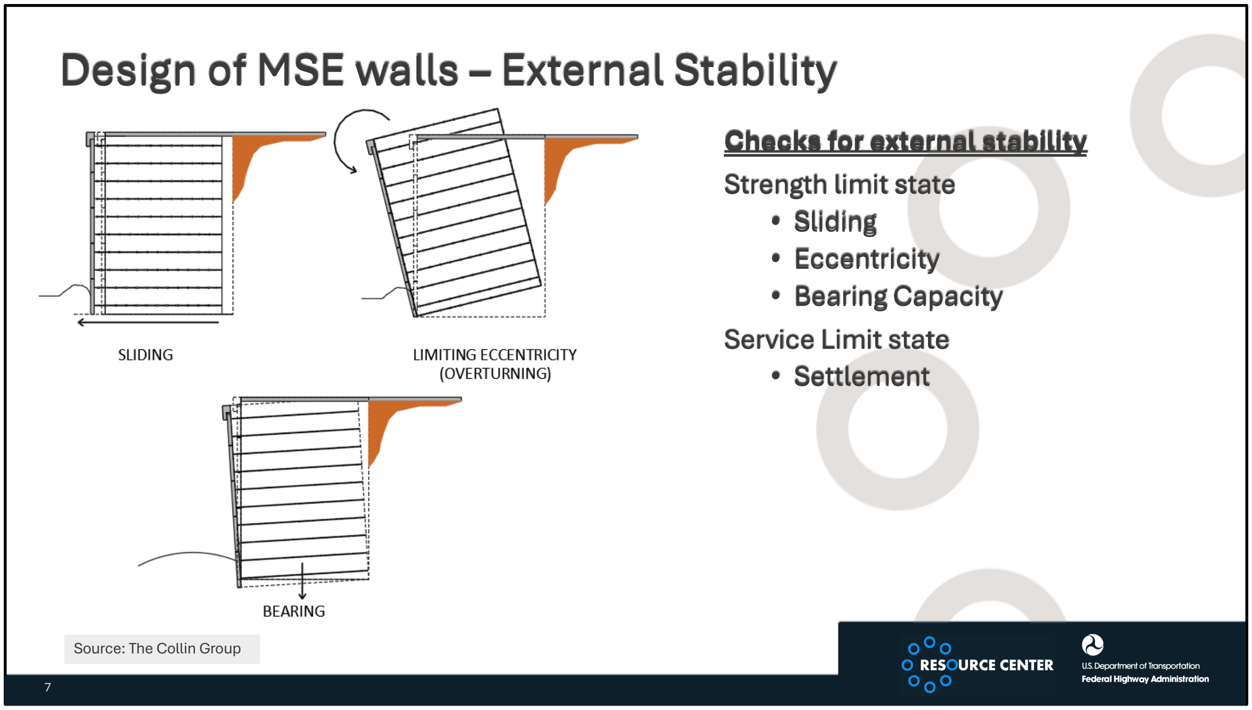
Key Message:

While the four design methods for mechanically stabilized earth (MSE) structures differ in their approach to internal stability, they share a common framework for external stability analysis.
External Stability Analysis:

Key Points:

1. **Unified Approach:**
   - All four design methods use the same external stability analysis
   - Treats the MSE structure as a coherent mass, similar to a conventional gravity structure
2. **Design Considerations:**
   - Analyzes the structure's ability to withstand forces from the retained soil mass
   - Considers sliding, overturning, bearing capacity, and global stability
3. **Limit State Analysis:**
   - Evaluate both strength and service limit states
   - Utilizes combinations of minimum and maximum load factors to identify critical load scenarios
4. **Coherent Mass Assumption:**
   - The reinforced soil zone is treated as a single, coherent unit
   - This simplification allows for conventional gravity wall analysis techniques
5. **Load Factor Application:**
   - Careful selection and combination of load factors ensure comprehensive analysis of potential failure modes

This approach to external stability ensures a consistent and thorough evaluation of MSE structures across different internal design methodologies, focusing on the overall stability and performance of the reinforced soil mass as a unified system.



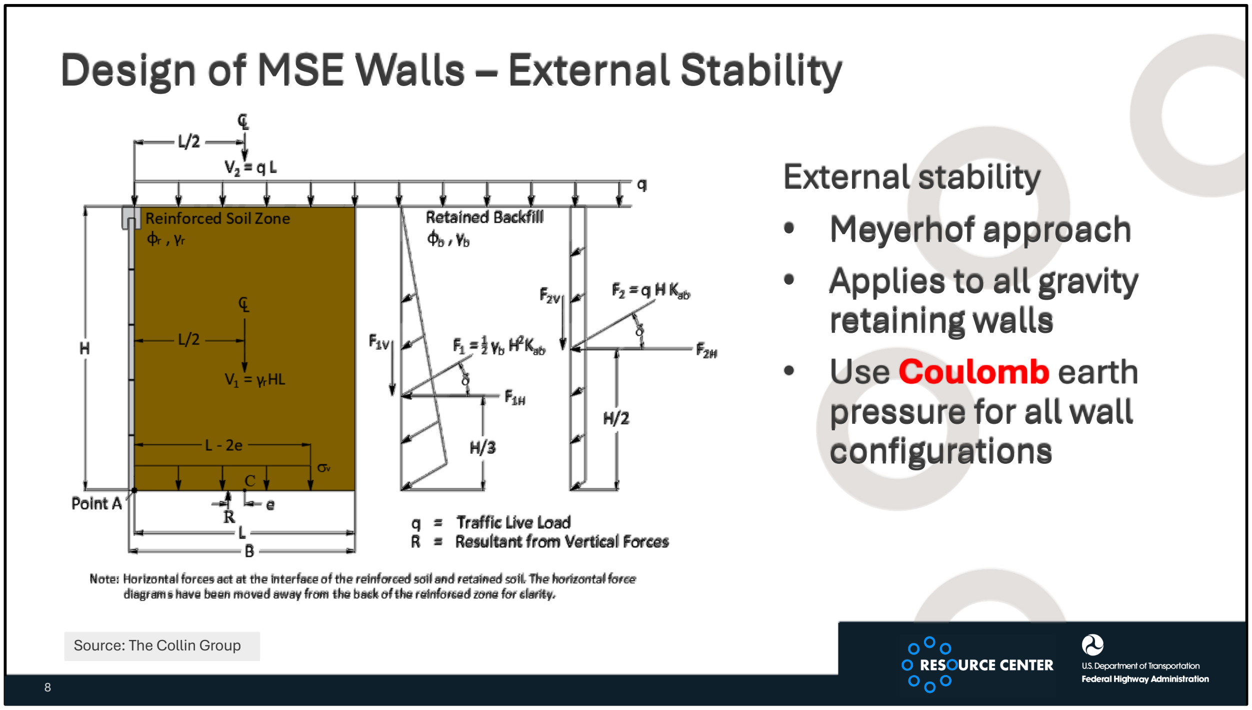
Key Message:
This slide outlines the critical failure modes and stability checks performed in the external stability analysis of Mechanically Stabilized Earth (MSE) structures.

Key Points:

External Stability Checks:

1. **Strength Limit State:**
   - Sliding: Assesses the structure's resistance to horizontal movement
   - Eccentricity: Evaluates the distribution of vertical loads and potential for overturning
   - Bearing Capacity: Determines if the foundation soil can support the structure's weight and applied loads
2. **Service Limit State:**
   - Settlement: Analyzes potential vertical displacement of the structure over time

These checks ensure a comprehensive evaluation of an MSE structure's stability under various loading conditions and potential failure modes, addressing both immediate strength concerns and long-term performance issues



Key Message:

Recent updates to external stability analysis for MSE structures involve significant changes in earth pressure calculations and stress distribution assumptions.

Key Points:

External Stability Analysis:

1. **Rigid Mass Assumption:**
   - The reinforced soil zone is treated as a rigid body for external stability calculations
2. **Meyerhof Stress Distribution:**
   - Applied to determine load distribution on the foundation soil
   - Validity condition: Maximum eccentricity (e) of resultant force R must be ≤ L/4 (Where L is the base width of the reinforced soil mass)
3. **Major Changes in Earth Pressure Calculation:**
   - Coulomb earth pressure theory is now used for all loading cases
   - Replaces the previous approach:
     - Rankine theory for level slope conditions
     - Modified Coulomb method for slopes above wall top (with limitations)
4. **Interface Friction Consideration:**
   - New approach allows full friction angle at the interface between reinforced and retained soil
   - Eliminates the previous limitation where delta angle was restricted to slope angle

These updates aim to provide a more accurate and consistent approach to external stability analysis across various MSE structure configurations and loading conditions

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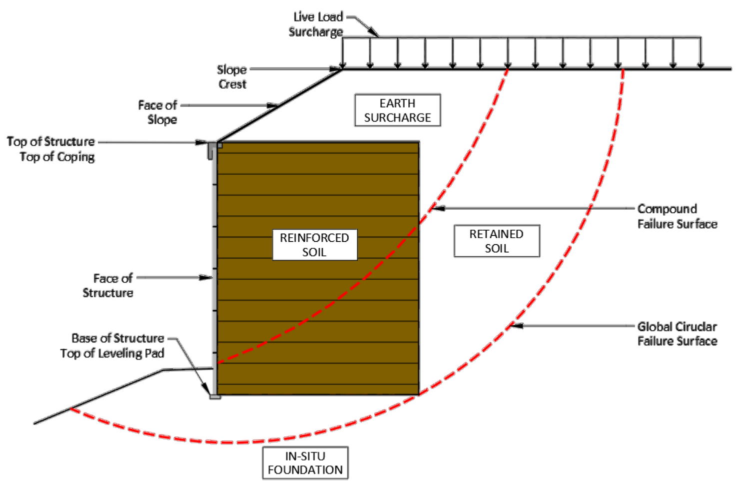
Design of MSE Walls – External Stability



Source: The Collin Group

Compound stability

- Considers failure planes that pass through the reinforced fill

Global stability

- Failure planes passing under and outside the reinforced fill

Both are analyzed using limit equilibrium methods

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Key Message:

Compound and global stability analyses are crucial in evaluating the overall stability of Mechanically Stabilized Earth (MSE) structures. Each focuses on different potential failure mechanisms.

Key Points:

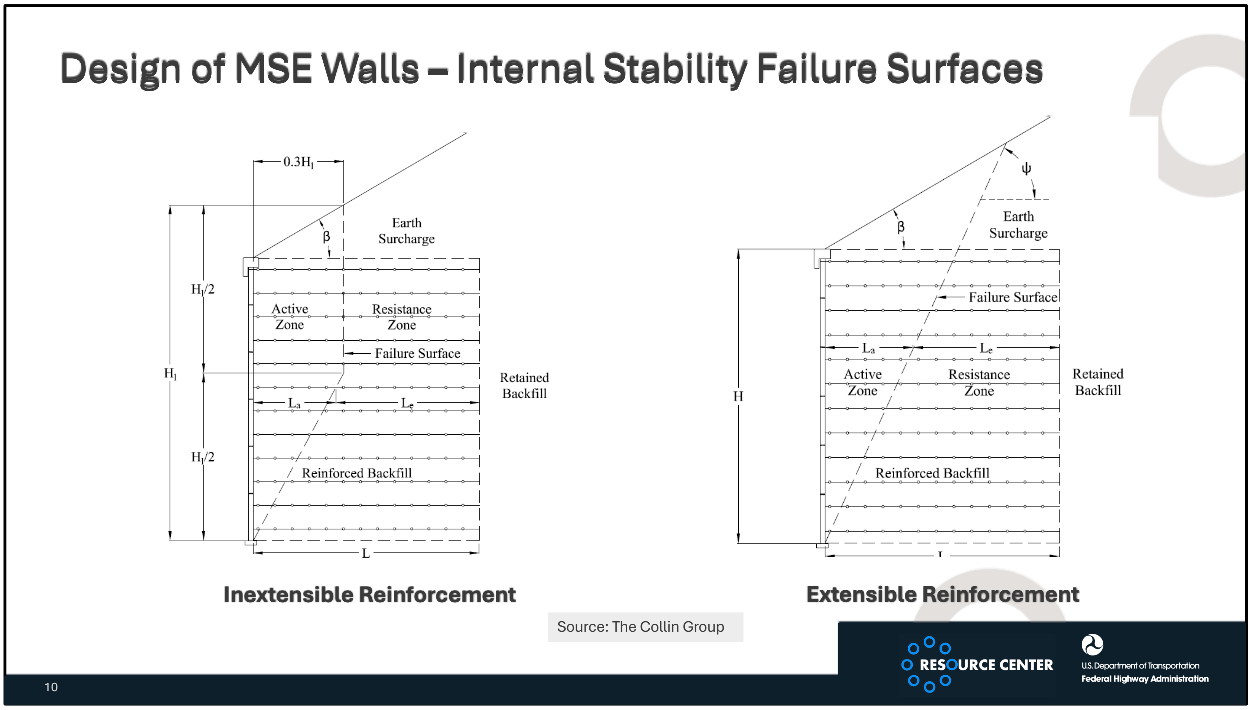
Stability Analysis Types:

1. Compound Stability:
   - Examines failure planes that pass through the reinforced fill
   - Assesses the interaction between the reinforced zone and the retained soil
2. Global Stability:
   - Analyzes failure planes that pass under and outside the reinforced fill
   - Evaluates the stability of the entire system, including the surrounding soil mass

Analysis Method:

- Both compound and global stability are analyzed using limit equilibrium methods
- These methods balance driving and resisting forces to determine the factor of safety against failure

This comprehensive approach ensures that both internal reinforced zone stability and overall site stability are thoroughly evaluated in MSE structure design



Key Message:
The stiffness of the reinforcement determines the internal failure surface in MSE structures, based on observations from instrumented structures.

