Appendix L

Mechanically Stabilized Earth Wall External Stability Calculations

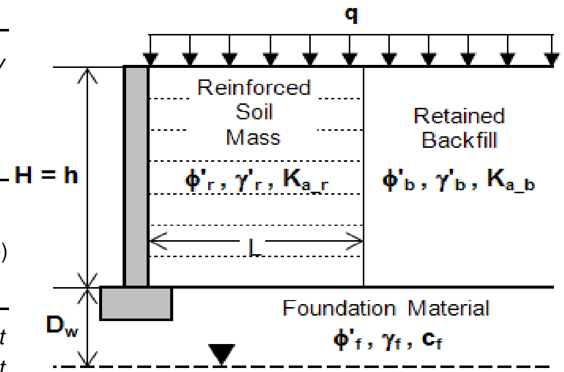
STATE OF NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION
GEOTECHNICAL ENGINEERING UNIT
1589 MAIL SERVICE CENTER

WBS NO.: TIP NO.: COUNTY:
SUBJECT: LRFD External Stability Analysis for MSE Walls
Wall 2 - I-85
PREPARED BY: CLB DATE: 09/11/15 STATION: 280+00
CHECKED BY: DATE: STR. NO.: SHEET: 1 OF 8

Input Traffic Surcharge, Backslope, Wall Geometry, and Soil Parameters

Traffic and Overlay Surcharge Surcharge

$q =$ 390 psf *Live Load Traffic Surcharge and Pavement Overlay*
35.9 % Surcharge due to overlay
$q_{ol} =$ 140 psf *Pavement overlay surcharge*



Typical MSE Wall with Level Backslope and Traffic Surcharge

Backslope

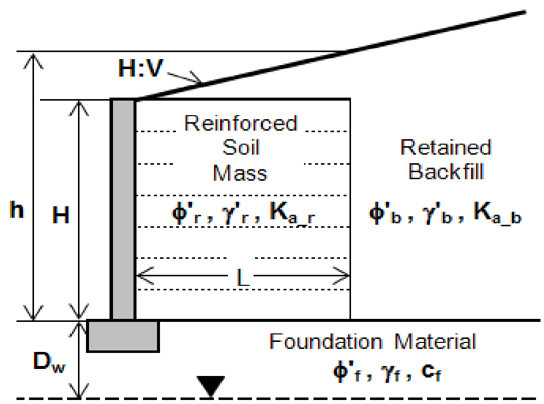
Horizontal Backslope

(d = horizontal distance from back of wall face to top of backslope)

Wall Geometry

$H =$ 17.00 ft *Wall Height*
$L/H =$ 0.76 *Ratio of Reinforcement Length to Wall Height*
(L/H ≥ 0.7 per NCDOT MSE Wall Standard Provision)
$L =$ 12.99 ft *Reinforcement Length*
(L ≥ 6 ft per NCDOT MSE Wall Standard Provision)
$h =$ 17.00 ft *Height of Wall & Slope at the back of Reinforced Zone*

$D_w =$ 40.00 ft *Distance of Water Table below the Bottom of the Wall*



Typical MSE Wall with Infinite Backslope

Soil Parameters for Reinforced Zone

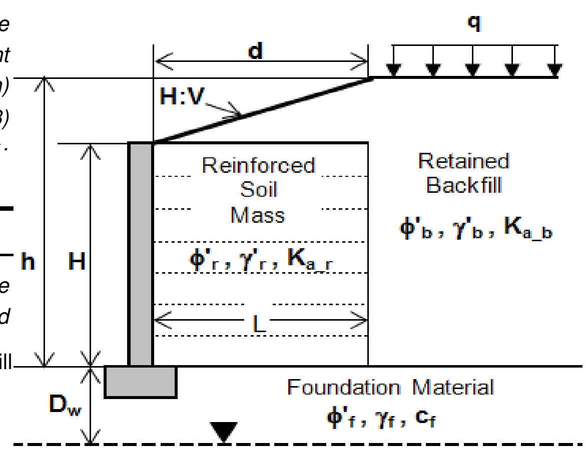
$\phi'_r =$ 36 deg *Effective Friction Angle*
$\gamma'_r =$ 120 pcf *Effective Unit Weight*
$K_{a\_r} =$ 0.260 *Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

Soil Parameters for Retained Backfill

$\phi'_b =$ 30 deg *Effective Friction Angle*
$\gamma'_b =$ 117 pcf *Effective Unit Weight*
$K_{a\_b} =$ 0.333 *Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

Soil Parameters for Foundation Soil

$\phi'_f =$ 30 deg *Effective Friction Angle*
$\gamma_f =$ 120 pcf *Total Unit Weight*
$c_f =$ 0 psf *Undrained Shear Strength (Cohesion)*
$\mu =$ 0.58 *Coefficient of Friction (AASHTO 11.10.5.3)*
The coefficient of friction shall be based on the lesser of ϕ'_r and ϕ'_f.



