U.S. Department of Transportation
Federal Highway Administration

Federal Highway Administration RESOURCE CENTER | 20 YEARS OF SERVICE

Three Design Methods for Geosynthetic-Reinforced Walls

Lesson 2: Simplified method

Daniel Alzamora, FHWA
February 5, 2023

Disclaimers

- Except for any statutes or regulations cited, the contents of this document do not have the force and effect of law and are not meant to bind the public in any way. This document is intended only to provide information regarding existing requirements under the law or agency policies.
- The approaches and methods discussed in the presentations are not Federal requirements unless otherwise stated. Some items may be required by State policy or specification.
- The U.S. Government does not endorse products, manufacturers, or outside entities. Trademarks, names, or logos appear in this presentation only because they are considered essential to the objective of the document. They are included for informational purposes only and are not intended to reflect a preference, approval, or endorsement of any one product or entity.

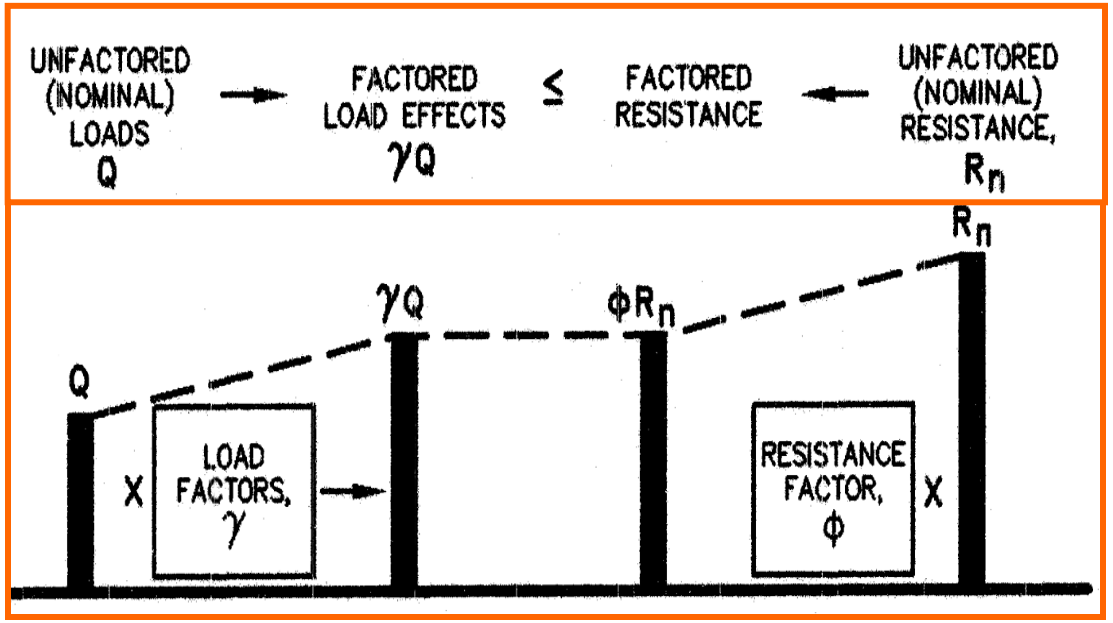
Updating Designs for Mechanically Stabilized Earth Walls in AASHTO

Lesson objective:

- Provide an overview of the simplified design method
- Develop design example for the simplified method - internal stability
- Check design example against MSEW results

Load and Resistance Factor Design - LRFD

- Design uncertainties are accounted for through load and resistance factors.
- Different load combinations through various limit states
  - Strength
  - Service
  - Extreme
- For each load combination the factored loads must be less than the factored resistance
- Load and resistance factors address design uncertainties
- Load and resistance factors are calibrated by fitting to ASD



$$\Sigma \gamma_i Q_i \leq \varphi R_n$$

Source: NHI course 132042

Load and Resistance Factor Design - LRFD

Table 3.4.1-1—Load Combinations and Load Factors

Load Combination Limit State	*DC* *DD* *DW* *EH* *EV* *ES* *EL* *PS* *CR* *SH*	*LL* *IM* *CE* *BR* *PL* *LS*	*WA*	*WS*	*WL*	*FR*	*TU*	*TG*	*SE*	Use One of These at a Time: *EQ*	*BL*	*IC*	*CT*	*CV*
Strength I (unless noted)	γ_p	1.75	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength II	γ_p	1.35	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength III	γ_p	—	1.00	1.00	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength IV	γ_p	—	1.00	—	—	1.00	0.50/1.20	—	—	—	—	—	—	—
Strength V	γ_p	1.35	1.00	1.00	1.00	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Extreme Event I	1.00	γ_{EQ}	1.00	—	—	1.00	—	—	—	1.00	—	—	—	—
Extreme Event II	1.00	0.50	1.00	—	—	1.00	—	—	—	—	1.00	1.00	1.00	1.00
Service I	1.00	1.00	1.00	1.00	1.00	1.00	1.00/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Service II	1.00	1.30	1.00	—	—	1.00	1.00/1.20	—	—	—	—	—	—	—
Service III	1.00	γ_{LL}	1.00	—	—	1.00	1.00/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Service IV	1.00	—	1.00	1.00	—	1.00	1.00/1.20	—	1.00	—	—	—	—	—
Fatigue I—*LL*, *IM* & *CE* only	—	1.75	—	—	—	—	—	—	—	—	—	—	—	—
Fatigue II—*LL*, *IM* & *CE* only	—	0.80	—	—	—	—	—	—	—	—	—	—	—	—

Note: For Service I, the load factor for *EV* equals 1.2 for Stiffness Method Soil Failure as shown in Table 3.4.1-2.

Source: AASHTO LRFD Bridge Design Specification, 9th Edition, 2020

Typical design Limit states Retaining walls

- Strength 1
- Service 1
- Extreme 1 and 2

U.S. Department of Transportation
Federal Highway Administration

Federal Highway Administration RESOURCE CENTER 20 YEARS OF SERVICE

Load and Resistance Factor Design - LRFD

Table 3.4.1-2—Load Factors for Permanent Load, γ_p

Type of Load, Foundation Type, and Method Used to Calculate Downdrag	Load Factor	
	Maximum	Minimum
DC: Component and Attachments	1.25	0.90
DC: Strength IV only	1.50	0.90
DD: Downdrag — Piles, α Tomlinson Method	1.40	0.25
Piles, λ Method	1.05	0.30
Drilled shafts, O'Neill and Reese (2010) Method	1.25	0.35
DW: Wearing Surfaces and Utilities	1.50	0.65
EH: Horizontal Earth Pressure		
• Active	1.50	0.90
• At-Rest	1.35	0.90
• *AEP* for anchored walls	1.35	N/A
EL: Locked-in Construction Stresses	1.00	1.00
EV: Vertical Earth Pressure		
• Overall and Compound Stability	1.00	N/A
• Retaining Walls and Abutments	1.35	1.00
• MSE wall internal stability soil reinforcement loads		
o Stiffness Method		
▪ Reinforcement and connection rupture	1.35	N/A
▪ Soil failure – geosynthetics (Service I)	1.20	N/A
o Coherent Gravity Method	1.35	N/A
• Rigid Buried Structure	1.30	0.90
• Rigid Frames	1.35	0.90
• Flexible Buried Structures		
o Metal Box Culverts, Structural Plate Culverts with Deep Corrugations, and Fiberglass Culverts	1.50	0.90
o Thermoplastic Culverts	1.30	0.90
o All others	1.95	0.90
• Internal and Compound Stability for Soil Failure in Soil Nail Walls	1.00	N/A
ES: Earth Surcharge	1.50	0.75