Key Points:

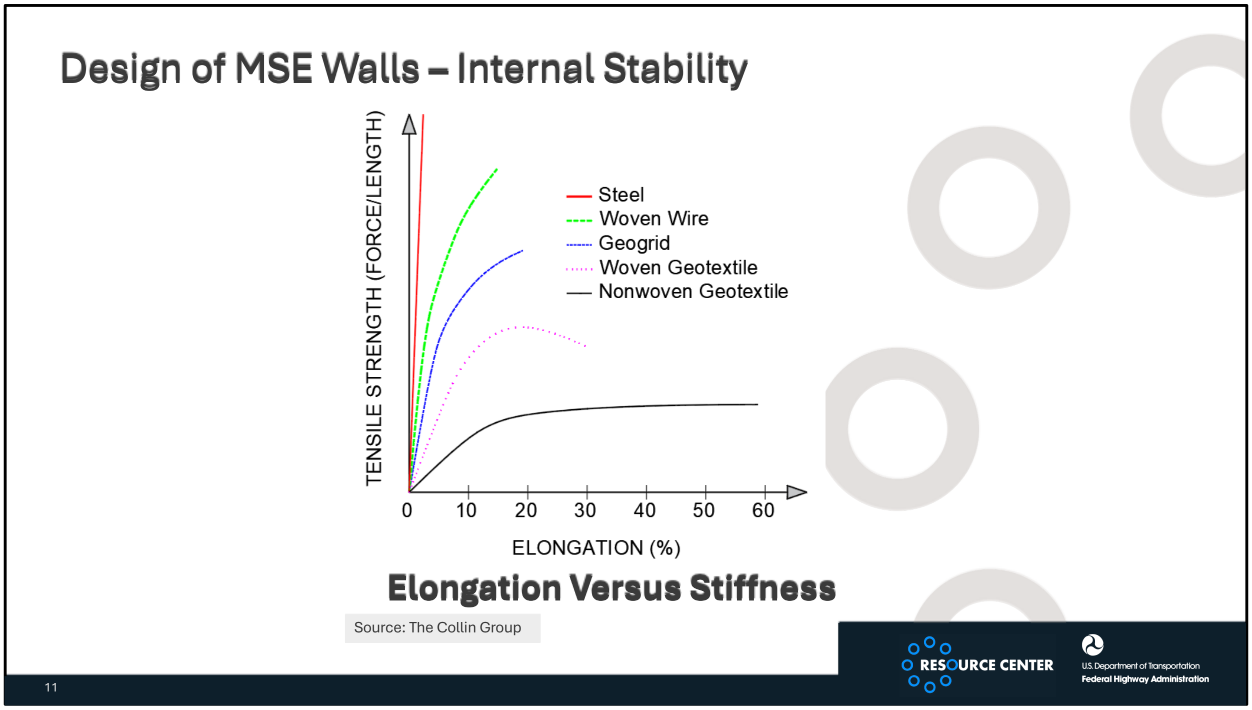
Reinforcement Types and Failure Surfaces:

1. Inextensible Reinforcements:
   - Failure surface: Logarithmic spiral, approximated as a bi-linear surface
   - Example materials: Steel strips, steel grids
   - Characteristic: Strain at failure is less than strain required for peak soil strength
2. Extensible Reinforcements:
   - Failure surface: Planar, based on Rankine earth pressure theory
   - Example materials: Geotextiles, geogrids
   - Characteristic: Strain at failure (≈10%) exceeds strain for peak soil strength (2-5%)

Significance:

- The difference in failure surfaces reflects how each reinforcement type interacts with the soil
- Inextensible reinforcements mobilize soil strength progressively, leading to a curved failure surface
- Extensible reinforcements allow full soil strength mobilization, resulting in a planar Rankine failure surface

This understanding of failure surfaces is crucial for accurate internal stability analysis and design of MSE structures.



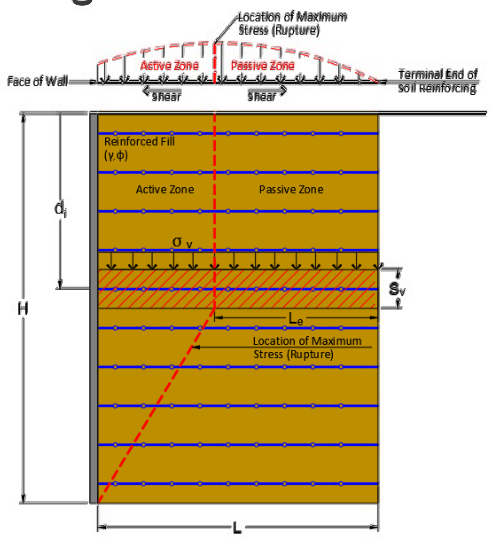
Key Message:
This graph illustrates the wide range of stiffness values across different soil reinforcement types, highlighting how material composition and manufacturing processes significantly influence reinforcement behavior.

Key Points:

1. **Stiffness Spectrum:**
   - The graph displays a broad range of stiffness values for various soil reinforcements
2. **Material Influence:**
   - Steel reinforcements generally exhibit higher stiffness compared to polymer-based options
   - Demonstrates the fundamental difference between inextensible (e.g., steel) and extensible (e.g., geosynthetic) reinforcements
3. **Manufacturing Process Impact:**
   - Significant variations in stiffness are observed even within similar material types
   - For example, woven geotextiles typically show higher stiffness than non-woven geotextiles
4. **Implications for Design:**
   - The choice of reinforcement material and type can greatly affect the behavior and performance of MSE structures
   - Understanding these stiffness differences is crucial for appropriate design and analysis methods
5. **Reinforcement Examples:**
   - Steel strips and grids at the higher end of the stiffness spectrum
   - Geogrids and geotextiles showing a range of lower stiffness values, varying by specific type and manufacturing process

This graph serves as a valuable reference for engineers in selecting appropriate reinforcement types based on project requirements and desired structural behavior

Design of MSE walls – Internal Stability



Source: The Collin Group

- Internal stability evaluates the ability of the reinforced fill to withstand the internal forces generated by the self weight of the fill and all externally applied forces.
- Modes of failure
  - Rupture of reinforcement
  - Pullout of reinforcement
  - Connection

Source: FHWA

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Key Message:
Understanding stress distribution in soil reinforcement and its failure modes is essential before comparing the four design methods for internal stability.
Key Points:
Stress Distribution in Soil Reinforcement:

1. **Critical Failure Surface:**
   - Maximum stress occurs at this location
   - Represents the theoretical division between active and resistant zones
2. **Stress Dissipation:**
   - Stress decreases from the critical failure surface towards both ends
   - Reaches zero at the terminal end of the reinforcement
   - Also decreases towards the face of the wall

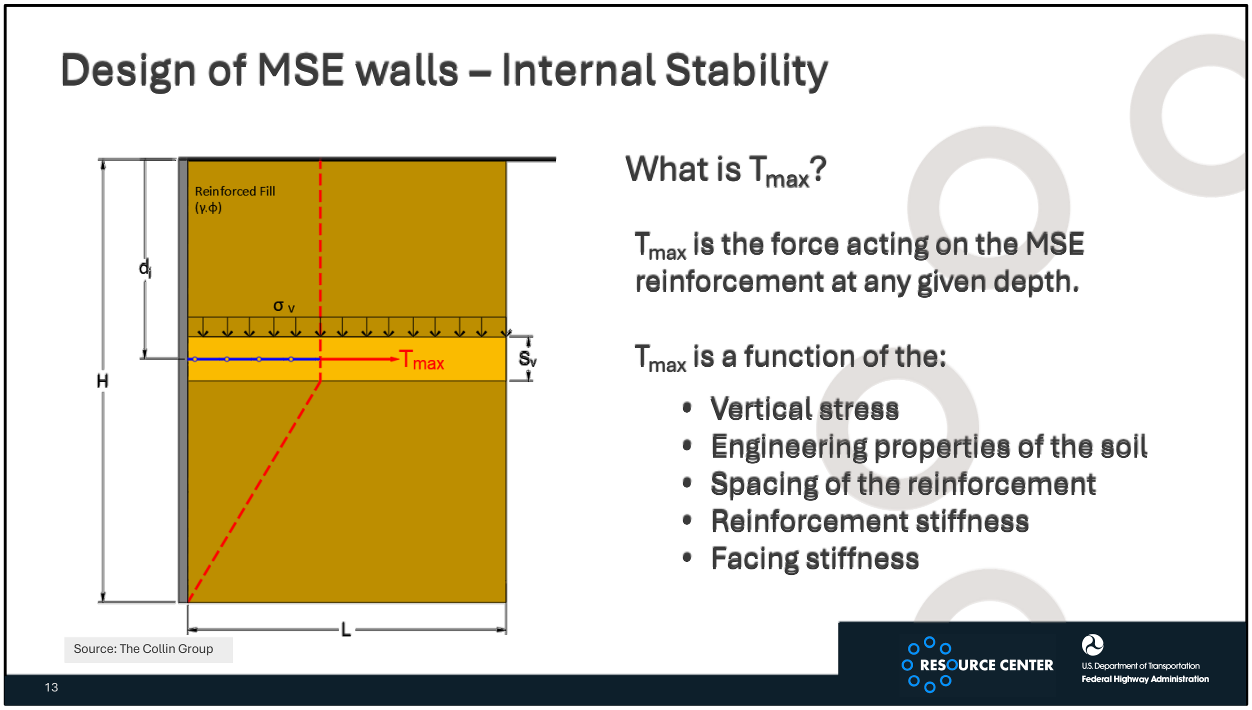
Internal Failure Modes:

1. **Rupture:**
   - Occurs when tensile stress exceeds the reinforcement's strength
   - Typically considered at the point of maximum stress (critical failure surface)
2. **Pullout:**
   - Failure due to insufficient anchorage behind the critical failure surface
   - Depends on reinforcement length and soil-reinforcement interaction
3. **Connection Failure:**
   - Occurs at the interface between reinforcement and wall facing
   - Influenced by connection strength and stress transfer mechanism

Significance:
Understanding this stress distribution and potential failure modes is essential for:

- Proper design of reinforcement length and strength
- Ensuring adequate anchorage behind the critical failure surface
- Designing appropriate connections at the wall face

This foundational knowledge sets the stage for comparing the four different design methods and their approaches to internal stability analysis



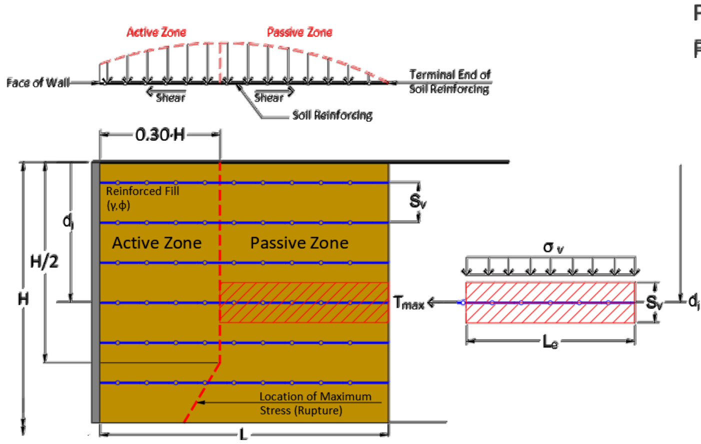
Key Message:
The maximum tension (Tmax) in MSE reinforcement is a critical design parameter that depends on multiple factors related to soil properties, reinforcement characteristics, and structural configuration.

Key Points:

1. **Definition of Tmax:**
   - Represents the maximum force acting on the MSE reinforcement at any given depth
   - Crucial for determining reinforcement strength requirements
2. **Influencing Factors:**
   - Vertical stress: Increases with depth, affecting the load on reinforcement
   - Soil engineering properties: Strength and stiffness of the reinforced fill
   - Reinforcement spacing: Both vertical and horizontal spacing impact load distribution
   - Reinforcement stiffness: Affects load-strain behavior and stress distribution
   - Facing stiffness: Influences stress transfer near the wall face
3. **Importance in Design:**
   - Tmax is used to determine reinforcement strength requirements
   - Helps in assessing potential failure modes (rupture, pullout, connection failure)
   - Critical for ensuring overall internal stability of the MSE structure
4. **Variability with Depth:**
   - Tmax typically varies with depth in the MSE structure
   - Generally increases with depth due to increasing overburden pressure
5. **Design Method Considerations:**
   - Different design methods may calculate Tmax using varying approaches
   - Understanding these factors is crucial for selecting and applying appropriate design methods

Understanding the factors influencing Tmax is essential for accurate and efficient design of MSE structures, ensuring their long-term stability and performance

Design of MSE walls – Internal Stability



Pullout Capacity –

$P_r = \phi_r F^* \alpha \sigma_v' L_e C R_c$ ➔ $P_r = \phi_r 2 F^* \sigma_v' L_e R_c$

- Φ_r – resistance factor
- F^* - Pullout resistance factor
  - Based on reinforcement interaction with the fill
- α – Scale correction factor for non-linear stress reduction over the embedded length
  - 1.0 for all reinforcements
- σ_v' = Effective vertical stress
  - $\sigma_v' = (\gamma_r\ d_i)$ + ...
- L_e – Reinforcement length in resistance zone
- C – Effective unit perimeter
  - 2 for sheet, strips, and grid reinforcement
- R_c = Percent coverage (width/horizontal spacing)