Typical MSE Wall with Broken Backslope and Traffic Surcharge

Input Load and Resistance Factors

Load Factors (See AASHTO Table 3.4.1-1 and 2)

$\Psi_{LS} =$ 1.75 *Lilve Load Surcharge*
$\Psi_{EH(A)} =$ 1.50 *Horizontal (Active) Earth Pressure Load*
$\Psi_{EV} =$ 1.00 min / 1.35 max Vertical Dead Load Generated from Earth Fill
$\Psi_{EQ\text{-}p} =$ 1.00
$\Psi_{EQ\text{-}LL} =$ 0.50

Resistance Factors (See AASHTO Table 11.5.6-1)

$\varphi_b =$ 0.65 *Bearing Resistance for MSE Walls*
$\varphi_\tau =$ 1.00 *Sliding Resistance for MSE Walls*

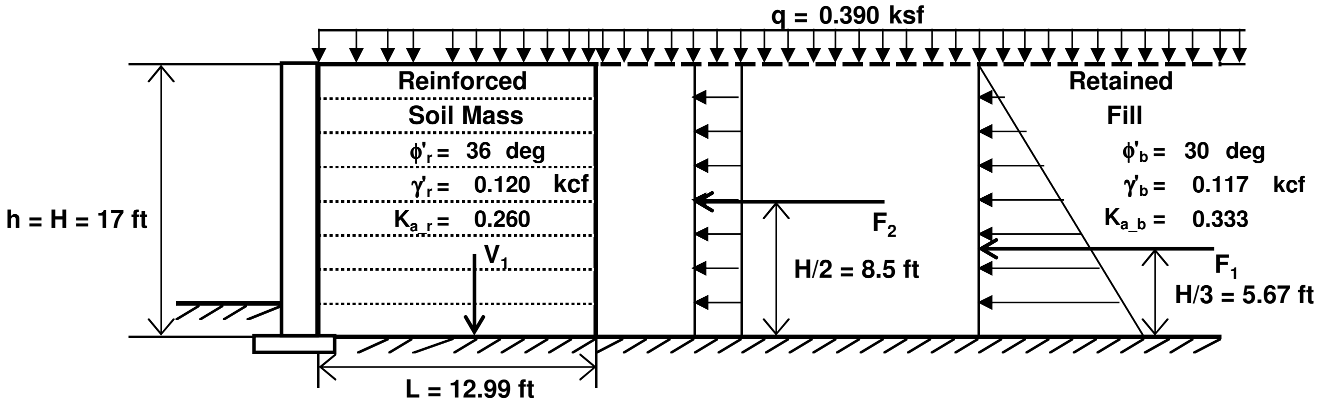
Seismic Design Acceleration Parameters

$k_{max} =$ 0.20 *Maximum Horizontal Ground Acceration (PGA)*
$S_{d1} =$ 0.14 *Peak spectral acceleration at 1 second*

References:

1. *AASHTO LRFD Bridge Design Specifications, 5th Edition, 2010*
2. *FHWA-NHI-10-024 Design and Construction of MSE Walls and Reinforced Soil Slopes - Vol I, 2009*
3. *SCDOT Geotechnical Design Manual version 1.1, 2010*

Calculate Forces acting on Wall



External Stability for MSE Walls: Earth Pressure - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Forces from Vertical Earth Loads

V_1 = Total Vertical Force from the Reinforced Soil Mass = $(\gamma_r)(H)(L)$
= (0.120 kcf)(17.00 ft)(12.99 ft) = 26.500 kips