Source: AASHTO LRFD Bridge Design Specification, 9th Edition, 2020

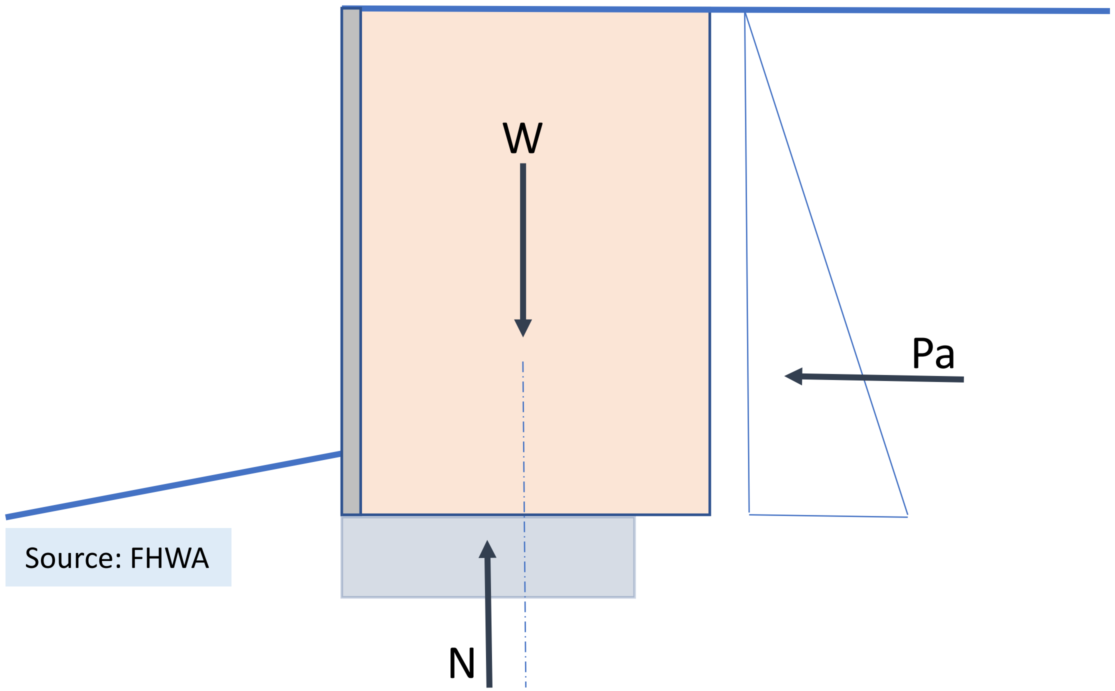
For the simplified Method using geosynthetic reinforcement

- Design method is moved to appendix B11 on page 11-161 of the 2020 AASHTO LRFD Bridge Design Specification
- Resistance factors are located in Section B11.2
  - Tensile Resistance – 0.9
  - Pullout Resistance – 0.9

Design of MSE walls – External Stability

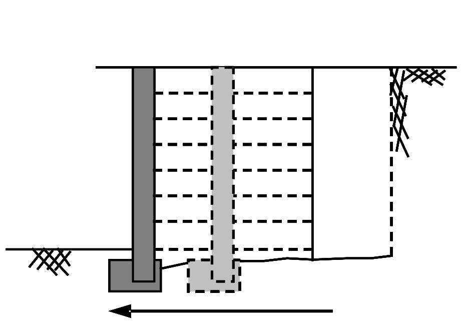
External stability

- Designed as gravity structure
- Assume to behave as a coherent mass
- Resists lateral earth pressure from retained soil
- Verify foundation capacity
- Calculate foundation settlement
- Check global and compound stability
- Use max/min load factors to determine most critical load effect.

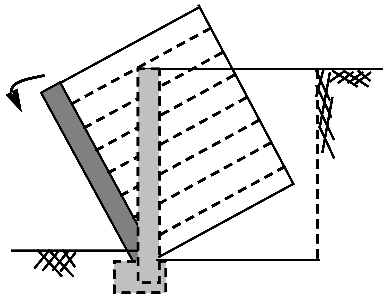


Source: FHWA

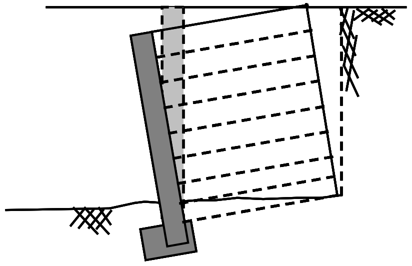
Design of MSE walls – External Stability



Sliding



Limiting Eccentricity (Overturning)



Bearing

Source: NHI course 132042

Checks for external stability

- Strength limit state
  - Sliding
  - Eccentricity
  - Bearing Capacity
- Service Limit state
  - Settlement

Applicable to all Gravity retaining Walls

Design of MSE walls – External Stability

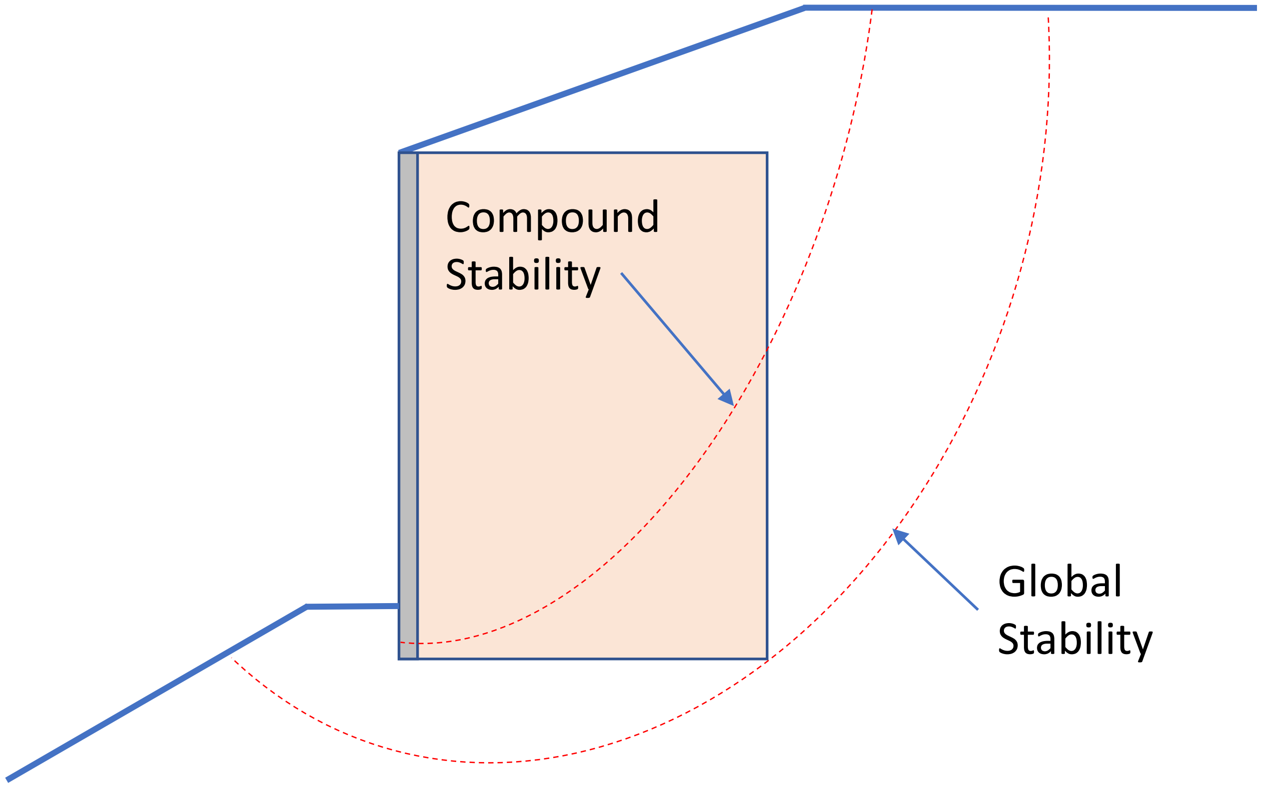
Compound stability

- Considers failure planes that pass through the reinforced fill

Global stability

- Failure planes passing under and outside the reinforced fill

Both are analyzed using the same methods and software and can be looked at concurrently