Source: The Collin Group

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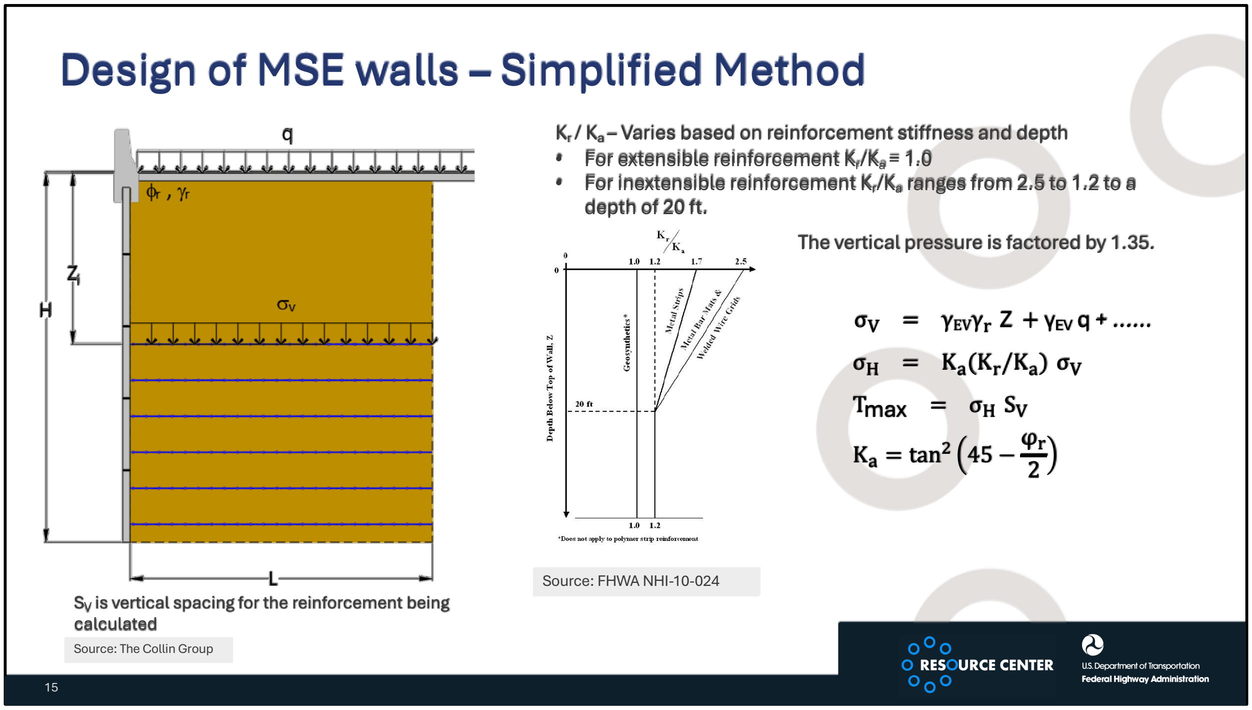
Key Message:
The latest GEC 11 update simplifies the pullout resistance calculation for soil reinforcement, focusing on the determination of maximum tensile force (Tmax) using different design methods.

Key Points:

1. **Pullout Equation Update:**
   - The scale effect factor has been removed from the pullout resistance equation
   - This simplification aligns with ASTM test methods requiring full mobilization of reinforcement
2. **Pullout Resistance Factors:**
   - Depends on vertical stress, soil properties, and reinforcement characteristics
   - Includes both friction and bearing resistance elements for geosynthetics
3. **ASTM Test Method Influence:**
   - ASTM D6706 standard now ensures full mobilization of reinforcement
   - Eliminates non-linear stress effects, simplifying the pullout resistance calculation
4. **Tmax Determination:**
   - The critical factor in pullout analysis is now the calculation of Tmax
   - Different design methods (e.g., Coherent Gravity, Simplified, Stiffness, Limit Equilibrium) may yield varying Tmax values
5. **Soil-Reinforcement Interaction:**
   - Pullout resistance involves both shear (friction) and bearing resistance mechanisms
   - The interaction depends on reinforcement type, soil properties, and loading conditions
6. **Design Implications:**
   - Engineers must carefully select the appropriate method for Tmax calculation
   - The chosen method impacts the overall pullout resistance assessment and reinforcement design

This update streamlines the pullout resistance calculation while emphasizing the importance of accurate Tmax determination in reinforced soil structure design



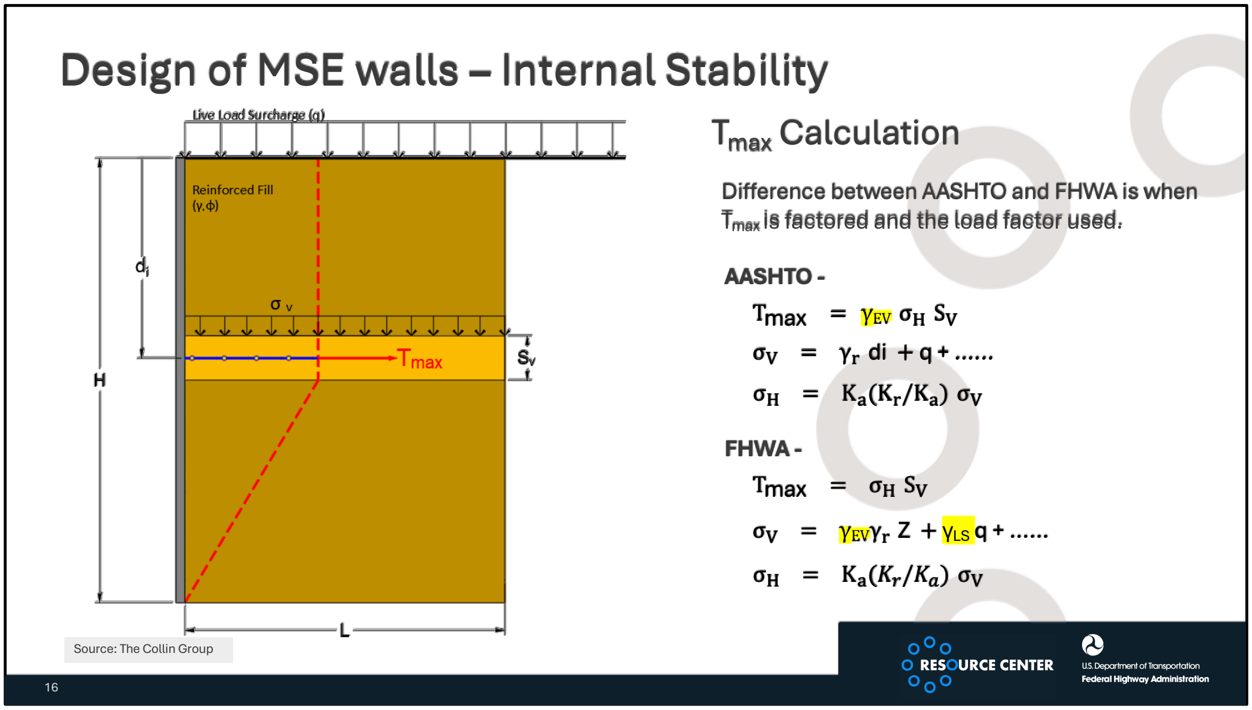
Key Message:

The Simplified Method for designing Mechanically Stabilized Earth (MSE) structures is an empirically developed approach based on Rankine earth pressure theory, offering a practical and widely used design methodology for MSE walls.

Key Points:

1. **Empirical Foundation:**
   - Developed from a series of instrumented MSE walls in Algonquin, IL
   - Incorporates data from various reinforcement types
2. **Theoretical Basis:**
   - Rooted in Rankine earth pressure theory, established over a century ago
   - Adapts classical soil mechanics principles to MSE structures
3. **Widespread Adoption:**
   - Commonly used by engineers for MSE wall design
   - Incorporated into AASHTO Standard Specifications for Highway Bridges
4. **Simplification of Design:**
   - Aims to unify and simplify MSE wall design methods
   - Balances theoretical concepts with empirical observations
5. **Versatility:**
   - Applicable to both steel and geosynthetic reinforced MSE walls
   - Adaptable to various soil and loading conditions
6. **Prediction Accuracy:**
   - Comparable to other available methods in terms of accuracy
   - Validated against full-scale MSE wall case histories
7. **Design Parameters:**
   - Considers factors such as vertical soil stresses and reinforcement stiffness
   - Provides a streamlined approach to calculating internal reinforcement stresses

This method offers a balance between theoretical soil mechanics and practical design considerations, making it a valuable tool for MSE wall designers.



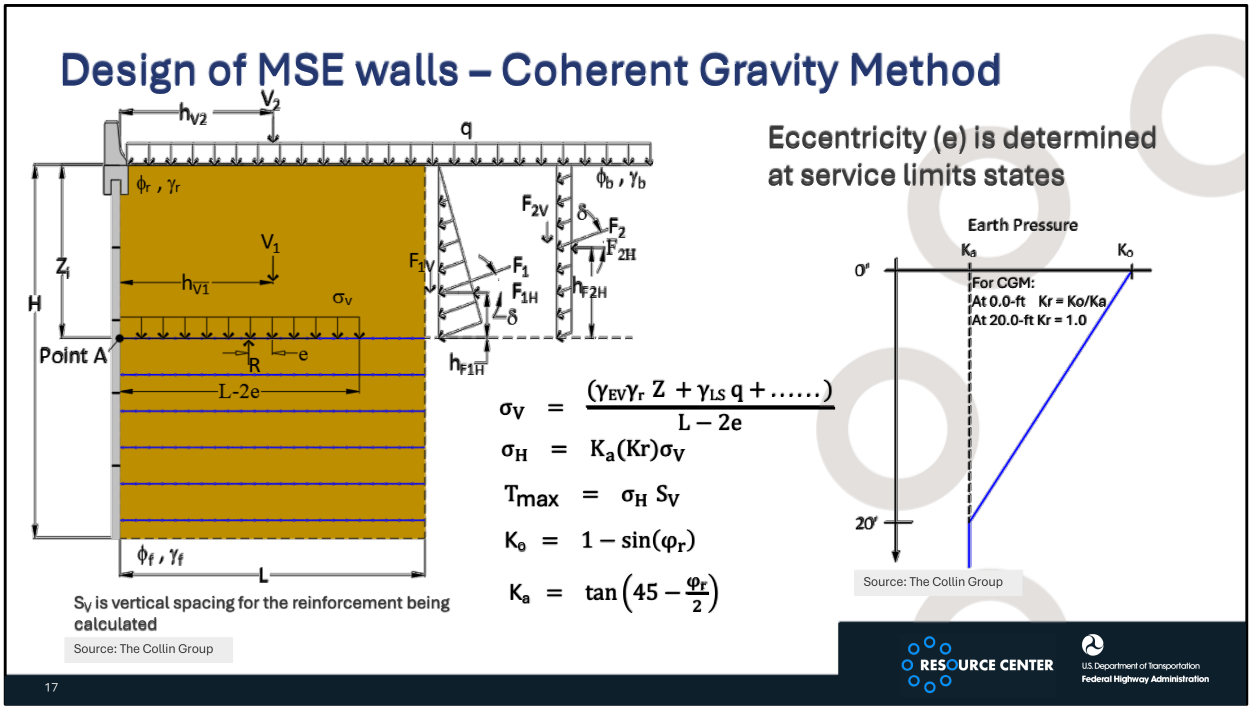
Key Message:

The calculation of Tmax in MSE wall design differs between AASHTO and FHWA approaches, primarily in the application of load factors, which impacts the final design values and potentially the overall wall performance.

Key Points:

1. **AASHTO Approach:**
   - Applies the load factor after determining the horizontal stress (σH)
   - Simplifies the calculation process
   - May result in a more conservative design in some cases
2. **FHWA Approach:**
   - Applies specific load factors to each component of the vertical load
   - Potentially more precise, accounting for variability in different load types
   - May lead to a more optimized design in certain situations
3. **Impact on Design:**
   - The FHWA method may result in lower Tmax values for some load combinations
   - AASHTO's approach might be more conservative, potentially leading to over-design
4. **Design Considerations:**
   - Engineers should be aware of these differences when interpreting design guidelines
   - The choice of method may affect reinforcement spacing, strength requirements, and overall wall economy
5. **Calibration and Reliability:**
   - Both methods aim to ensure adequate safety and performance of MSE structures
   - The differences reflect ongoing efforts to balance simplicity, accuracy, and conservatism in design

Understanding these differences is crucial for engineers to make informed decisions in MSE wall design, ensuring both safety and efficiency



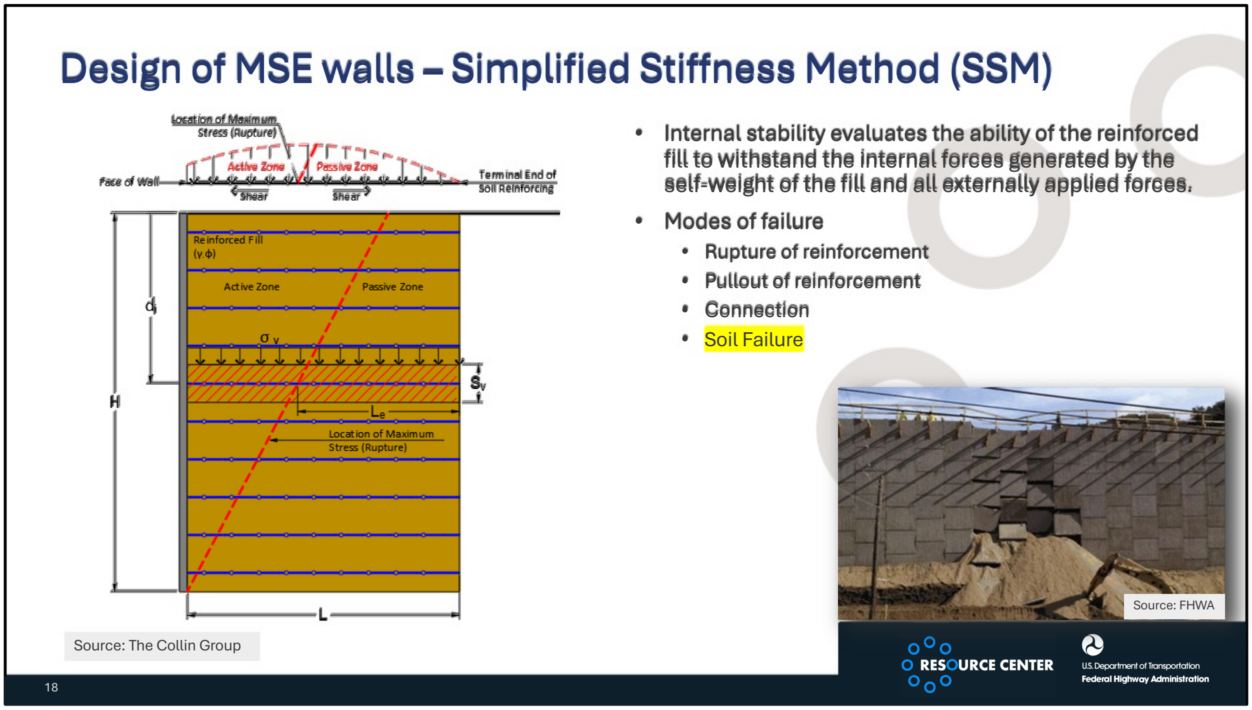
Key Message:

The Coherent Gravity Method for designing Mechanically Stabilized Earth (MSE) structures is specifically tailored for inextensible reinforcements, incorporating a variable earth pressure coefficient and a unique approach to vertical stress distribution.