Forces from Lateral Earth Pressure

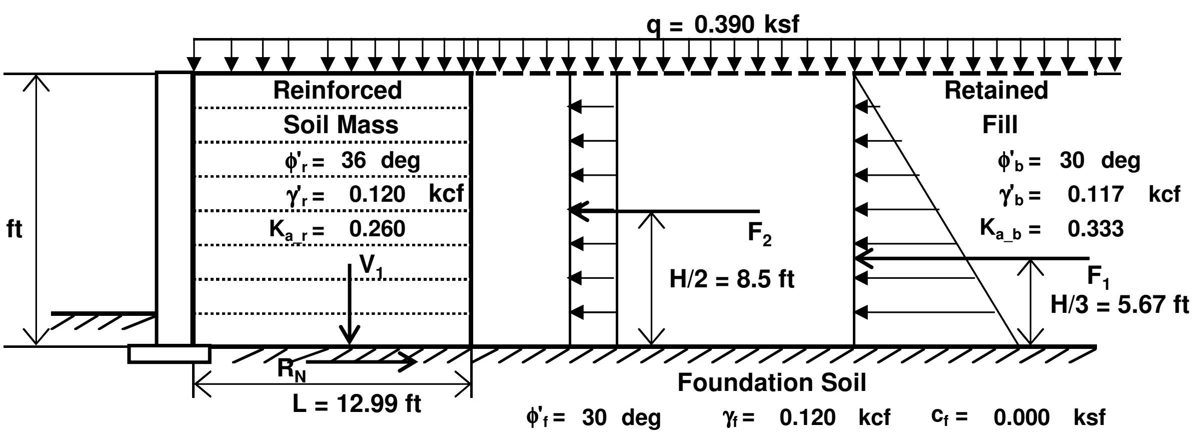
F_1 = Total Force Generated from Lateral Earth Pressure = $0.5(\gamma_b)(H^2)(K_{ab})$ FHWA Eqn. 4-5
= (0.5)(0.117 kcf)(17.00 ft)^2(0.333) = 5.630 kips

Horizontal Force from Traffic Surcharge

F_2 = Force Generated from Traffic Surcharge = $(q)(H)(K_{ab})$ *FHWA Eqn. 4-6*
= (0.390 ksf)(17.00 ft) (0.333) = 2.208 kips

Sliding Stability - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

The passive resistance at the toe due to embedment is ignored due to the potential for soil to be removed through natural or manmade processes.
(per FHWA 4.4.6.a)



External Stability for MSE Walls: Sliding Stability - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Factored Sliding Resistance (R_R)

$R_R = \varphi R_N = \varphi_\tau R_\tau$ *AASHTO Eqn. 10.6.3.4-1*

Sliding Stability Continued - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

φ_τ = *Resistance Factor for Sliding* = 1.00 — *AASHTO Table 11.5.6-1*

R_τ = *Nominal Sliding Resistance between Reinforced Soil Mass and Foundation Soil*

= $\Psi_{EV}(V_1)\mu + (c_f)(L)$ — *FHWA Eqn. 4-12 and AASHTO 10.6.3.4*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 — *AASHTO Table 3.4.1-1*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

V_1 = Total Vertical Force from the Reinforced Soil Mass = 26.500 kips

μ = Coefficent of Friction between Reinforced Soil Mass and Foundation Soil = 0.58 — *AASHTO 11.10.5.3*

c_f = Cohesion for Foundation Soil = 0.000 ksf

L = Reinforcement Length = 12.99 ft

R_τ = (1.00)(26.50 kips)(0.58) + (0.000 ksf)(12.99 ft) = 15.37 kips

R_R = (1.00)(15.37 kips) = 15.37 kips

Calculate Factored Horizontal Driving Force (P_d)

$P_d = (\Psi_{EHA})(F_1) + (\Psi_{LS})(F_2)$ — *FHWA Eqn. 4-9*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 — *AASHTO Table 3.4.1-1*

F_1 = Force Generated from Lateral Earth Pressure = 5.630 kips — *FHWA Eqn. 4-5*

Ψ_{LS} = Load Factor for Horizontal (Active) Earth Pressure = 1.75 — *AASHTO Table 3.4.1-1*