Source: FHWA

Design of MSE walls – Internal Stability

Internal Stability of MSE Walls

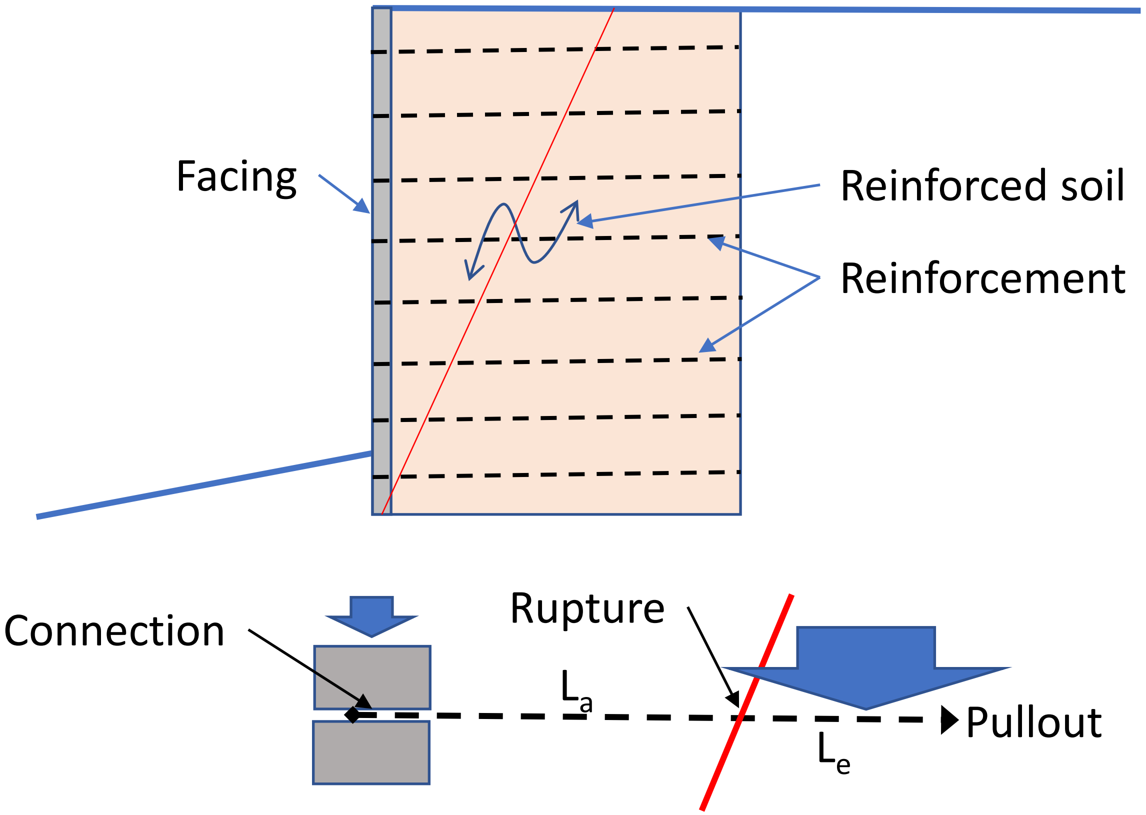
- Assume a composite mass
- MSE mass is composed of:
  - Reinforced fill
  - Reinforcement
  - Facing element
- The components work together to provide an internally stable soil mass

Source: FHWA

Source: CA DOT

Design of MSE walls – Internal Stability

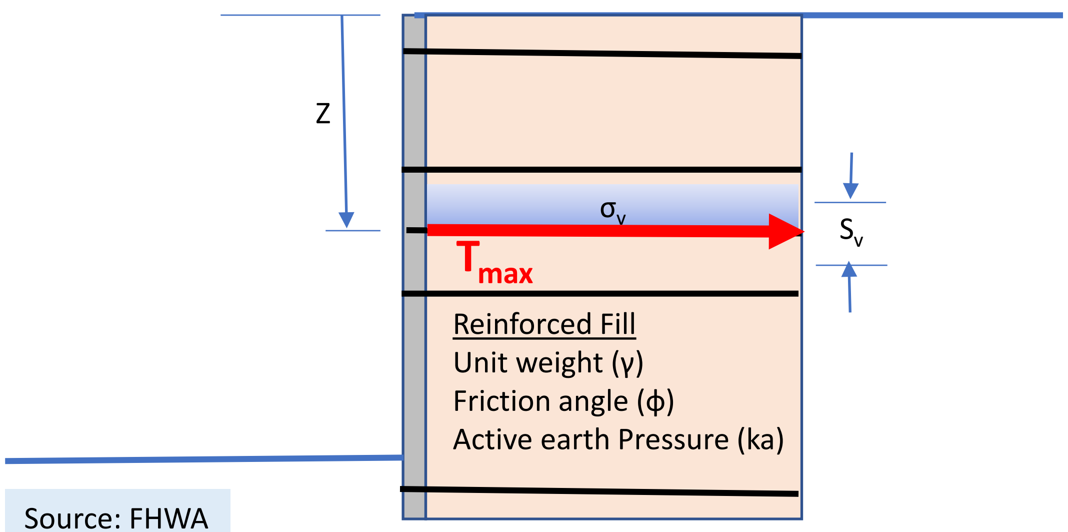
- Internal stability evaluates the ability of the reinforced fill to withstand the internal forces generated by the self weigh of the fill in addition to external forces.
- Modes of failure
  - Rupture of reinforcement
  - Connection
  - Pullout



Source: FHWA

Design of MSE walls – Internal Stability

What is Tmax?



Source: FHWA

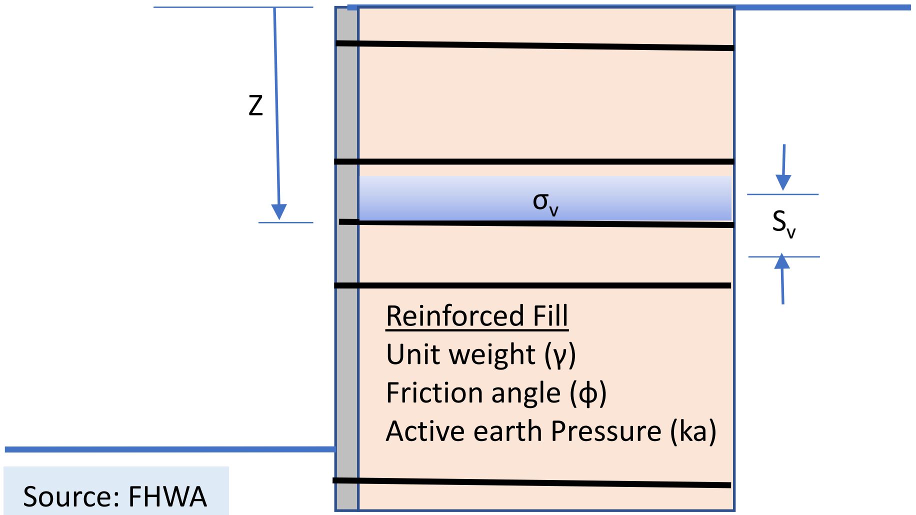
T_{max} is the force acting on the MSE reinforcement at any given depth.

T_{max} is a function of the:

- Vertical stress
- Strength of the soil
- Spacing of the reinforcement
- Reinforcement stiffness
- Facing

Updating Designs for Mechanically Stabilized Earth Walls in AASHTO

Simplified Method

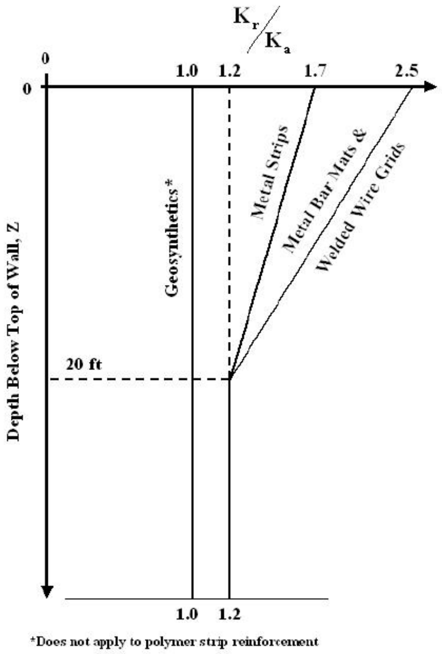


Source: FHWA

S_V is vertical reinforcement spacing, for equally spaced reinforcements

K_r / K_r – Varies based on reinforcement stiffness and depth

- For extensible reinforcement $K_r/K_a = 1.0$
- For inextensible reinforcement K_r/K_a ranges from 2.5 to 1.2 to a depth of 20 ft.