Key Points:

1. **Applicability:**
   - Exclusively used for inextensible reinforcement (e.g., steel strips, steel grids)
2. **Earth Pressure Coefficient:**
   - Varies from K_o at the top to K_a at the bottom of the wall
   - For 34° soil friction angle: K_o = 0.44, K_a = 0.28, K_o/K_a = 1.6
   - For 40° soil friction angle: K_o = 0.36, K_a = 0.22, K_o/K_a = 1.6
3. **Comparison with Simplified Method:**
   - K_o/K_a ratio aligns closely with the Simplified Method's K_r/K_a ratio of 1.7 at the wall top
4. **Vertical Stress Distribution:**
   - Distributed over a shorter length compared to other methods
   - Includes vertical components of retained soil load and surcharge load
5. **Stress Calculation:**
   - Incorporates both the reinforced soil mass and the retained backfill in stress calculations
6. **Design Implications:**
   - May result in higher reinforcement loads near the top of the wall
   - Potentially more conservative design in the upper wall sections
7. **Historical Context:**
   - Developed based on observations from instrumented MSE walls
   - Reflects the behavior of inextensible reinforcements in soil interaction

This method provides a nuanced approach to MSE wall design, particularly suited for structures using steel reinforcements, by accounting for the unique stress distribution patterns observed in such systems



Key Message: The Simplified Stiffness Method (SSM) evaluates the internal stability of reinforced soil structures, focusing on the reinforced fill's capacity to resist internal forces from self-weight and external loads.

Key Points:

Purpose of Internal Stability Analysis:

- Assesses the reinforced fill's ability to withstand internal forces
- Considers forces from self-weight of fill
- Accounts for all externally applied forces

Modes of Failure Evaluated

1. Rupture of reinforcement
2. Pullout of reinforcement
3. Connection failure
4. Soil failure

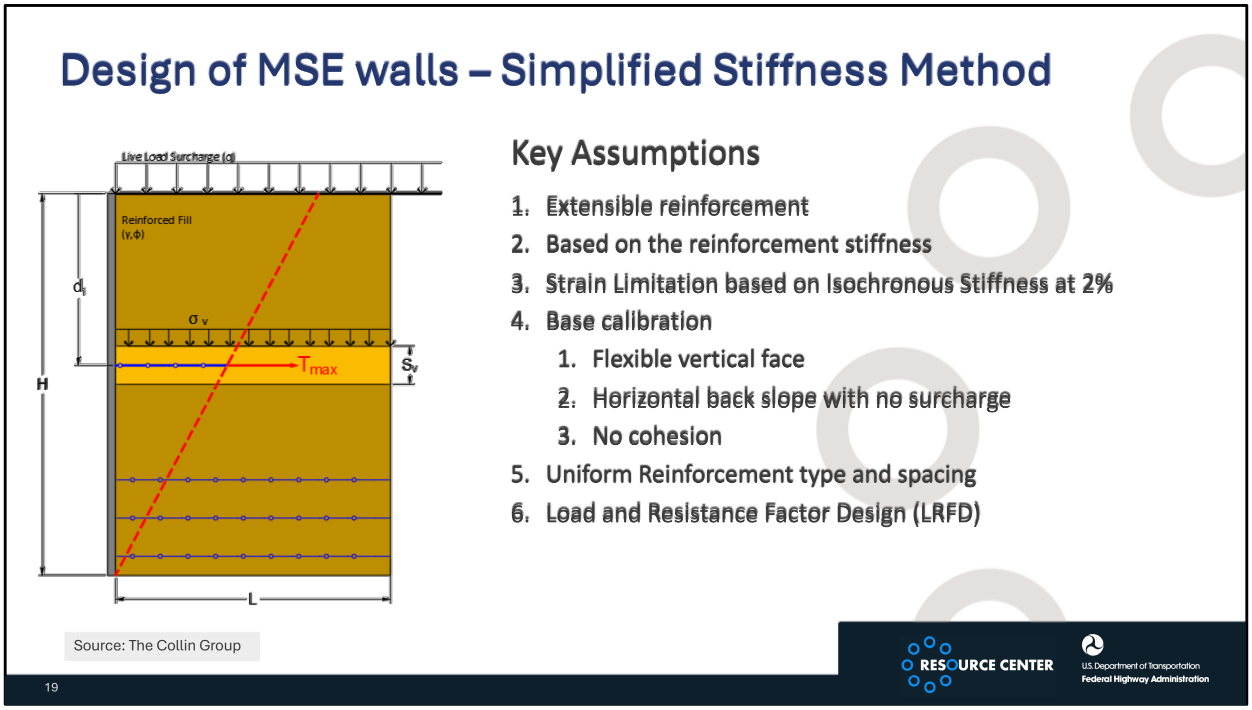
Importance in Design:

- Ensures overall structural integrity of reinforced soil systems
- Helps prevent localized failures within the reinforced mass
- Guides the selection and spacing of reinforcement elements

Comprehensive Approach:

- Addresses multiple potential failure mechanisms
- Provides a holistic view of internal stability

This method offers a streamlined yet thorough approach to assessing the internal stability of reinforced soil structures, covering key aspects of potential failure modes.

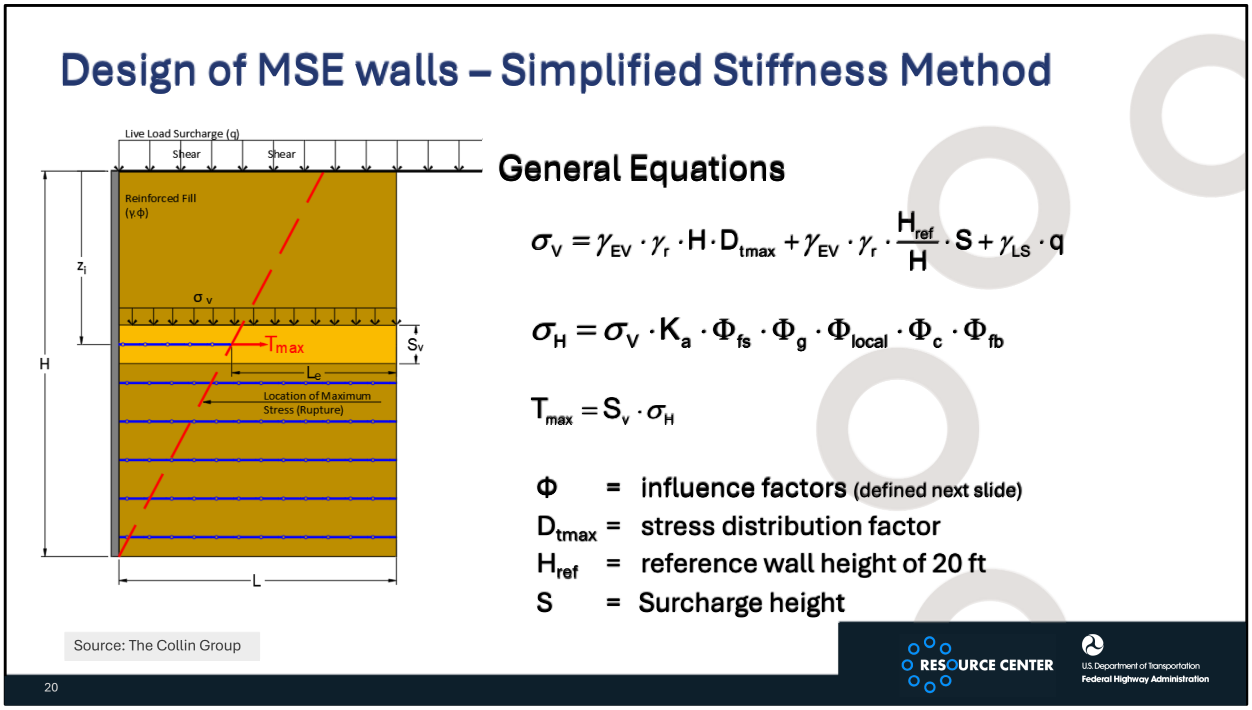


Key Message:
The Simplified Stiffness Method is an empirically based approach for designing Mechanically Stabilized Earth (MSE) structures, specifically tailored for extensible soil reinforcements. It incorporates reinforcement stiffness and strain limitations as critical design parameters while being compatible with Load and Resistance Factor Design (LRFD) principles.

Key Assumptions:

1. **Reinforcement Type:**
   - Designed for extensible soil reinforcements (e.g., geosynthetics)
2. **Reinforcement Stiffness:**
   - Considers reinforcement stiffness as a crucial factor in determining tensile load distribution
3. **Strain Limitation:**
   - Aims to limit reinforcement strain, treating it as a serviceability limit state
4. **Empirical Basis:**
   - Developed and calibrated using full-scale MSE wall case history data
   - Assumes:
     a) Flexible vertical face
     b) Horizontal back slope (adjustable for other conditions)
     c) Cohesionless soil (can be adapted for cohesive soils)
5. **Uniform Reinforcement:**
   - Typically assumes uniform reinforcement material and spacing
   - Can accommodate variations if necessary
6. **LRFD Compatibility:**
   - Incorporates resistance factors based on available data and understanding
7. **Wall Configuration:**
   - Basic formulation assumes no surcharge, though adjustable using influence factors

These assumptions enable the Simplified Stiffness Method to provide a balanced approach to MSE wall design, combining accuracy with practicality while accounting for key factors influencing wall performance.

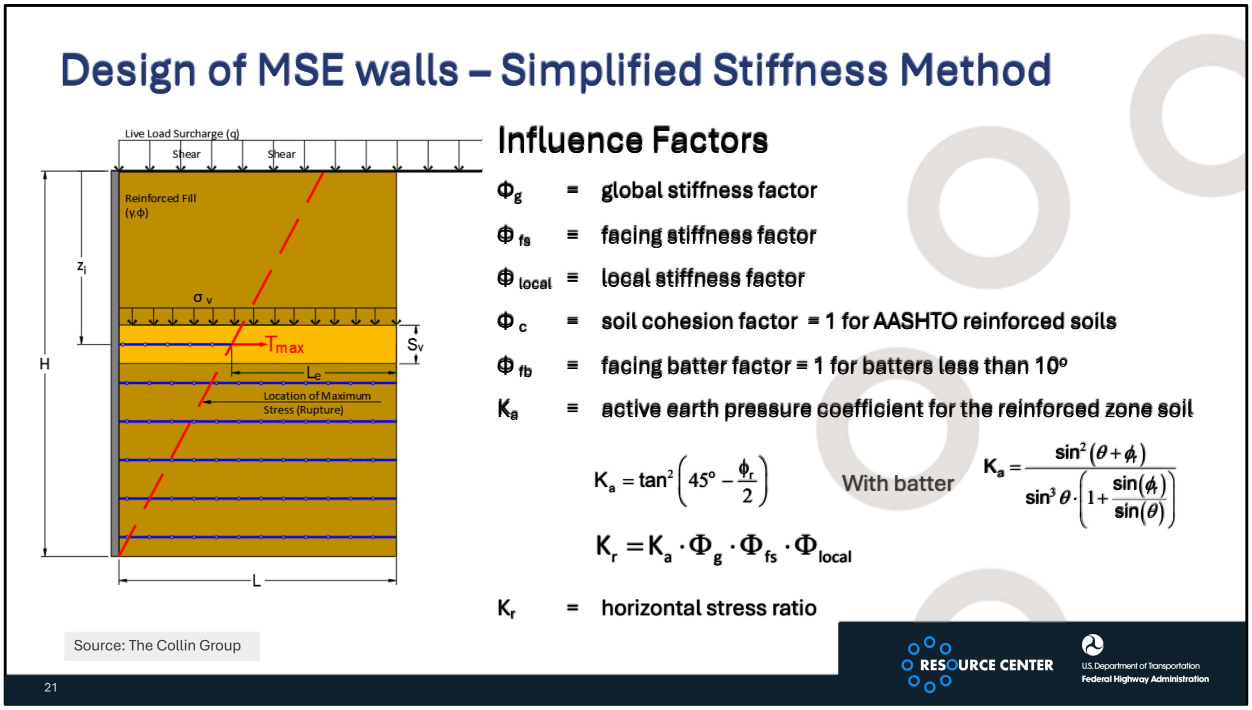


Key Message: The SSM methodology is like the CG and SM methodologies. The goal is to find the Tmax for every reinforcement layer.