F_2 = Force Generated from Traffic Surcharge = 2.208 kips — *FHWA Eqn. 4-6*

P_d = (1.50)(5.630 kips) + (1.75)(2.208 kips) = 12.308 kips

Check Sliding

R_R must be greater than or equal to P_d

15.37 kips ≥ 12.308 kips

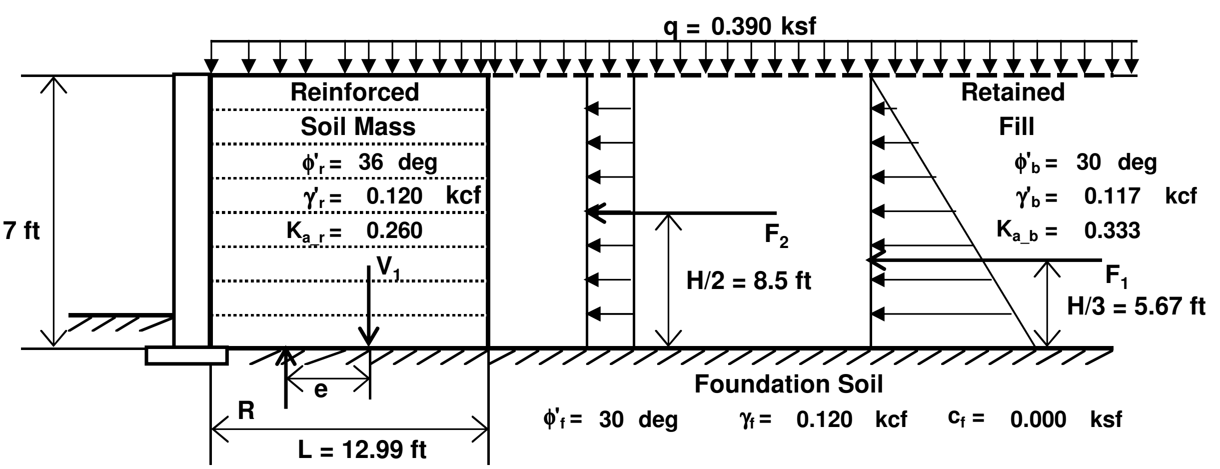
OK

Calculated Resistance Factor

$P_d/(Rr/\varphi_t)$ = **0.80**

Overturning (Limiting Eccentricity) - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Eccentricity (e) = the distance between the resultant foundation load (R) and the center of the reinforced zone



External Stability for MSE Walls: Overturning - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
Figure Not Drawn to Scale - All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity (e)

$$e = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1}$$ — *FHWA Eqn. 4-15*

Overturning (Limiting Eccentricity) Continued - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00
(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75
F_1 = Force Generated from Lateral Earth Pressure = 5.630 kips
F_2 = Force Generated from Traffic Surcharge = 2.208 kips
V_1 = Total Vertical Force from the Reinforced Soil Mass = 26.500 kips
H = MSE Wall Height = 17.00 ft

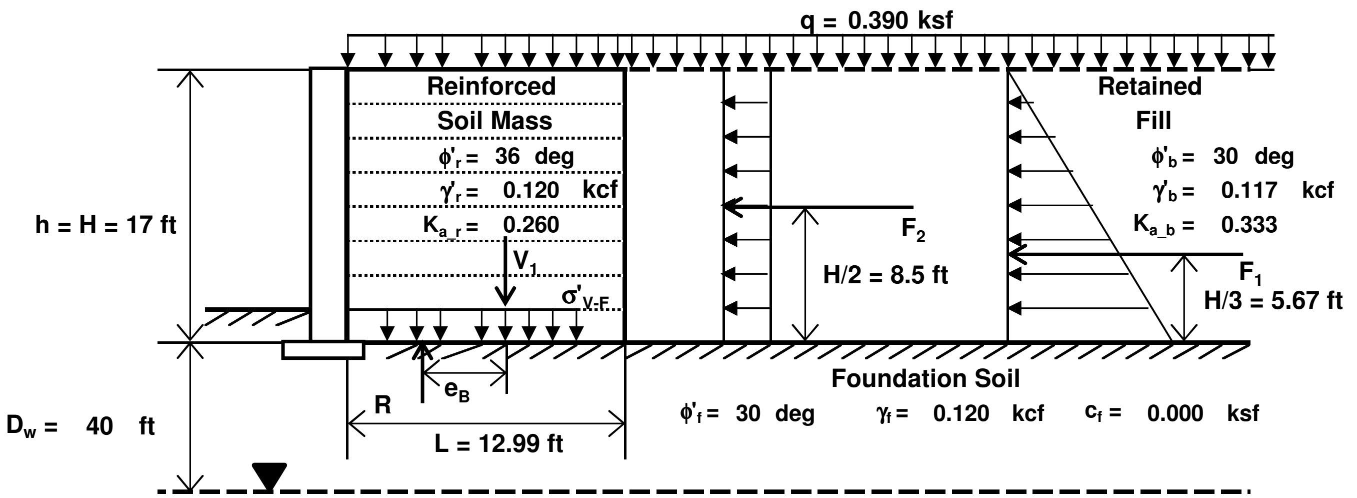
$$e = \frac{(1.50)(5.630\ \text{kips})(5.67\ \text{ft}) + (1.75)(2.208\ \text{kips})(8.50\ \text{ft})}{(1.00)(26.500\ \text{kips})}$$