Source: FHWA NHI-10-024

$$\sigma_V = \gamma_r Z + \ldots\ldots$$

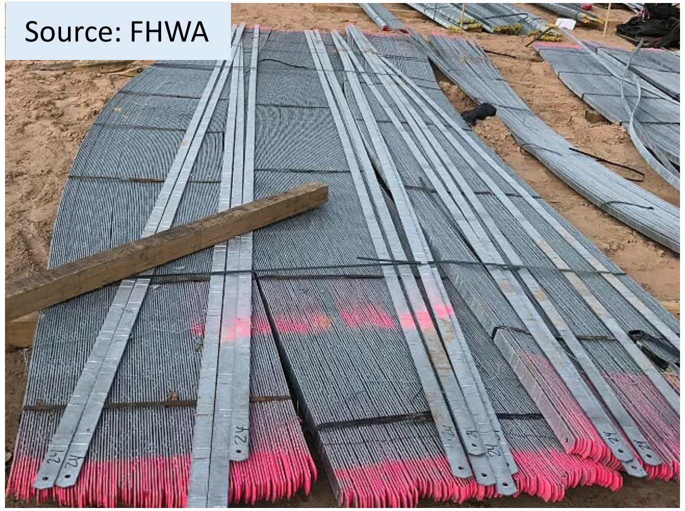
$$\sigma_H = K_a (K_r / K_a)\, \sigma_V$$

$$T_{MAX} = \sigma_H S_V$$

U.S. Department of Transportation
Federal Highway Administration

Federal Highway Administration RESOURCE CENTER 20 YEARS OF SERVICE

Design of MSE walls – Internal Stability

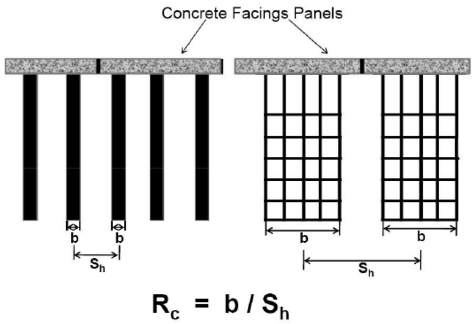


Source: FHWA

Source: FHWA

Reinforcement rupture:

- Steel –Yield strength of steel reduced to account for corrosion. Steel is assumed to be galvanized.
- Corrosion rates:
    - Zinc
        - 0.58 mils/yr for 2 years
        - 0.16 mils/yr
    - Steel at 0.47 mils/yr after zinc depleted



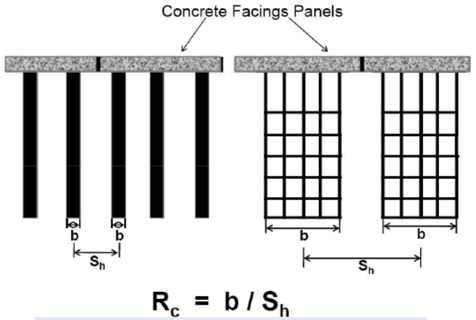
Source: FHWA NHI-10-024

- $T_{al} = F_y * A_c * R_c$
    - A_c = steel cross section area minus corrosion losses for design life
    - R_c = Percent coverage (width/horizontal spacing)

Design of MSE walls – Internal Stability

Reinforcement rupture:

- Geosynthetics – Based on the ultimate tensile capacity (Tult) using ASTM 6637
- The Tult strength is reduced to account for creep, durability, and construction damage
- Tal = Tult * R_c/RF
- RF = RF_{CR} x RF_D x RF_{ID}
- RF – product of all the material reduction factors
- R_c – Percent coverage



Source: FHWA NHI-10-024

Source: FHWA

Source: FHWA

U.S. Department of Transportation
Federal Highway Administration

Federal Highway Administration RESOURCE CENTER 20 YEARS OF SERVICE

Design of MSE walls – Internal Stability

In all cases the load at the connection $T_0 = T_{max}$

- Steel reinforcement –
  - Embedded elements are designed to resist the connection forces.
  - Connections shall be designed to address strength losses due to corrosion
  - Consider potential differences in the environment between the reinforced fill and at the facing
  - Connection capacity is determined based on testing of the connections

Source: FHWA

Source: FHWA

Design of MSE walls – Internal Stability

In all cases the load at the connection $T_0 = T_{max}$

Geosynthetic reinforcement connection strength

- $T_{ac} = T_{ult} * CR_{cr}/RF_D$
  - CR_{cr} – Long-term connection strength reduction factor, accounts for strength loss due to connection
- Long term test
  - $CR_{cr} = T_{crc}/ T_{lot}$ ➔ Long term test
    - T_{crc} – Long term test connection strength
    - T_{lot} – Ultimate wide-width tensile strength of the material tested
- Short Term Test
  - $CR_u = T_{ultconn}/T_{lot}$ ➔ short term test reduction factor
    - $T_{ultconn}$ – Short term test connection strength
  - $CR_{cr} = CR_u /RF_{CR}$ ➔ Long term factor from short term test

Source: NHI course 132080

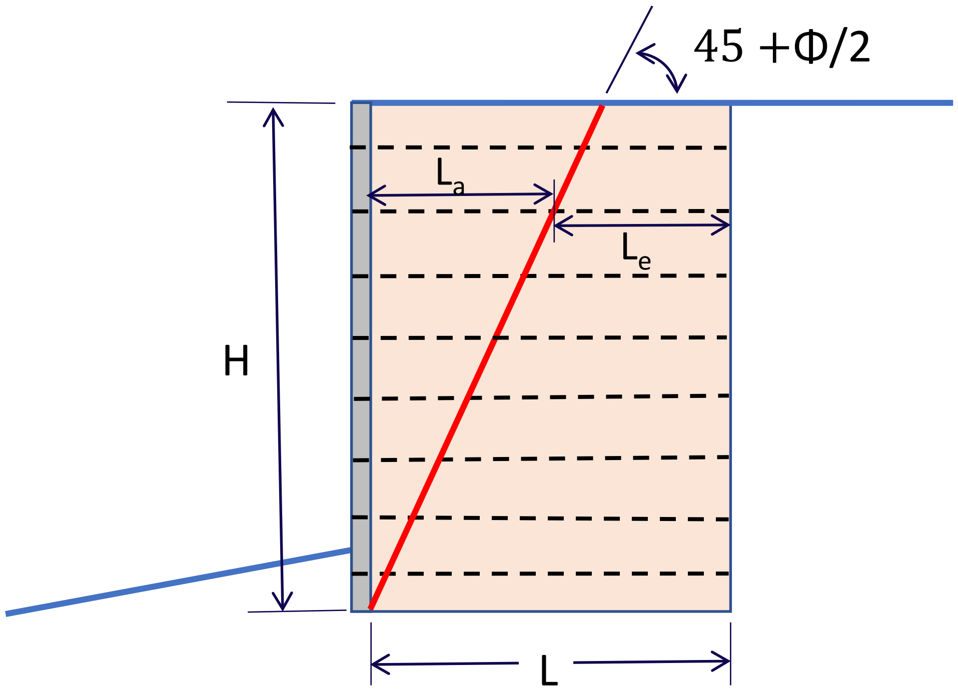
Design of MSE walls – Internal Stability

Pullout Capacity -

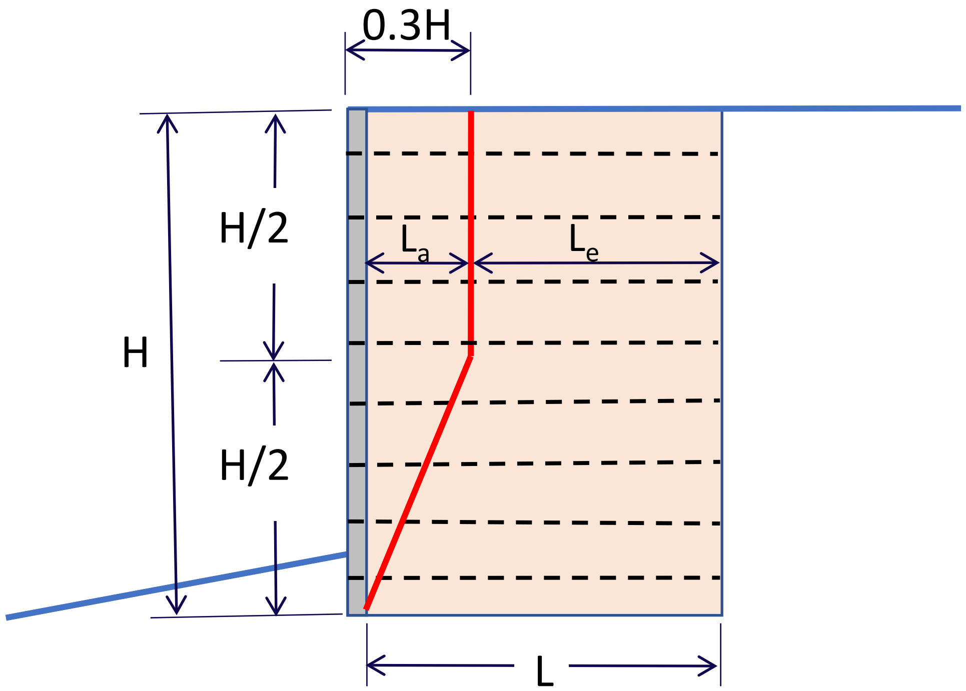
- Pullout capacity is the ability to resist the force on the reinforcement from pulling out from the fill.
- It is dependent on:
  - Type of reinforcement
  - Interaction between fill and reinforcement
  - Length and width of the reinforcement
  - Overburden pressure on the reinforcement