Key Steps in SSM Methodology:

1. **Vertical Pressure Calculation:**
   - Determines vertical pressure for reinforced soil layer using a stress distribution factor
   - Includes external surcharge
   - Accounts for live load surcharge
2. **Horizontal Pressure Determination:**
   - Uses active earth pressure coefficient as an index by applying the product of influence factors
   - Applies soil surcharge and live load surcharge
3. **Required Tension (T) Calculation:**
   - Multiplies horizontal pressure by tributary spacing

This streamlined approach allows for efficient analysis of internal stability in reinforced soil structures. It focuses on key parameters to determine the critical tension in each reinforcement layer.



Key Message:

The Simplified Stiffness Method (SSM) employs a series of influence factors to refine the calculation of maximum tensile load (Tmax) in each reinforcement layer, accounting for various structural and material conditions in MSE wall design.

Key Points:

1. **Influence Factors:**
    - Φg accounts for the effect of reinforcement stiffness
    - Φfs considers the impact of facing stiffness
    - Φlocal adjusts for local variations in reinforcement stiffness or spacing
    - Φc accounts for the presence of soil cohesion, if it is determined to be permanent over the structure's lifetime
    - Φfb reduces Tmax as the wall batter increases
2. **Factor Characteristics:**
    - All influence factors are ≤ 1
    - Act to attenuate the maximum tensile load under specific conditions
3. **Application in Design:**
    - Factors are incorporated into the SSM equation
    - Modify calculated Tmax based on specific design conditions and material properties
4. **Design Flexibility:**
    - Allows for more nuanced and potentially optimized designs
    - Accounts for a wide range of structural and material variables

This approach enables a more refined and potentially more economical design of MSE structures while maintaining safety and performance standards

Secant stiffness values for geosynthetic soil reinforcing can be obtained from the NTPEP

- As of May 23, 2024, NTPEP is renamed to "AASHTO Product Evaluation and Audit Solution"
- Continues to play a crucial role in evaluating transportation products

Determining T_{max} – SSM

Vertical Stress is distributed to reinforcement layers using the base pressure and empirical distribution factor D_{tmax}

$$D_{tmax} = D_{tmax0} + \left(\frac{z}{z_b}\right) \cdot (1 - D_{tmax0})$$

$$D_{tmax} = 1.0 \quad \text{for} \quad z \geq z_b$$

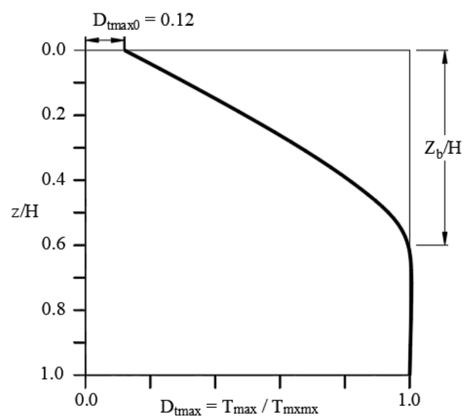
$$z_b = C_h \cdot (H)^{1.2}$$

Height influence factor coefficient

C_h = 0.32 for imperial (ft)

= 0.40 for metric (m)

$$\gamma_r \cdot H \cdot D_{tmax}$$



z = depth to reinforcement

Source: GEC11

Key Message: The Simplified Stiffness Method (SSM) employs a unique approach to calculate the reinforcement tension. It differs from the Coherent Gravity Method (CGM) and Simplified Method (SM) by using a base stress (Hγ without surcharge) and distribution factor rather than calculating stress at each reinforcement layer.

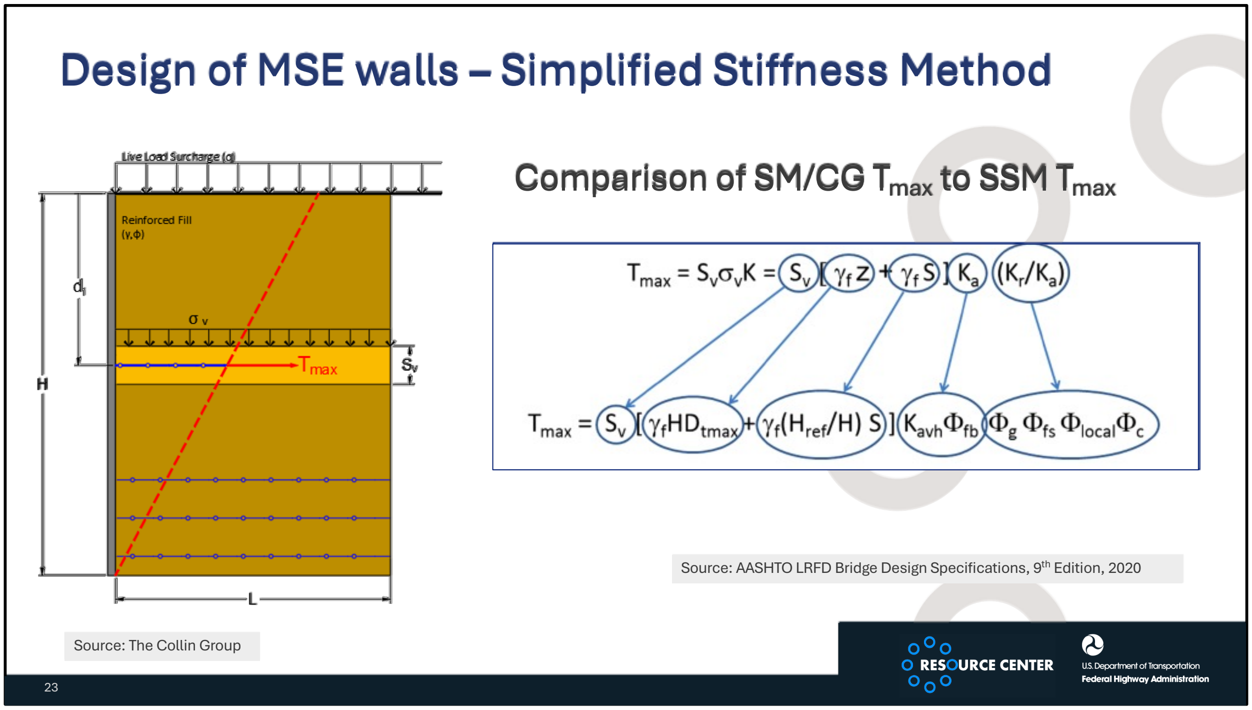
Key Points:

Stress Distribution:
- Uses empirical T_{MAX} distribution factor (Dtmax)
- Dtmax is normalized to wall height and maximum tension at the base of the wall

Distribution Factor Characteristics:
- Reaches 1.0 at approximately 60% of normalized depth
- Remains 1.0 from this point to the wall base

This method provides a streamlined approach to tension calculation in reinforced soil structures, focusing on overall stress distribution rather than layer-by-layer analysis.

Reference: *Design and Construction of MSE Walls, FHWA GEC 011, Resource Manual, 2023 edition, Chapter 4, Section 4.4.9.4.3 (page 135)*

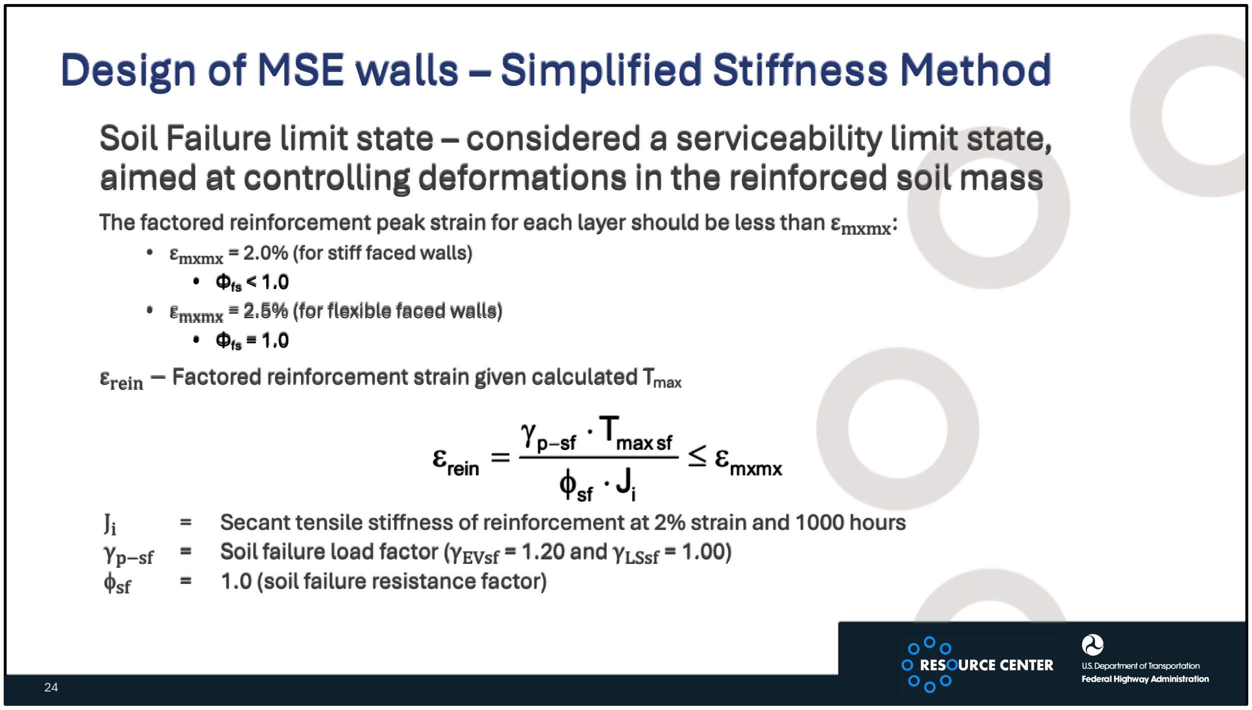


Key Message:
The Simplified Stiffness Method (SSM) shares fundamental components with both the Simplified Method (SM) and the Coherent Gravity Method (CGM) in the analysis of mechanically stabilized earth structures.

Common Components:

1. Soil Stress Component:
   - All methods account for the stress generated by the soil mass itself
2. External Surcharge Pressure:
   - Each method incorporates the effects of additional loads applied to the top of the structure
3. External Live Load Surcharge Pressure:
   - All three methods consider the impact of temporary or moving loads on the structure
4. Earth Pressure Coefficient:
   - Each method uses an earth pressure coefficient
   - This coefficient is a function of reinforcement stiffness in all three approaches

Significance:
While the SSM introduces some unique features, it maintains consistency with established methods by including these core elements, ensuring a comprehensive analysis of MSE structures.



Key Message:

The Simplified Stiffness Method (SSM) is grounded in empirical data from service load conditions. It necessitates calculating reinforcement strain to ensure structural integrity and prevent soil failure.

Key Points:

- Failure Mechanism:
  - Failure occurs when reinforcement strain exceeds a critical value
  - Excessive strain allows soil to reach or surpass peak shear strength
  - Results in continuous shear failure zone within the reinforced fill
- Service Limit State Check:
  - Soil failure check is considered a service limit state assessment
  - Requires recalculation of Tmax using different load factors (γ_{EVsf}) for vertical loads
- Purpose of Soil Failure Check:
  - Ensures limited deformation of reinforced soil structures
  - Maintains structural integrity under service conditions
- Importance in Design:
  - Critical for preventing progressive failure
  - Helps maintain long-term stability and serviceability of the structure

This approach in the SSM emphasizes the importance of controlling reinforcement strain to prevent soil failure and ensure the long-term performance of mechanically stabilized earth structures.

Design of MSE walls – Stiffness Method

Soil Failure Check:

$$\varepsilon_{rein} = \frac{T_{max\,sf}}{\phi \cdot J_i} \le \varepsilon_{mxmx}$$

$$T_{max\,sf} = S_V \cdot \left[\gamma_{EVsf} \cdot H \cdot \gamma_r \cdot D_{tmax} + \gamma_{EVsf} \cdot \gamma_{es} \cdot \left(\frac{H_{ref}}{H}\right) \cdot S_{AVG} + \gamma_{LSsf} \cdot \sigma_q\right] \cdot k_{avh} \cdot \Phi$$

γ_{EVsf} = load factor for prediction of T_{max} for the soil failure limit state (dimensionless)

$T_{max\,sf}$ = the reinforcement tensile load occurring at a horizontal strain equal to the soil strain at which the reinforced zone soil is at its peak shear strength.