$= 3.05$ ft

Check Eccentricity

e must be less than or equal to L/4 per AASHTO 11.6.3.3
3.05 ft ≤ 3.25 ft
OK

Bearing Resistance (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c



External Stability for MSE Walls: Bearing Resistance - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1 + \Psi_{LS}qL}$$ *FHWA Eqn. 4-19*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 *AASHTO Table 3.4.1-1*
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75 *AASHTO Table 3.4.1-1*
F_1 = Force Generated from Lateral Earth Pressure = 5.630 kips *FHWA Eqn. 4-5*
F_2 = Force Generated from Traffic Surcharge = 2.208 kips *FHWA Eqn. 4-6*
V_1 = Total Vertical Force from the Reinforced Soil Mass = 26.500 kips

Bearing Resistance Continued (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c

q = Live Load Traffic Surcharge = 0.390 ksf
H = MSE Wall Height = 17.00 ft
L = Reinforcement Length = 12.99 ft

$$e_B = \frac{(1.50)(5.630\text{ kips})(5.67\text{ ft}) + (1.75)(2.208\text{ kips})(8.50\text{ ft})}{(1.35)(26.5\text{ kips}) + (1.75)(0.390\text{ ksf})(12.99\text{ ft})}$$

$= 1.81$ ft

Calculate Nominal Bearing Resistance, (q_n) — *AASHTO Eqn. 10.6.3.1.2a-1*

$q_n = c_f N_c + 0.5\gamma B' N_\gamma C_{w\gamma}$ — *AASHTO Eqn. 10.6.3.1.2a-1*

c_f = Cohesion for Foundation Soil = 0.000 ksf
N_c = Bearing Capacity Factor (based on ϕ'_f) = 30.10 — *AASHTO Table 10.6.3.1.2a-1*
γ_f = Total Unit Weight for Foundation Soil = 0.120 kcf
B' = Effective Foundation Width = $L - 2e_B$ — *AASHTO C11.10.5.4*
= 13.0 ft - 2(1.81 ft) = 9.37 ft
N_γ = Bearing Capacity Factor (based on ϕ'_f) = 22.40 — *AASHTO Table 10.6.3.1.2a-1*
$C_{w\gamma}$ = Correction Factor to Account for Location of Groundwater Table = 1.0 — *AASHTO Table 10.6.3.1.2a-2*

q_n = (0.000 ksf)(30.10) + (0.5)(0.120 kcf)(9.37 ft)(22.40)(1.00)

= 12.593 ksf

Calculate Factored Bearing Resistance, (q_r)

$q_r = \varphi_b q_n$ — *AASHTO Eqn. 10.6.3.1.1-1*

φ_b = Resistance Factor for Bearing = 0.65 — *AASHTO Table 11.5.6-1*
q_n = Nominal Bearing Resistance = 12.593 ksf — *AASHTO Eqn. 10.6.3.1.2a-1*

q_r = (0.65)(12.593 ksf) = 8.185 ksf

Calculate Factored Vertical Bearing Pressure at the base, ($q_{V\text{-}F}$)

$$\sigma_{V\text{-}F} = \frac{\Psi_{EV} V_1 + \Psi_{LS} q L}{L - 2e_B}$$ — *FHWA Eqn. 4-20*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 — *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.c, AASHTO C3.4.1, and AASHTO C11.5.5)
V_1 = Total Vertical Force from the Reinforced Soil Mass = 26.500 kips
Ψ_{LS} = Load Factor for Surcharge = 1.75 — *AASHTO Table 3.4.1-1*
q = Live Load Traffic Surcharge = 0.390 ksf
L = Reinforcement Length = 12.99 ft
e_B = Eccentricity for Bearing = 1.81 ft — *FHWA Eqn. 4-19*

$$\sigma_{V\text{-}F} = \frac{(1.35)(26.50\text{ kips ft}) + (1.75)(0.390\text{ ksf})(12.99\text{ ft})}{12.99\text{ ft} - 2(1.81\text{ ft})}$$

= 4.764 ksf

Check Bearing

q_R must be greater than or equal to $q_{V\text{-}F}$
8.185 ksf ≥ 4.764 ksf
OK

Calculated Resistance Factor

$\sigma_{V\text{-}F}/q_n$ = **0.38**

Bearing Resistance (Local/Punching Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1.2b, and FHWA 4.4.6.c

Local and Punching shear failure occurs in loose or compressible soils and in weak soils under slow (drained) loading. This mode of failure will only be considered for foundation material that is cohesive.