Design of MSE walls – Internal Stability

Pullout Capacity



Extensible Reinforcement



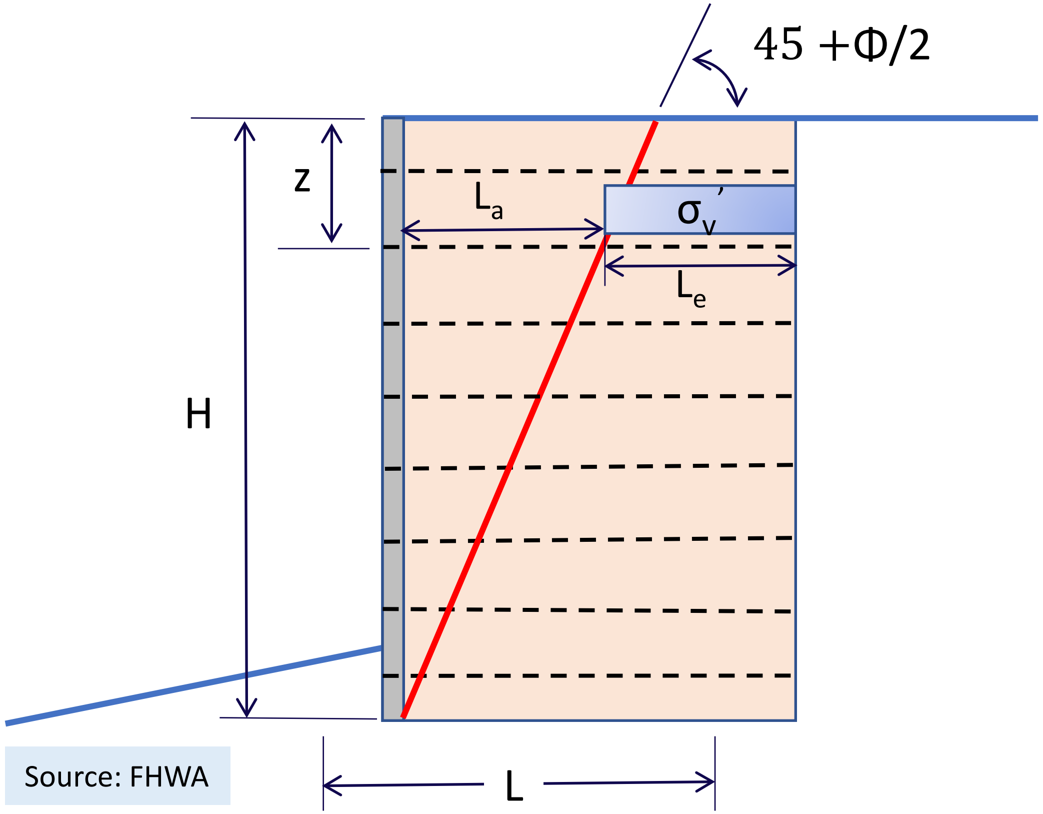
Inextensible Reinforcement

Source: FHWA

Design of MSE walls – Internal Stability

Pullout Capacity –

- $P_r = F^* \alpha \sigma_v' L_e C R_c$
  - 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 inextensible reinforcement
    - 0.6 to 1.0 for extensible reinforcements
  - σ_v' – Effective vertical stress
    - $\sigma_v' = (\gamma_r \times z) + \ldots\ldots$
  - 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: FHWA

U.S. Department of Transportation
Federal Highway Administration
Federal Highway Administration RESOURCE CENTER 20 YEARS OF SERVICE

Design of MSE walls – Internal Stability

Check internal stability – Simplified and Coherent Gravity Methods

- Rupture
  - $T_{max}\ (\gamma_{EV}) < T_{al}\ (\phi)$
- Connection
  - $T_{max}\ (\gamma_{EV}) < T_{ac}\ (\phi)$
- Pullout
  - $T_{max}\ (\gamma_{EV}) < P_r\ (\phi)$
- $\gamma_{EV} = 1.35$
  - AASHTO Table 3.4.1-2
  - Other load factors may be applicable for additional loads

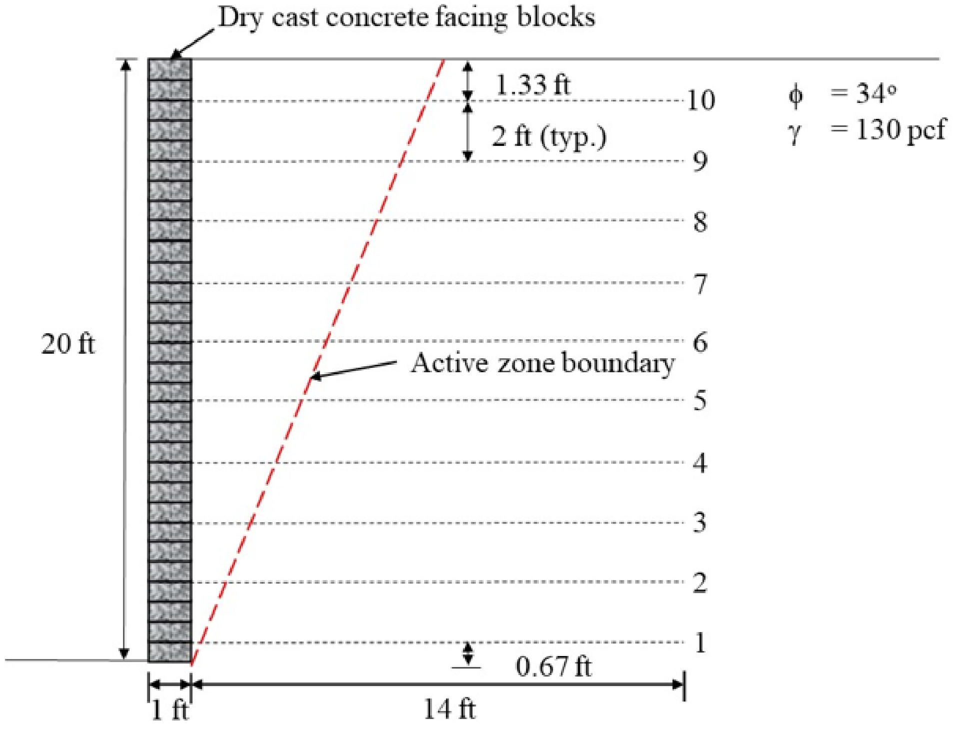
For the simplified Method using geosynthetic reinforcement

- Design method is moved to appendix B11 on page 11-161 of the 2020 AASHTO LRFD Bridge Design Specification
- Resistance factors are located in Section B11.2
  - Tensile Resistance – 0.9
  - Pullout Resistance – 0.9

Source: AASHTO LRFD Bridge Design Specification, 9th Edition, 2020

Design of MSE walls – Design Example

Property	Design Value
Grid A # 11,000 hr, 2% secant J_i (lbs/ft)	14,500
Tult (lbs/ft)	2,465
Grid B # 11,000 hr, 2% secant J_i (lbs/ft)	8,600
Tult (lbs/ft)	1,462
RF_{ID} RF_{CR} RF_D = RF	1.12x1.5x1.3 = 2.18
Coverage ratio, R_c	1.0
Facing block unit weight, γ_{block} (pcf)	120
Facing block height (ft)	0.67
Facing block width, W_u (face to tail) (ft)	1.0
Connection strength as fraction of T_{ult}, CR_u	0.75