ϕ_{sf} = the resistance factor that accounts for uncertainty in the measurement of the reinforcement stiffness at the specified strain = 1.0

ϵ_{mxmx} = the maximum acceptable strain (<2% for stiff-faced walls, and <2.5% for flexible-faced walls) in the wall section corresponding to T_{max} in any reinforcement layer (%)

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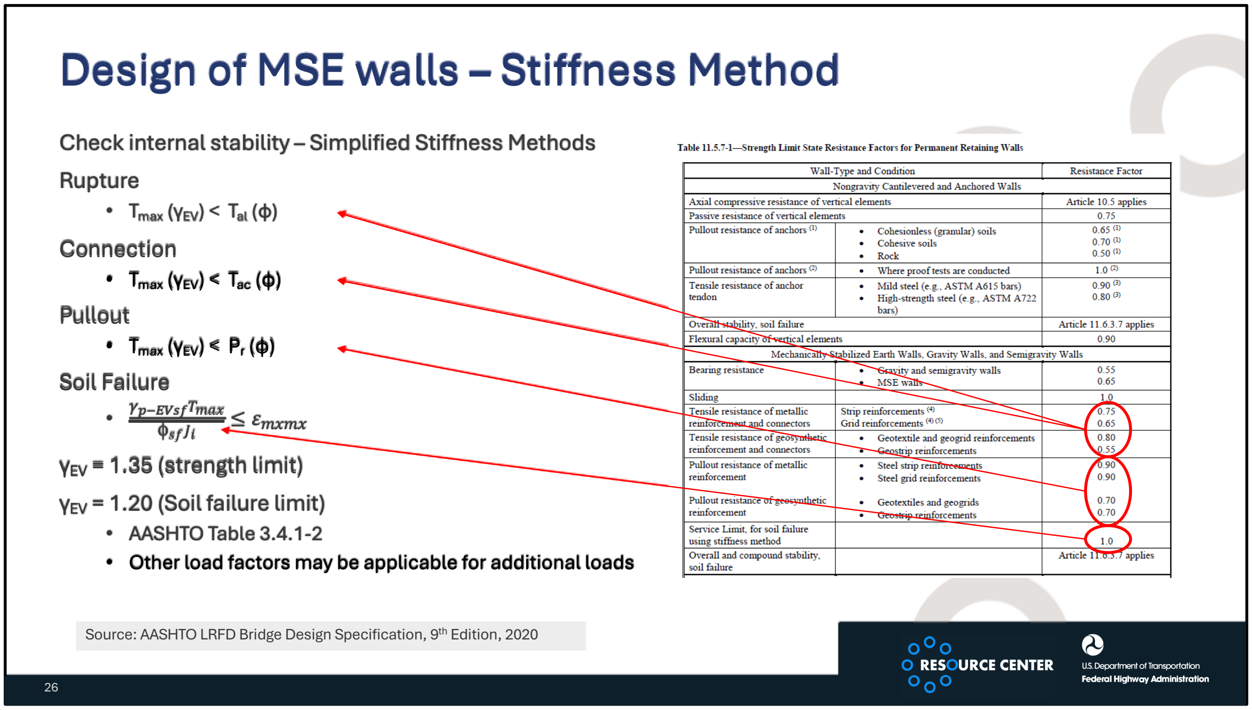
Key Message:
The soil failure check in the Simplified Stiffness Method (SSM) is a service limit state analysis, requiring a recalculation of Tmax using empirically derived load and resistance factors.

Key Points:

- **Service Limit State Analysis:**
  - Soil failure check is categorized as a service limit state
  - Focuses on structure performance under normal operating conditions
- **Recalculation of Tmax:**
  - Tmax must be recalculated specifically for this check
  - Different from the initial Tmax calculation used in other analyses
- **Empirical Factors:**
  - Uses load factors derived from empirical data
  - Employs resistance factors based on observed performance
- **Purpose:**
  - Ensures accurate assessment of soil-reinforcement interaction at service conditions
  - Helps prevent excessive deformation and maintain structural integrity
- **Distinction from Strength Limit State:**
  - Emphasizes serviceability rather than strength
  - Reflects the unique requirements of soil failure analysis in reinforced structures

This approach in the SSM highlights the importance of using appropriate, empirically based factors to assess soil failure potential under service conditions.

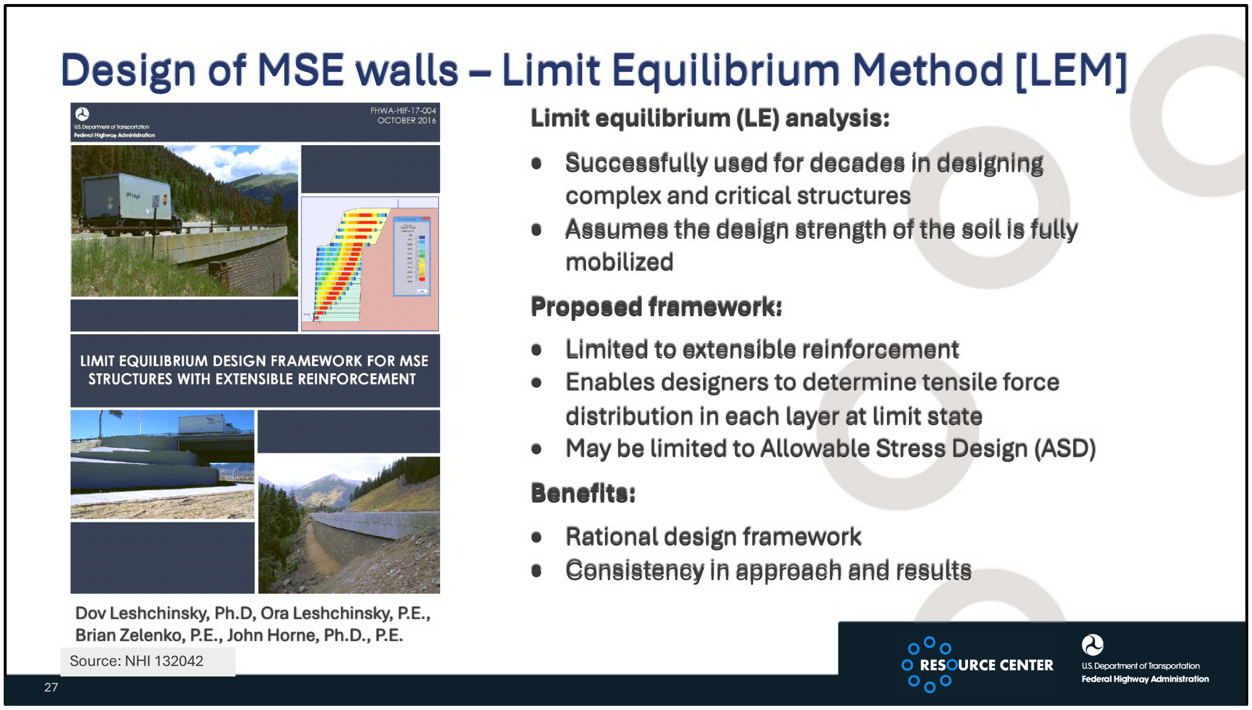


Key Message:
When applying design methods for mechanically stabilized earth structures, it is crucial to use the appropriate resistance and load factors for different failure modes, considering the analysis methodology and reinforcement stiffness.

Key Points:

- Critical Failure Modes:
  - Rupture
  - Pullout
  - Connection
  - Soil failure
- AASHTO Guidance:
  - Article 3: Provides guidance on load factors
  - Article 11.5: Offers guidance on resistance factors
- Factor Determination:
  - Factors vary based on:
    Analysis methodology used
    Stiffness of the reinforcement
- Importance of Correct Application:
  - Ensures accurate assessment of structural safety
  - Accounts for uncertainties in loads and material properties
  - Leads to more reliable and efficient designs
- Consideration of Reinforcement Type:
  - Factors may differ for extensible (e.g., geosynthetics) vs. inextensible (e.g., steel) reinforcements

This approach emphasizes the need for careful selection and application of load and resistance factors to ensure comprehensive and accurate design of reinforced soil structures.



In 2016, the Federal Highway Administration (FHWA) published a significant document titled "Limit Equilibrium Design Framework for MSE Structures with Extensible Soil Reinforcement," authored by Dov and Ora Leshchinsky. This design method has since been incorporated into the GEC 11.

Key aspects of this framework include:

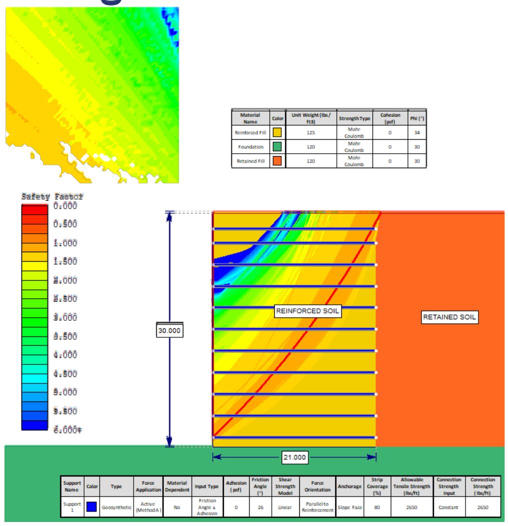
1. Versatility: The term "framework" indicates that any slope stability analysis can be used, provided it is properly modified to accommodate reinforcement
2. Established foundation: Limit equilibrium (LE) analysis has been successfully used for decades in designing complex and critical structures, assuming full mobilization of soil design strength
3. Scope: The framework is limited to extensible reinforcement and enables designers to determine tensile force distribution in each layer at the limit state
4. Design approach: It may be limited to Allowable Stress Design (ASD)

Benefits of this framework include:

1. Rational design: It provides a rational approach to designing reinforced soil structures
2. Consistency: The framework offers consistency in approach and results across various applications
3. Versatility: It enables wide and consistent usage for complex geometries and soil profiles
4. Unified approach: The framework eliminates arbitrary distinctions between 'walls' and 'slopes', reducing confusion in design
5. Economic design: It allows designers to select geosynthetics and connectors with sufficient long-term strengths economically

This LE framework represents a significant advancement in the design of mechanically stabilized earth structures with extensible reinforcement, offering a more comprehensive and consistent approach to analysis and design.

Design of MSE walls – Limit Equilibrium Method [LEM]



Source: The Collin Group

- Use extensible reinforcement only
- The LEM is suitable for flexible earth structures that allow deformations and **full mobilization of soil strength** at failure.
- There are several LEMs available in the literature. (i.e., Bishop, GLE, Spencer, Morgenstern-Price, etc.)
- In the LEM the slip surface can be planar, bi-planar, multi-planar, circular or log-spiral.
- Does not consider deformation

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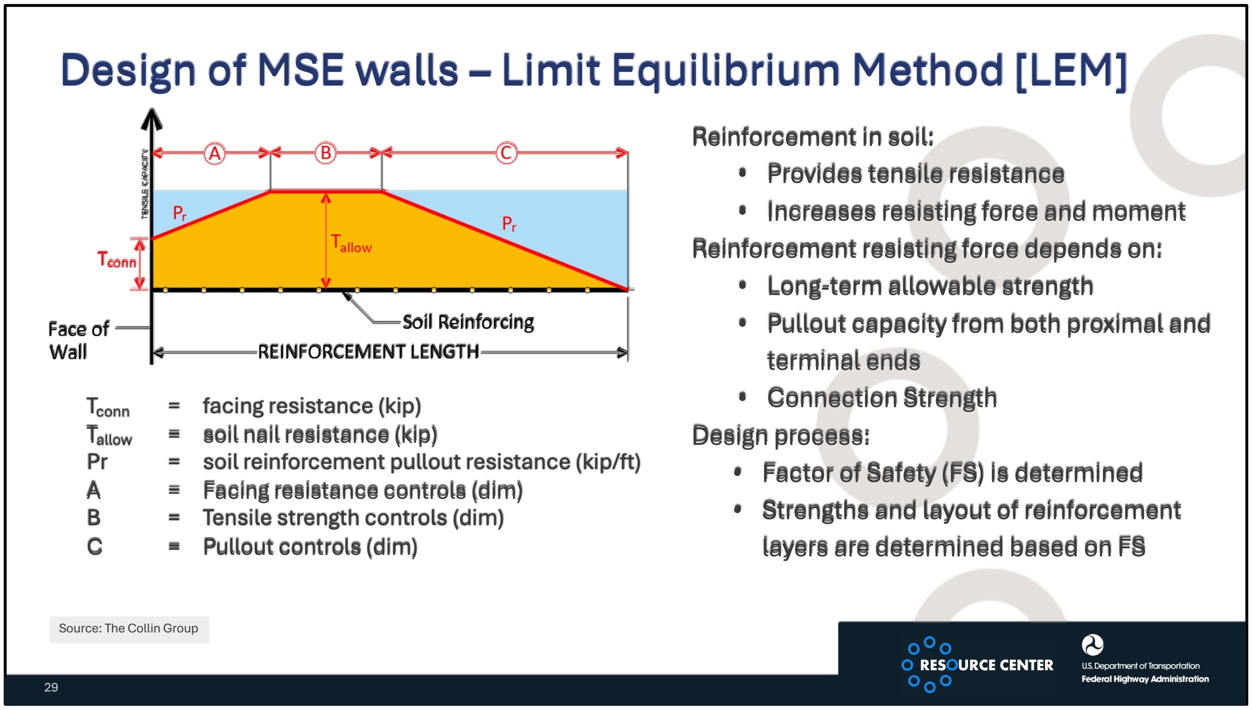
Key Message:

The LE is a versatile approach for analyzing extensible reinforced soil structures with specific characteristics and limitations.