The Foundation Material for this Project is not Cohesive.

Seismic Stablity - SCDOT GDM Section 14.12

Calculate Wave Scattering Effects

Wave Scattering Coefficient, α_w =1+0.01H((0.5β)-1<1.0 — SCDOT Equation 13-103

α_w = 0.8895

Ground Motion Index, $\beta = k_{max}/S_{d1}$ = 0.70 — SCDOT Equation 13-104

Average seismic horizontal coefficient due to wave scattering

$k_h = \alpha_w * k_{max}$ = 0.2 — SCDOT Equation 13-102

Calculate Seismic Active Earth Pressure Coefficicnet (Mononobe -Kobe Method) SCDOT GDM Section 14.4.1

Seismic Active Earth Pressure Coefficient Reinforced Soils, K_{AEr} = 0.584

Seismic Active Earth Pressure Coefficient Retained, K_{AEb} = 0.678

$$K_{ae} = \frac{\cos^2(\phi - \Psi - \theta)}{\cos(\Psi)\cos^2(\theta)\cos(\delta+\theta+\Psi)\left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\Psi-\beta)}{\cos(\delta+\theta+\Psi)\cos(\beta-\theta)}}\right]^2} \quad \text{Equation 14-2}$$

Where,

γ	=	unit weight of soil
H	=	height of wall or effective height of wall (h_{eff})
ϕ	=	angle of internal friction of soil
Ψ	=	$\tan^{-1}[k_h/(1-k_v)]$
δ	=	angle of friction between soil and wall
k_h	=	horizontal acceleration coefficient
k_v	=	vertical acceleration coefficient, typically set to zero.
β	=	backfill slope angle
θ	=	angle of backface of the wall with the vertical

	Reinforced Soil		Retained Soil	
φ	36.0	deg	30.0	deg
Ψ	11.3	deg	11.3	deg
θ	0	deg	0	deg
δ	0	deg	0.00	deg
β	0	deg	0	deg

Calculate Inertial Wall Width, $B_{inertial} = \omega H$ 12

coefficient, ω = 0.70

Calculate Active Earth Thrust Force, $P_{AE} = \gamma_p * 0.5K_{AEr} * \gamma_p * H^2$ = 11.5 kips — GDM Eq. 14-40

Calculate Intertial Reinforced Soil Mass Force, $P_{IR} = \gamma_p * k_{avg} * B_{inertial} * H_{wall} *$ = 0.29 kips — GDM Eq. 14-41

Dead Load Surcharge Force, P_{DC} = = 1.613 kips — GDM Eq. 14-45

Live Load Surcharge Force, P_{LL} = = 1.44 kips — GDM Eq. 14-46

Total Seismic Driving Force, F_H = 14.8 kip

Calculated Resistance Factor, $\varphi = F_H/R_t$ = **0.96**

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EQ\text{-}P}F_{1s}(H/2) + \Psi_{EQ\text{-}LL}F_{2s}(H/2)}{\Psi_{EV}V_1 + \Psi_{EQ\text{-}LL}qL}$$ *FHWA Eqn. 4-19*

Ψ_{EHAeq} = $\Psi_{EQ\text{-}p}$ = Load Factor for Horizontal (Active) Earth Pressure = 1.00 *AASHTO Table 3.4.1-1*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

Ψ_{LSeq} = $\Psi_{EQ\text{-}p}$ = Load Factor for Surcharge = 1.00 *AASHTO Table 3.4.1-1*

F_{1s} = Force Generated from Lateral Earth Pressure = 13.357 kips *FHWA Eqn. 4-5*

F_{2s} = Force Generated from Traffic Surcharge = 1.440 kips *FHWA Eqn. 4-6*

V_1 = Total Vertical Force from the Reinforced Soil Mass = 26.500 kips

q = Live Load Traffic Surcharge = 0.250 ksf *FHWA Eqn. 4-19*

H = MSE Wall Height = 17.00 ft

L = Reinforcement Length = 12.99 ft

$$e_B = \frac{(\ 1.00\ )(\ 13.357\ \text{kips})(\ 8.50\ \text{ft}) + (\ 1.00\ )(\ 1.440\ \text{kips})(\ 8.50\ \text{ft})}{(\ 1.00\ )(\ 26.5\ \text{kips}) + (\ 1.00\ )(\ 0.250\ \text{ksf})(\ 12.99\ \text{ft})}$$