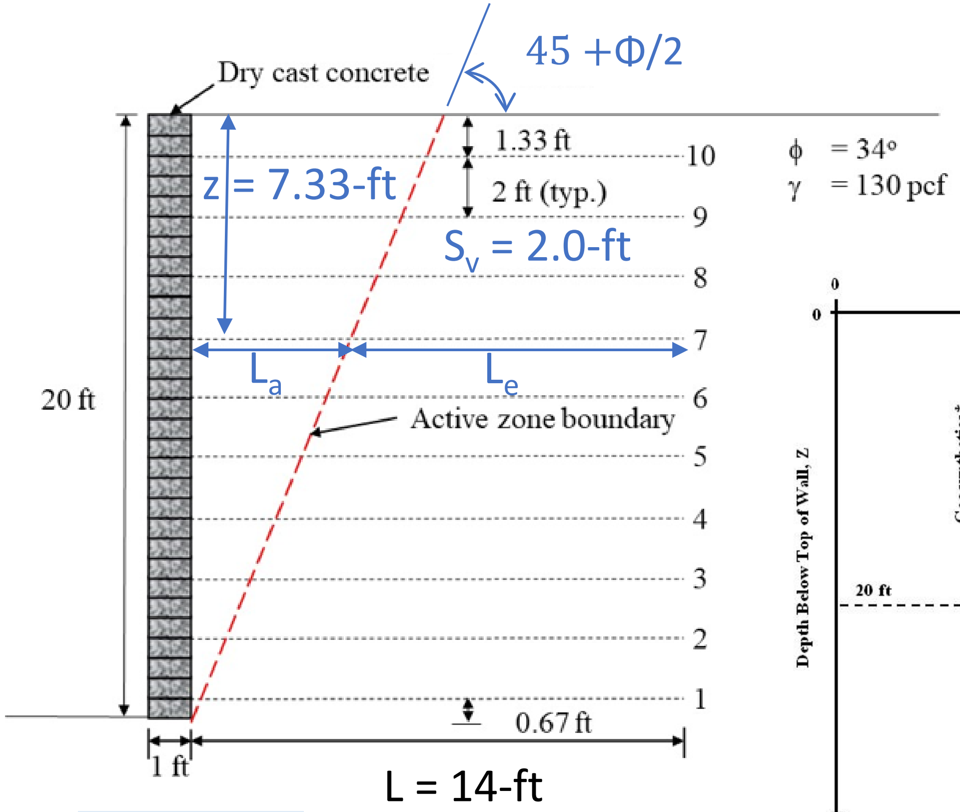


Source: WA DOT Geotechnical Design Manual

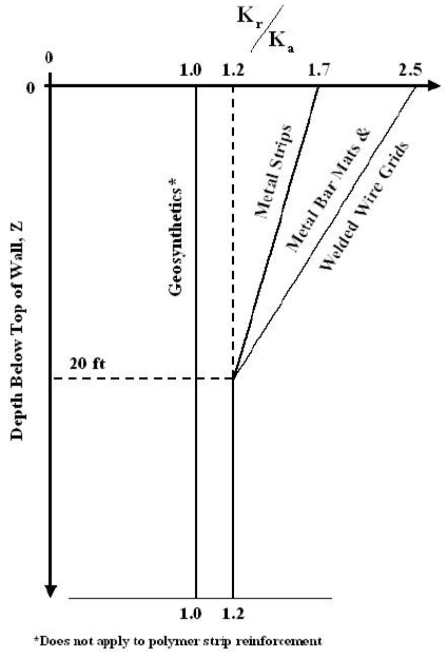
Design of MSE walls – Design Example

<u>Internal stability example – Layer #7</u>

- Depth of layer: z_7 = 7.33-ft
- S_v = 2.0-ft
- $\sigma_v{}' = (\gamma_r\, z) = 130\,(7.33) = 953$-psf
- $K_r/K_a = 1.0$
- $K_a = \text{Tan}^2\,(45\text{-}\phi/2) = \text{Tan}^2\,(45\text{-}34/2)$
- $K_a = 0.283$
- $\sigma_H{}' = \sigma_v{}' * K_a * (K_r/K_a)$
- $\sigma_H{}' = 953*0.283*1.0 = 270$-psf
- $T_{max} = \sigma_H{}' * S_v = 270*2.0 = 540$-lbs/ft



Source: FHWA



Source: FHWA NHI-10-024

U.S. Department of Transportation
Federal Highway Administration

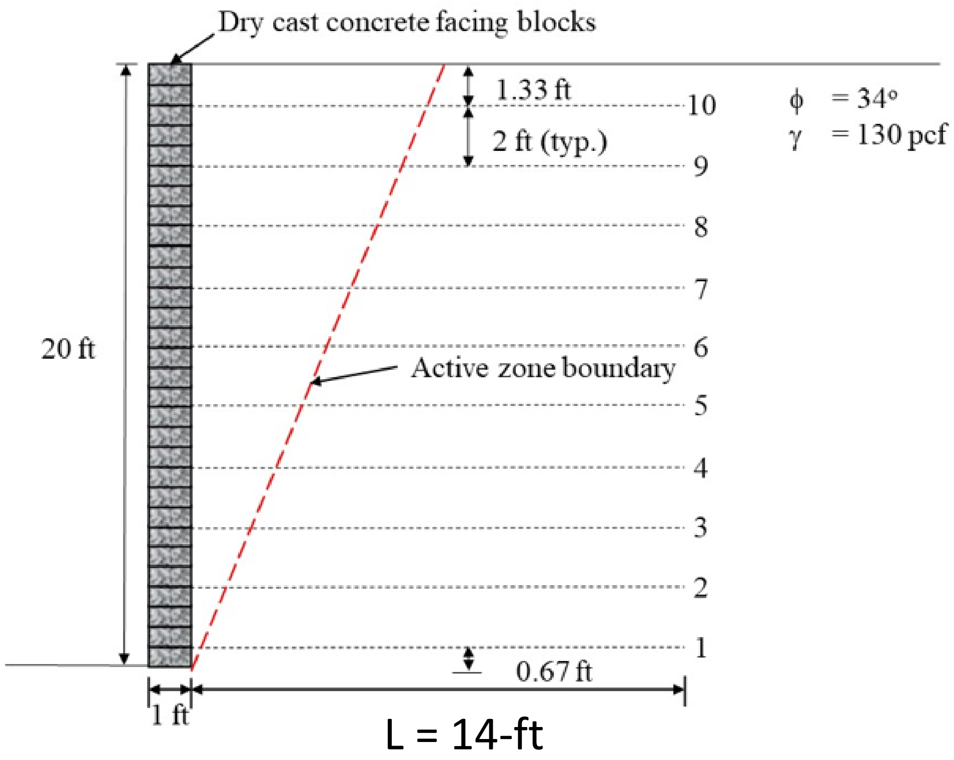
Federal Highway Administration RESOURCE CENTER 20 YEARS OF SERVICE

Design of MSE walls – Design Example

<u>Internal stability example – Layer #7</u>

Reinforcement strength – Grid A

- T_{ult} = 2,465-lbs/ft
- Reduction Factors –
- RF = 1.5*1.3*1.12 = 2.18
  - Creep = 1.5
  - Durability = 1.3
  - Installation Damage = 1.12
- $T_{al} = T_{ult}/RF$ = 2,465/2.18 = 1,131-lbs/ft