Key Points:

1. **Extensible Reinforcement Only:**
   - Framework is specifically designed for extensible reinforcement materials
2. **Suitable for Flexible Structures:**
   - Applicable to earth structures that allow deformations
   - Assumes full mobilization of soil strength at failure
3. **Multiple LEM Variations:**
   - Various methods available, including:
     - Bishop's method
     - General Limit Equilibrium (GLE)
     - Spencer's method
     - Morgenstern-Price method
4. **Flexible Slip Surface Geometry:**
   - Can accommodate different slip surface shapes:
     - Planar
     - Bi-planar
     - Multi-planar
     - Circular
     - Log-spiral
5. **Limitations on Deformation Analysis:**
   - Does not consider or calculate deformations
   - Focuses on strength limit state analysis
6. **Rational Design Framework:**
   - Provides a consistent approach for complex geometries and soil profiles
7. **Economic Design:**
   - Allows for efficient selection of geosynthetics and connectors
8. **Unified Approach:**
   - Eliminates arbitrary distinctions between 'walls' and 'slopes'

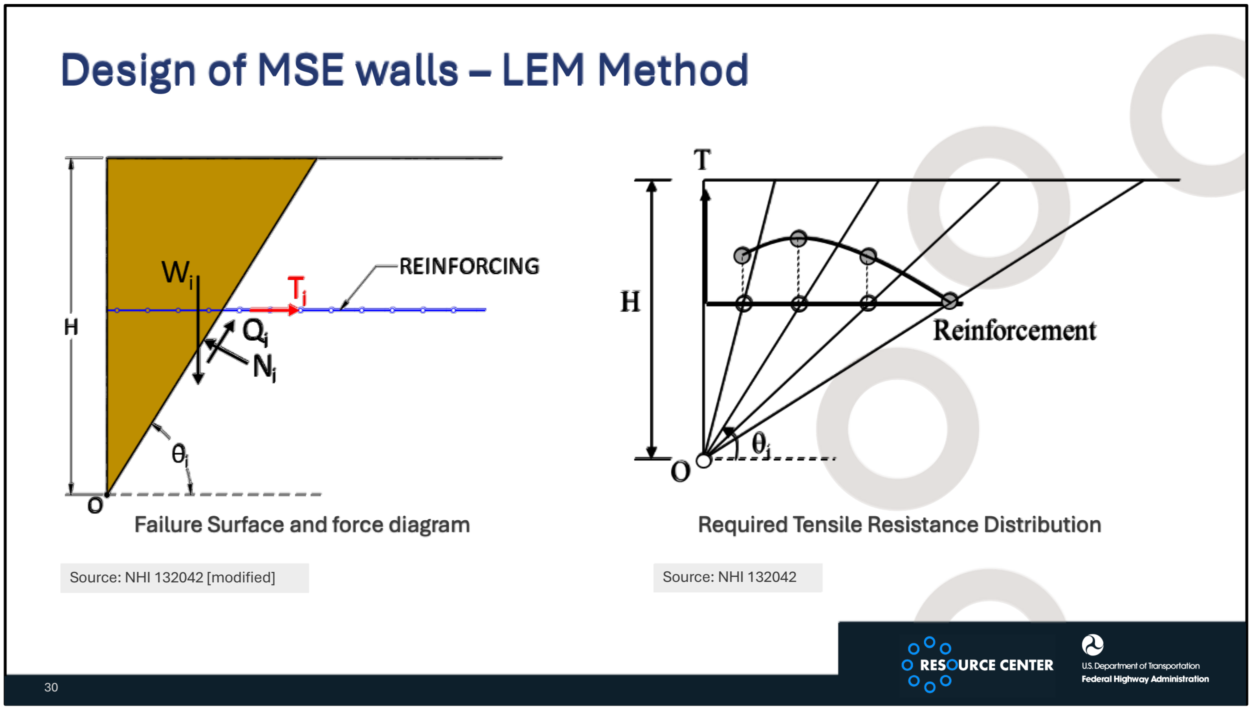


Key Message:

The resistance of soil reinforcement in mechanically stabilized earth structures is determined by three primary factors: soil reinforcement resistance, pullout resistance, and facing resistance. The controlling factor depends on where the failure surface intersects the soil reinforcement.

Key Points:

1. **Resistance Zones:**
   - Zone A: Facing resistance controls
   - Zone B: Soil tensile resistance controls
   - Zone C: Pullout resistance controls
2. **Failure Surface Intersection:**
   - The reinforcement resistance is determined by the zone where the failure surface intersects the soil reinforcement
3. **Varying Uncertainties:**
   - Each zone has different associated uncertainties
4. **Different Safety Factors:**
   - Due to varying uncertainties, each zone has different Factors of Safety (FS)
5. **Varying Resistance Factors:**
   - The resistance factors differ for each zone, reflecting the different levels of uncertainty and safety factors



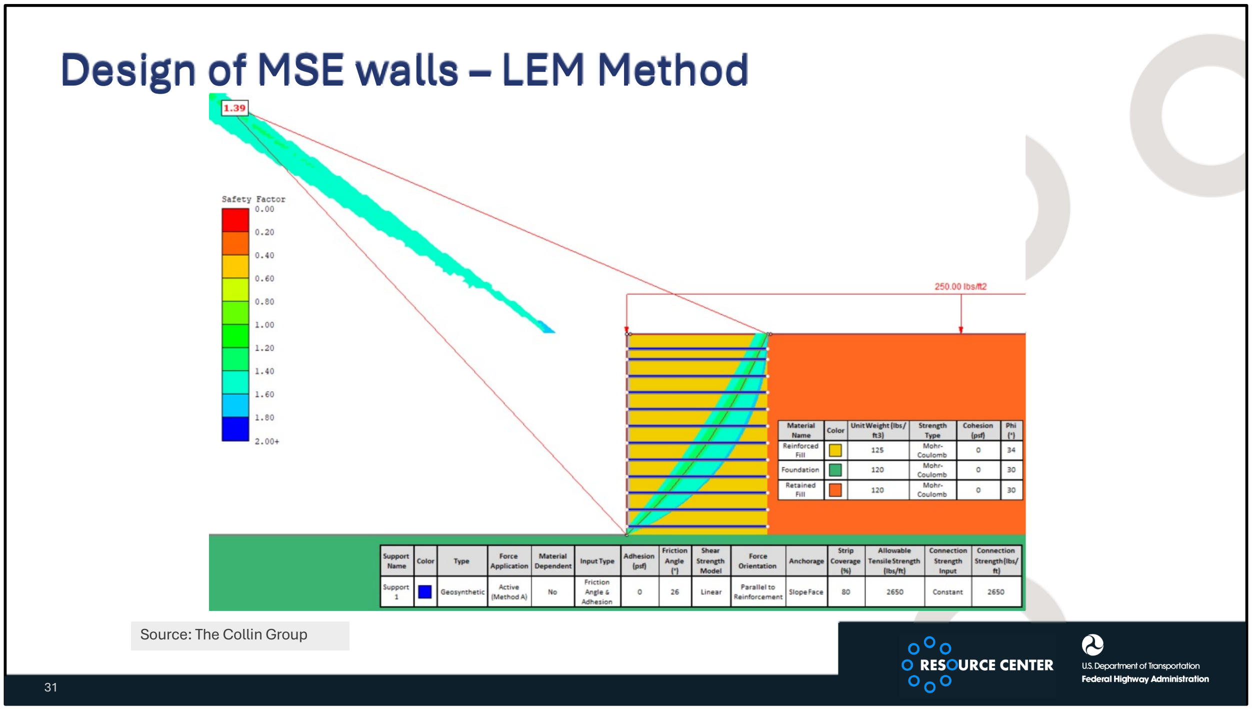
Key Message:
The Limit Equilibrium Method (LEM) for reinforced soil structures uses a simplified model to analyze stability and determine reinforcement requirements.

Key Points:

1. Planar Slip Surface:
   - LEM concepts are demonstrated using a planar slip surface
   - Simplifies analysis while capturing essential stability mechanics
2. Soil Mass Division:
   - Unstable wedge identified at the front of the structure
   - Area behind the wedge considered stable
3. Reinforcement Function:
   - Soil reinforcement added to provide tensile resistance
   - Stabilizes the otherwise unstable wedge
4. Slip Surface Angle and Tensile Resistance:
   - For each slip surface angle (θi), the reinforcement layer provides specific tensile resistance (Ti)
   - Tensile force calculated to maintain wedge stability
5. Force Diagram Illustration:
   - Concept visualized through force diagram for a vertical wall
   - Shows interaction between soil forces and reinforcement resistance
6. Design Importance:
   - Critical for designing and analyzing reinforced soil structures
   - Ensures stability under various loading conditions

This method provides a practical approach to reinforced soil design, balancing simplicity with effective stability analysis.

- Wi is the weight of the wedge within the slip plane
- Ni is the normal force applied on the slip plane,
- Qi is the shear force applied on the slip plane
- Ti is the required tensile resistance of the reinforcement at the intersection between the reinforcement and the slip plane

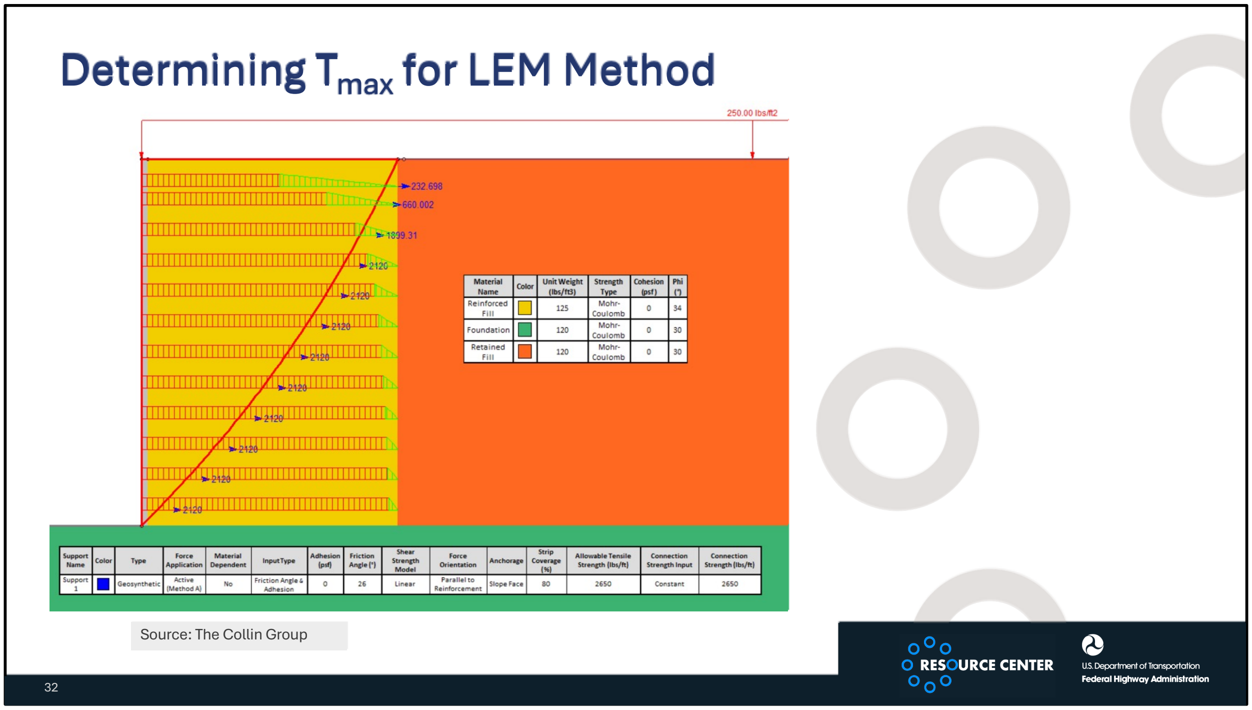


Key Message:
A comprehensive limit equilibrium analysis of a 30-foot reinforced soil structure reveals critical stability characteristics using the GEC11 design approach and Spencer method.

Key Analysis Parameters:

1. Structure Dimensions:
   - Total height: 30 feet
   - Reinforcement length: 21 feet
   - Reinforcement layers: 12 equally spaced layers
2. Analysis Methodology:
   - Method: Spencer method
   - Slip surface type: Circular
   - Reinforcement strength input: Allowable strength (Method A)
3. Stability Assessment:
   - Critical failure surface identified
   - Factor of Safety (FS): 1.39
   - FS > 1.0 indicates structural stability
4. Design Approach:
   - Follows GEC11 guidelines
   - Utilizes LRFD principles
   - Accounts for different uncertainty factors
5. Significance:
   - Demonstrates a systematic approach to reinforced soil structure analysis
   - Provides quantitative assessment of structural stability
   - Enables informed design decisions

This analysis comprehensively evaluates the reinforced soil structure's stability under specified conditions.

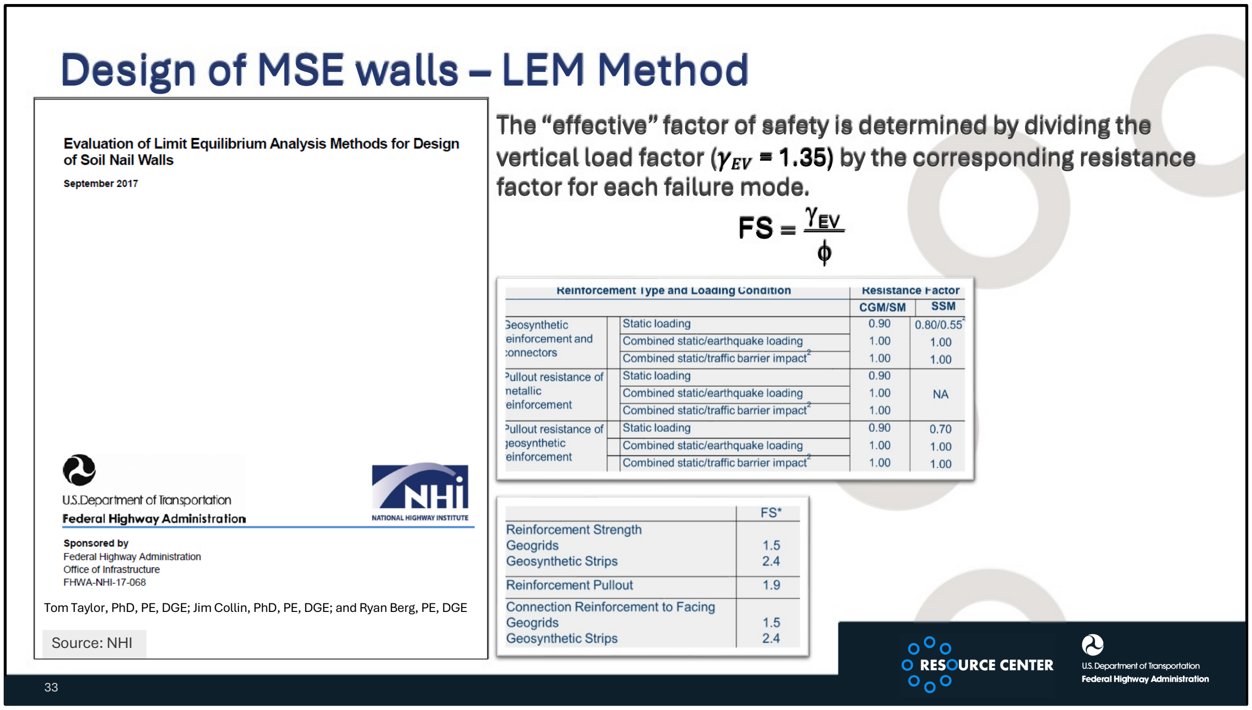


Key Message:
This slide presents the force diagram along with the calculated tensile forces at each reinforcement location within the structure.