= 4.23 ft

Calculate Factored Vertical Bearing Pressure at the base, ($q_{V\text{-}F}$)

$$\sigma_{V\text{-}F} = \frac{\Psi_{EQ\text{-}P}V_1 + \Psi_{EQ\text{-}LS}qL}{L - 2e_B}$$ *FHWA Eqn. 4-20*

$\Psi_{EQ\text{-}p}$ = Load Factor for Dead Load of Earth Fill = 1.00

V_1 = Total Vertical Force from the Reinforced Soil Mass = 26.500 kips

Ψ_{LSeq} = $\Psi_{EQ\text{-}ll}$ = Load Factor for Surcharge = 1.00

q = Live Load Traffic Surcharge = 0.250 ksf

L = Reinforcement Length = 12.99 ft

e_B = Eccentricity for Bearing = 4.23 ft

$$\sigma_{V\text{-}F} = \frac{(\ 1.00\ )(\ 26.50\ \text{kips})(\ \text{ft}) + (\ 1.00\ )(\ 0.250\ \text{ksf})(\ 12.99\ \text{ft})}{13.0\ \text{ft} - 2(\ 4.23\ \text{ft})}$$

= 6.968 ksf

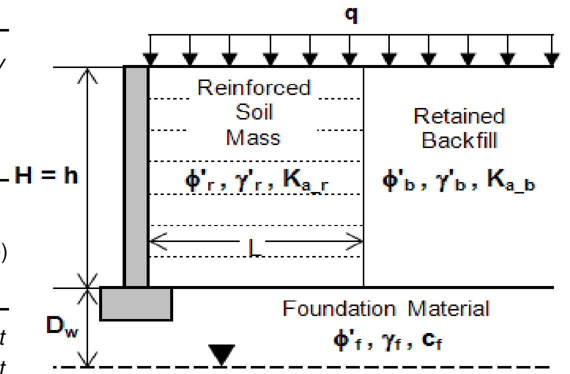
Calculated Resistance Factor

$\sigma_{V\text{-}F}/q_n$ = **0.55**

Input Traffic Surcharge, Backslope, Wall Geometry, and Soil Parameters

Traffic and Overlay Surcharge Surcharge

q =	390	psf	*Live Load Traffic Surcharge and Pavement Overlay*
	35.9	% Surcharge due to overlay	
q_{ol} =	140	psf	*Pavement overlay surcharge*



Typical MSE Wall with Level Backslope and Traffic Surcharge

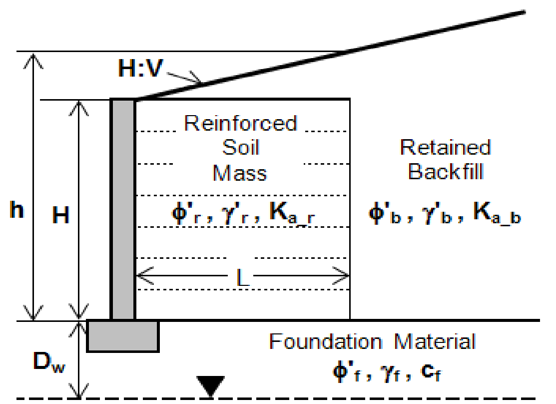
Backslope

Horizontal Backslope

(d = horizontal distance from back of wall face to top of backslope)

Wall Geometry

H =	41.50	ft	*Wall Height*
L/H =	0.71		*Ratio of Reinforcement Length to Wall Height*
			(L/H ≥ 0.7 per NCDOT MSE Wall Standard Provision)
L =	29.47	ft	*Reinforcement Length*
			(L ≥ 6 ft per NCDOT MSE Wall Standard Provision)
h =	41.50	ft	*Height of Wall & Slope at the back of Reinforced Zone*
D_w =	18.00	ft	*Distance of Water Table below the Bottom of the Wall*



Typical MSE Wall with Infinite Backslope

Soil Parameters for Reinforced Zone

ϕ'_r =	36	deg	*Effective Friction Angle*
γ'_r =	120	pcf	*Effective Unit Weight*
K_{a_r} =	0.260		*Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