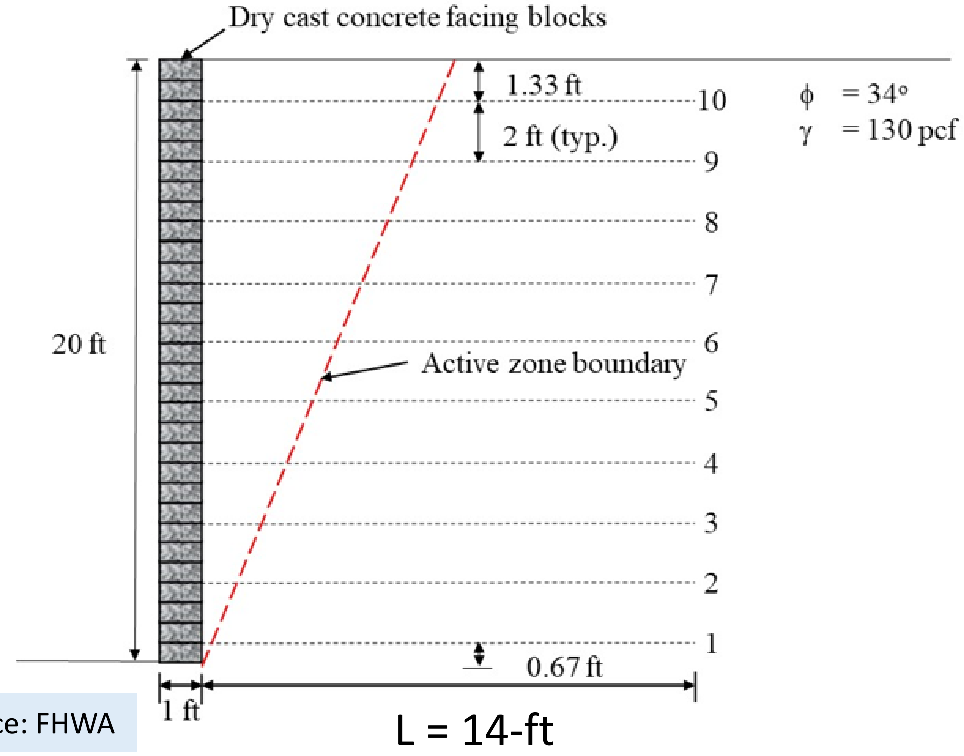
Source: FHWA

Design of MSE walls – Design Example

<u>Internal stability example – Layer #7</u>

Connection strength – Grid A

- T_{ult} = 2,465-lbs/ft
- CR_{cr} = 0.75, RF_D = 1.3, RF_{creep} = 1.5
- $T_{ac} = T_{ult} * CR_{cr}/(RF_D * RF_{creep})$
- T_{ac} = 2,465 * 0.75/(1.3*1.5)
- T_{ac} = 948-lbs/ft



Source: FHWA

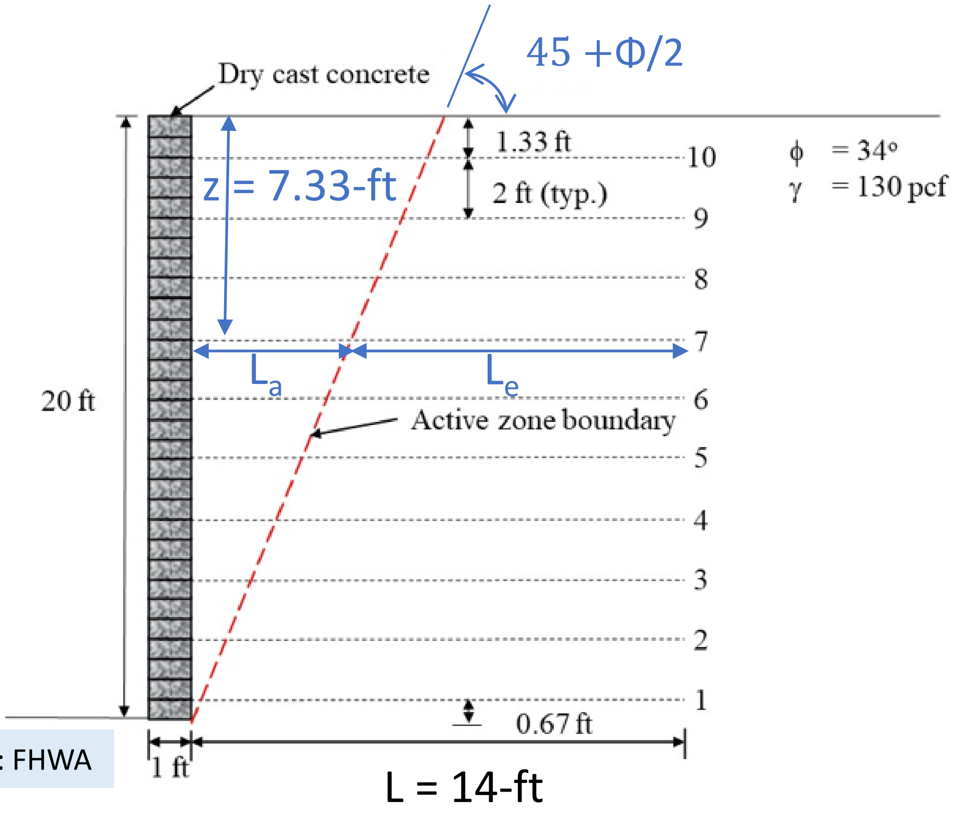
U.S. Department of Transportation
Federal Highway Administration

Federal Highway Administration RESOURCE CENTER 20 YEARS OF SERVICE

Design of MSE walls – Design Example

<u>Internal stability example – Layer #7</u>

- $P_r = F^* \alpha \sigma_v' L_e C R_c$
- Depth of layer = 7.33-ft
- $\sigma_v' = (\gamma_r z) = 130 (7.33) = 953$-psf
- $L_a = (H\text{-}z) \tan (45\text{-}\Phi/2)$
- $L_a = (20\text{-}7.33) \tan (45\text{-}34/2) = 6.74$-ft
- $L_e = L – La = 14 – 6.74 = 7.26$-ft
- $F^* = 0.667 \tan (\Phi) = 0.667 \tan (34) = 0.45$
- $\alpha = 0.8$, $C = 2.0$, $R_c = 1.0$
- $P_r = 0.45*0.8*953*7.26*2.0*1.0$
- $P_r = 4{,}981$-lbs/ft



Source: FHWA

Design of MSE walls – Design Example

Check internal stability –

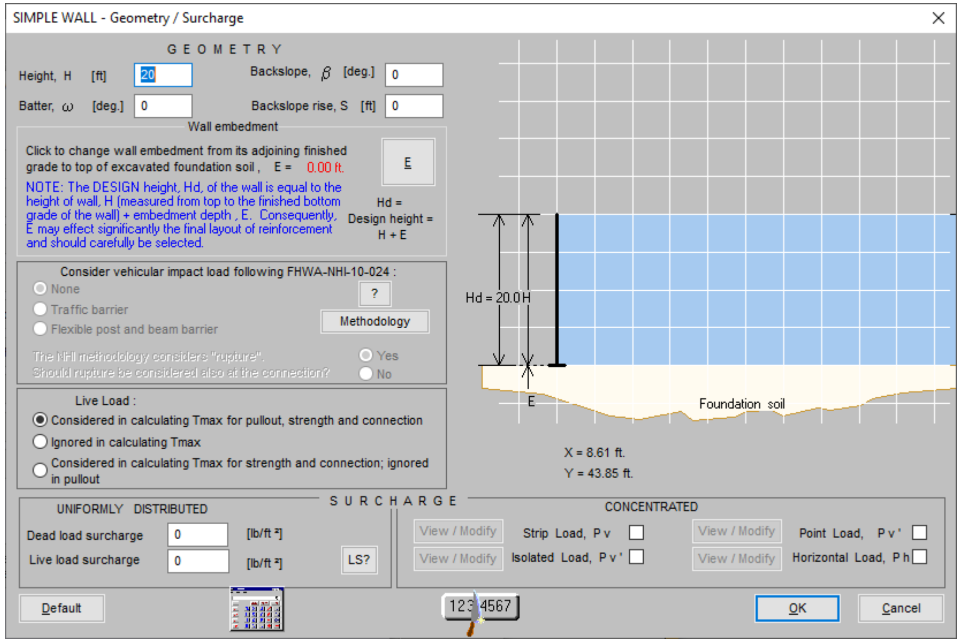
- Rupture
  - Tmax (γ_{EV}) < T_{al} (ϕ)
  - 540 (1.35) < 1131(0.9)
  - 729 < 1,018 OK ➔ CDR = 1,018/729 = 1.40
- Connection
  - Tmax (γ_{EV}) < T_{ac} (ϕ)
  - 540 (1.35) < 948 (0.9)
  - 729 < 853 OK ➔ CDR = 853/729 = 1.17
- Pullout
  - Tmax (γ_{EV}) < P_r (ϕ)
  - 540 (1.35) < 4,981 (0.9)
  - 729 < 4,483 OK ➔ CDR = 4,483/729 = 6.15
- γ_{EV} = 1.35
  - AASHTO Table 3.4.1-2
  - Other load factors may be applicable for additional loads