Key Points:

1. Force Diagram Overview:
    - Illustrates the distribution of forces acting on the reinforcement layers
2. Tensile Force Calculation:
    - Displays calculated tensile forces for each reinforcement location
3. Control Mechanisms:
    - In the bottom nine layers, the allowable tensile capacity of the reinforcement governs performance
    - In the top three layers, pullout resistance becomes the controlling factor

This analysis highlights how different factors influence the effectiveness of reinforcement at various depths within the structure.



Reinforcement Type and Loading Condition		Resistance Factor CGM/SM	Resistance Factor SSM
eosynthetic einforcement and onnectors	Static loading	0.90	0.80/0.55[2]
	Combined static/earthquake loading	1.00	1.00
	Combined static/traffic barrier impact[2]	1.00	1.00
ullout resistance of netallic einforcement	Static loading	0.90	NA
	Combined static/earthquake loading	1.00	
	Combined static/traffic barrier impact[2]	1.00	
ullout resistance of jeosynthetic einforcement	Static loading	0.90	0.70
	Combined static/earthquake loading	1.00	1.00
	Combined static/traffic barrier impact[2]	1.00	1.00

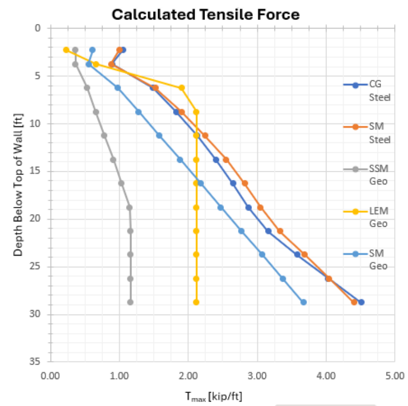
	FS*
Reinforcement Strength	
Geogrids	1.5
Geosynthetic Strips	2.4
Reinforcement Pullout	1.9
Connection Reinforcement to Facing	
Geogrids	1.5
Geosynthetic Strips	2.4

Key Message:
When using software based on the Allowable Stress Design (ASD) method, it's essential to ensure compatibility with the Load and Resistance Factor Design (LRFD) methodology. This process involves several steps to calculate the Capacity Demand Ratio (CDR) and ensure that the design meets LRFD requirements.
Key Points:
1. Understanding ASD and LRFD:
    - In the ASD method, the allowable strength is determined by dividing the nominal strength by a safety factor.
    - In contrast, the LRFD method calculates design strength by multiplying the nominal strength by resistance factors.
2. Calculating Factor of Safety in ASD:
    - The factor of safety (FS) in ASD is defined as:
      FS = Available Strength/Required Strength
    - This ensures that the available strength exceeds the required strength for stability.
3. Converting ASD to LRFD:
    - To convert an ASD factor of safety into a comparable CDR for LRFD:
        - Identify the nominal loads from the ASD analysis for each soil reinforcement.
        - Apply appropriate load and resistance factors to these nominal loads.
        - Calculate the CDR using:
          CDR=Factored Resistance/Factored Load
    - Ensure that the CDR is greater than or equal to 1.0 to meet LRFD criteria.
4. Adjustments and Compliance:
    - If the calculated CDR is less than 1.0, adjustments to the design may be necessary.
5. Conclusion:
    - By following these steps, engineers can effectively transition from an ASD-based analysis to an LRFD framework, ensuring their designs are safe and reliable under varying load conditions.

This approach highlights the importance of understanding both design methodologies and their compatibility when designing earth structures.

Summary of CGM, SM, SSM and LEM

	T_{req} (kip/ft)				
Depth [ft]	CG Steel	SM Steel	SM Geo	SSM Geo	LEM Geo
2.25	1.050	1.000	0.610	0.360	0.233
3.75	0.890	0.880	0.550	0.360	0.660
6.25	1.490	1.520	0.980	0.530	1.899
8.75	1.820	1.900	1.280	0.660	2.120
11.25	2.130	2.240	1.580	0.780	2.120
13.75	2.400	2.550	1.880	0.910	2.120
16.25	2.650	2.820	2.180	1.030	2.120
18.75	2.870	3.050	2.470	1.150	2.120
21.25	3.160	3.330	2.770	1.160	2.120
23.75	3.580	3.690	3.070	1.160	2.120
26.25	4.030	4.040	3.370	1.160	2.120
28.75	4.510	4.400	3.670	1.160	2.120
Total	30.580	31.420	24.410	10.420	21.872



Source: The Collin Group

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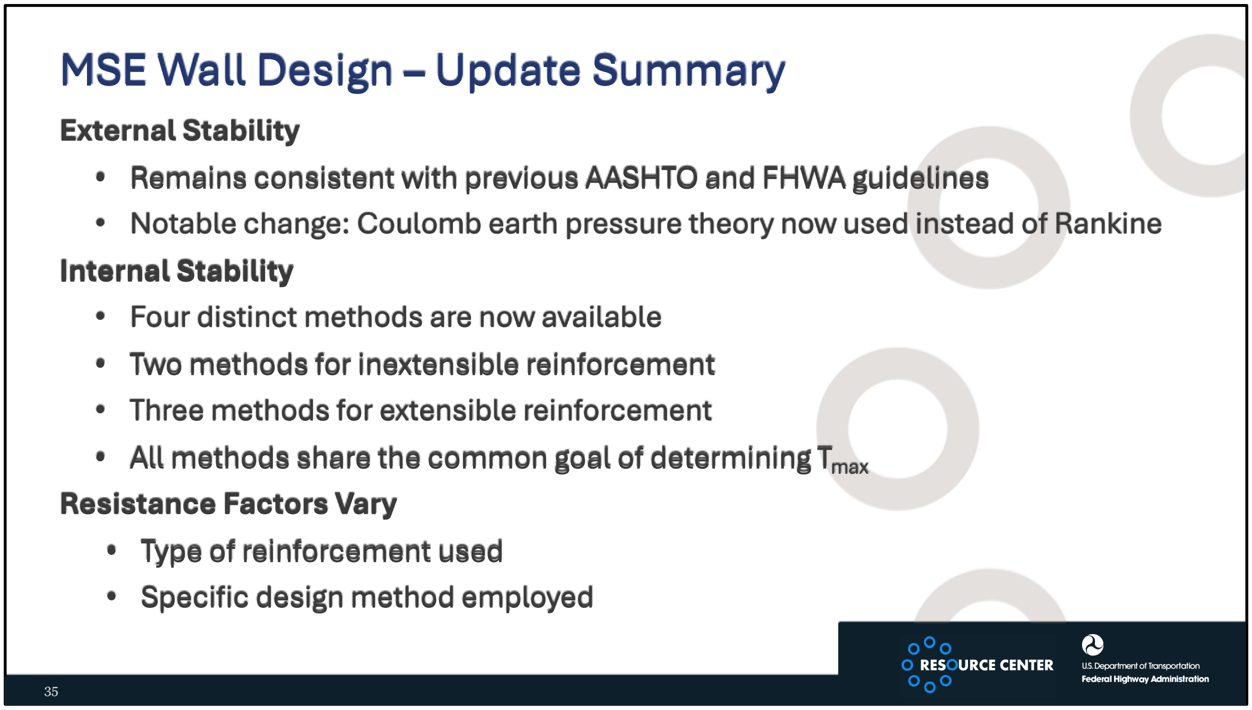
Key Message:
This slide presents a comprehensive table and graphical representation of tensile forces at each soil reinforcement layer for a 30-foot-tall structure with 21 feet of soil reinforcement.

Key Points:

1. **Data Presentation:**
   - The table and graph display tensile force results for various analysis methods.
2. **Methods Compared:**
   - Coherent Gravity Method and Simplified Method using inextensible soil reinforcement
   - Simplified Method, Simplified Stiffness Method, and Limit Equilibrium Method using extensible soil reinforcement
3. **Analysis of Results:**
   - Highlights the differences in tensile forces calculated by each method
   - Provides insights into how the choice of method influences the assessment of reinforcement forces
4. **Visual Comparison:**
   - The graphical representation allows for easy comparison of tensile forces across different methods, facilitating a better understanding of their performance.

This analysis underscores the importance of selecting the appropriate design method when evaluating tensile forces in reinforced soil structures.



Key Message:

Summary of External and Internal Stability Design Guidelines

Key Points:

External Stability:

- The design approach remains consistent with previous AASHTO and FHWA guidelines.
- A notable update is the adoption of **Coulomb's earth pressure theory** in place of **Rankine's theory** for calculating earth pressures.

Internal Stability:

- There are now **four distinct methods** available for assessing internal stability:
  - **Two methods** specifically for inextensible reinforcement.
  - **Three methods** designed for extensible reinforcement.
- All methods share the common objective of determining the maximum tensile force (Tmax) in the reinforcement layers.

Resistance Factors:

- The resistance factors vary based on:
  - The type of reinforcement used.
  - The specific design method employed.

This summary highlights the evolution of design methodologies in reinforced soil structures, emphasizing the integration of Coulomb's theory and the variety of methods available for ensuring both external and internal stability.

QUESTIONS/COMMENTS

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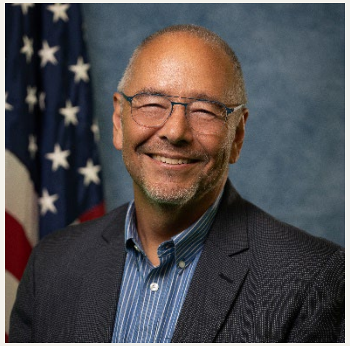

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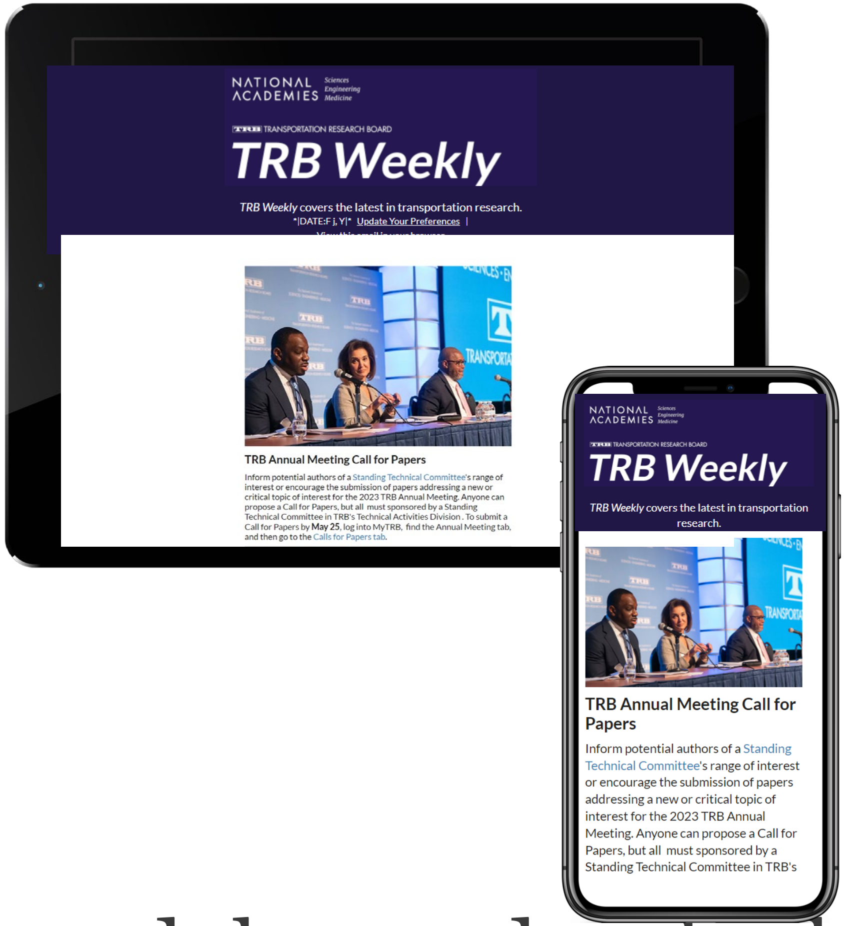

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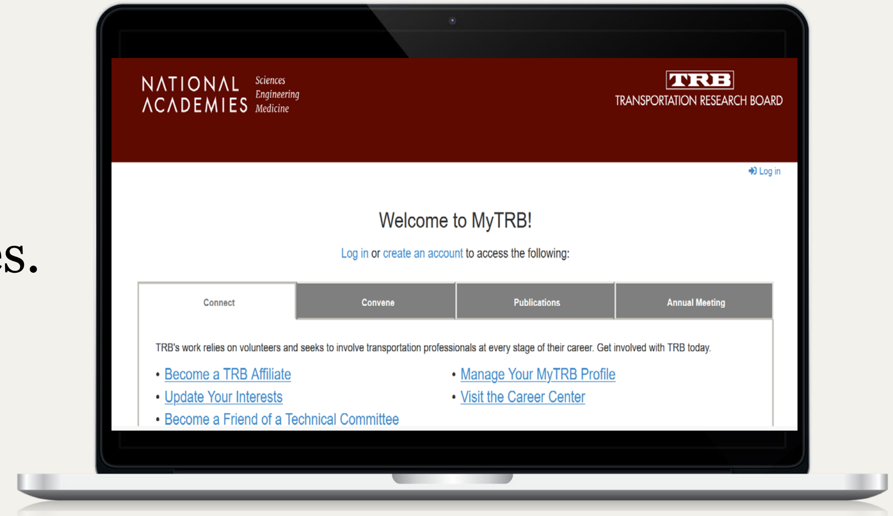

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