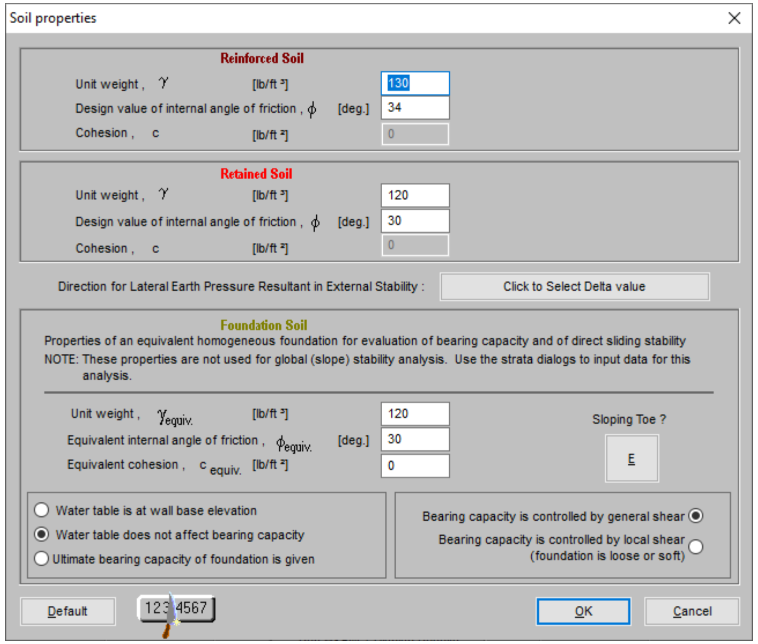
For the simplified Method using geosynthetic reinforcement

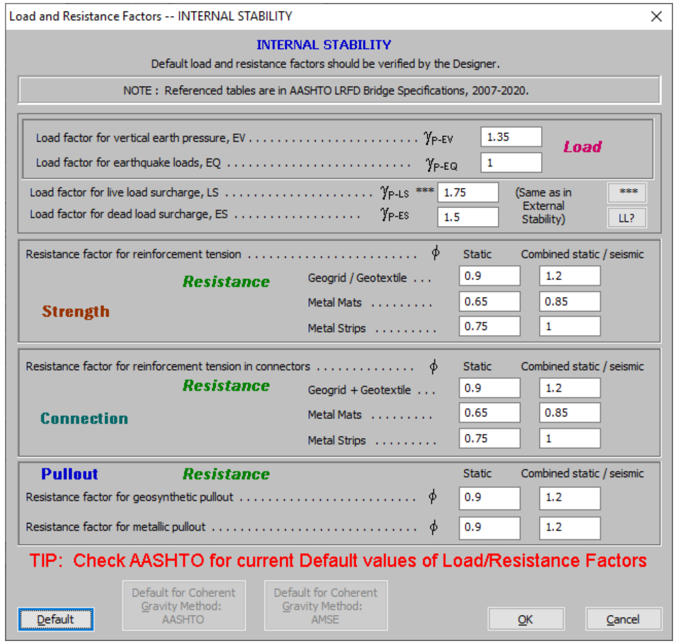
- Design method is moved to appendix B11 on page 11-161 of the 2020 AASHTO LRFD Bridge Design Specification
- Resistance factors are located in Section B11.2
  - Tensile Resistance – 0.9
  - Pullout Resistance – 0.9

Source: AASHTO LRFD Bridge Design Specification, 9th Edition, 2020

Design of MSE walls – Design Example







Source: Output generated from MSEW+ software, generated by FHWA

U.S. Department of Transportation
Federal Highway Administration
Federal Highway Administration RESOURCE CENTER 20 YEARS OF SERVICE

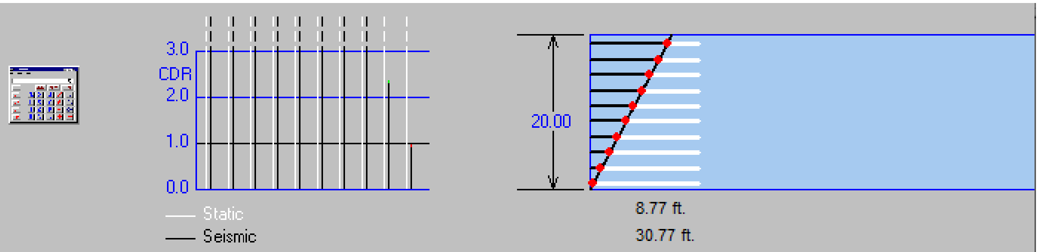
Design of MSE walls – Design Example

Internal Stability -- extended table

LAYER #	Geogrid Elevation [ft]	Tributary Range Z bottom [ft]	Tributary Range Z top [ft]	Given Information Coverage Ratio, Rc	Given Information Factored LTDS Adjusted for Rc [lb/ft]	Calculated Values Factored Tmax (LL included) [lb/ft]	Calculated Values T md, Includes Face Inertia [lb/ft]	Calculated Values Actual Calculated CDR
1	0.67	0.00	1.67	1.00	1015.80	1588.00	0.00	0.640
2	2.67	1.67	3.67	1.00	1015.80	1719.71	0.00	0.591
3	4.67	3.67	5.67	1.00	1015.80	1521.24	0.00	0.668
4	6.67	5.67	7.67	1.00	1015.80	1322.77	0.00	0.768
5	8.67	7.67	9.67	1.00	1015.80	1124.31	0.00	0.903
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	12.67	11.67	13.67	1.00	1015.80	727.38	0.00	1.397
8	14.67	13.67	15.67	1.00	1015.80	528.91	0.00	1.921
9	16.67	15.67	17.67	1.00	1015.80	330.45	0.00	3.074
10	18.67	17.67	20.00	1.00	1015.80	134.68	0.00	7.542

Connection -- Extended Table

LAYER #	Elevation [ft]	CDR Connection Strength	Coverage Ratio, Rc	Factored Tmax (LL included) [lb/ft]	Factored T md, Includes Face Inertia [lb/ft]	Factored Required Long-term Connection Strength, Tac (req.) [lb/ft]	Reduction Factor for Connection, (Short-term Strength), CRu	Available Short-term connection Strength, Tult-con [lb/ft]	Factored Available Long-term Connection Strength, Adj. for Rc, Tac(avail.) [lb/ft]
1	0.67	0.537	1.00	1588.00	0.00	1588.00	0.75	1848.8	853.3
2	2.67	0.496	1.00	1719.71	0.00	1719.71	0.75	1848.8	853.3
3	4.67	0.561	1.00	1521.24	0.00	1521.24	0.75	1848.8	853.3
4	6.67	0.645	1.00	1322.77	0.00	1322.77	0.75	1848.8	853.3
5	8.67	0.759	1.00	1124.31	0.00	1124.31	0.75	1848.8	853.3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	12.67	1.173	1.00	727.38	0.00	727.38	0.75	1848.8	853.3
8	14.67	1.613	1.00	528.91	0.00	528.91	0.75	1848.8	853.3
9	16.67	2.582	1.00	330.45	0.00	330.45	0.75	1848.8	853.3
10	18.67	6.335	1.00	134.68	0.00	134.68	0.75	1848.8	853.3



LAYER #	Geogrid Elevation [ft]	Geogrid Length [ft]	Coverage Ratio, Rc	Calculated Values Factored Tmax (LL included) [lb/ft]	T md, Includes Face Inertia [lb/ft]	Le [ft]	La [ft]	F*	Calculated CDR	STATUS
7	12.67	14.00	1.00	727.38	0.00	7.26	6.74	0.450	6.16	N/A
8	14.67	14.00	1.00	528.91	0.00	6.20	7.80	0.450	5.26	N/A
9	16.67	14.00	1.00	330.45	0.00	5.14	8.86	0.450	4.35	N/A
10	18.67	14.00	1.00	134.68	0.00	4.07	9.93	0.450	3.38	N/A

Click on numeral buttons to view Tmax

Seismic lengths | Static lengths | RETURN

Source: Output generated from MSEW+ software, generated by FHWA

Updating Designs for Mechanically Stabilized Earth Walls in AASHTO

Lesson objective:

- Provide an overview of the simplified
- Develop design example for the simplified method - internal stability
- Check design example against MSEW results

Questions?

Daniel Alzamora, P.E.

Senior Geotechnical Engineer

Geotechnical and Hydraulic Engineering Team

Federal Highway Administration

Daniel.Alzamora@dot.gov