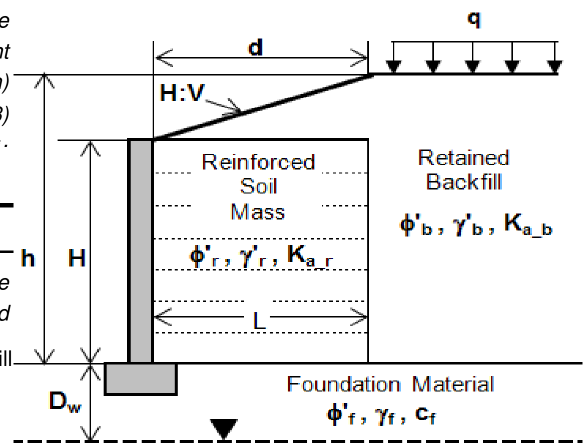
Soil Parameters for Retained Backfill

ϕ'_b =	28	deg	*Effective Friction Angle*
γ'_b =	117	pcf	*Effective Unit Weight*
K_{a_b} =	0.361		*Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

Soil Parameters for Foundation Soil

ϕ'_f =	30	deg	*Effective Friction Angle*
γ_f =	120	pcf	*Total Unit Weight*
c_f =	0	psf	*Undrained Shear Strength (Cohesion)*
μ =	0.58		*Coefficient of Friction (AASHTO 11.10.5.3)*

The coefficient of friction shall be based on the lesser of ϕ'_r and ϕ'_f.



Typical MSE Wall with Broken Backslope and Traffic Surcharge

Input Load and Resistance Factors

Load Factors (See AASHTO Table 3.4.1-1 and 2)

Ψ_{LS} =	1.75		*Lilve Load Surcharge*
$\Psi_{EH(A)}$ =	1.50		*Horizontal (Active) Earth Pressure Load*
Ψ_{EV} =	1.00	min	Vertical Dead Load Generated from Earth Fill
	1.35	max	
$\Psi_{EQ\text{-}p}$ =	1.00		
$\Psi_{EQ\text{-}LL}$ =	0.50		

Resistance Factors (See AASHTO Table 11.5.6-1)

φ_b =	0.65	*Bearing Resistance for MSE Walls*
φ_τ =	1.00	*Sliding Resistance for MSE Walls*

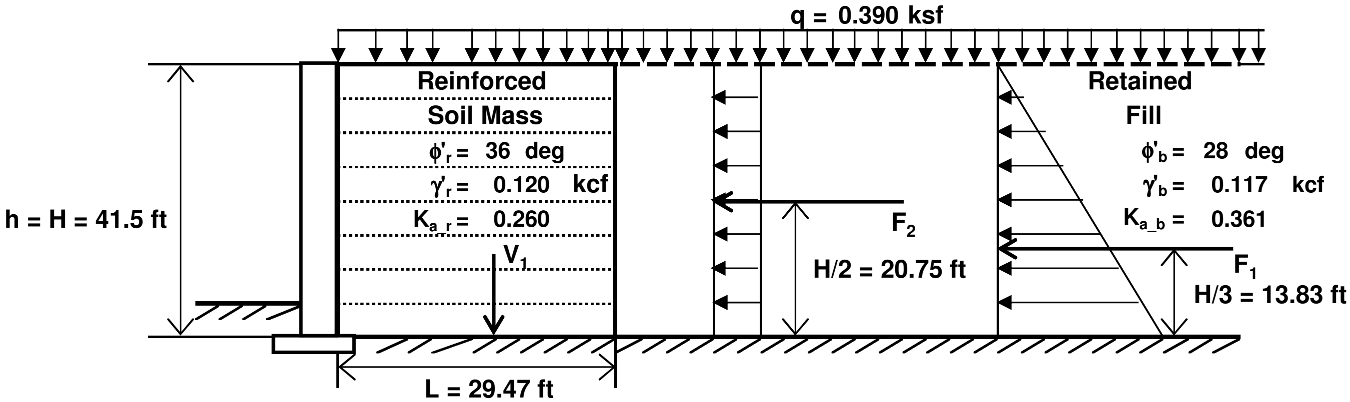
Seismic Design Acceleration Parameters

k_{max} =	0.20	*Maximum Horizontal Ground Acceleration (PGA)*
S_{d1}=	0.14	*Peak spectral acceleration at 1 second*

References:

1. *AASHTO LRFD Bridge Design Specifications, 5th Edition, 2010*
2. *FHWA-NHI-10-024 Design and Construction of MSE Walls and Reinforced Soil Slopes - Vol I, 2009*
3. *SCDOT Geotechnical Design Manual version 1.1, 2010*

Calculate Forces acting on Wall



External Stability for MSE Walls: Earth Pressure - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Forces from Vertical Earth Loads

V_1 = Total Vertical Force from the Reinforced Soil Mass = $(\gamma_r)(H)(L)$
= (0.120 kcf)(41.50 ft)(29.47 ft) = 146.761 kips

Forces from Lateral Earth Pressure

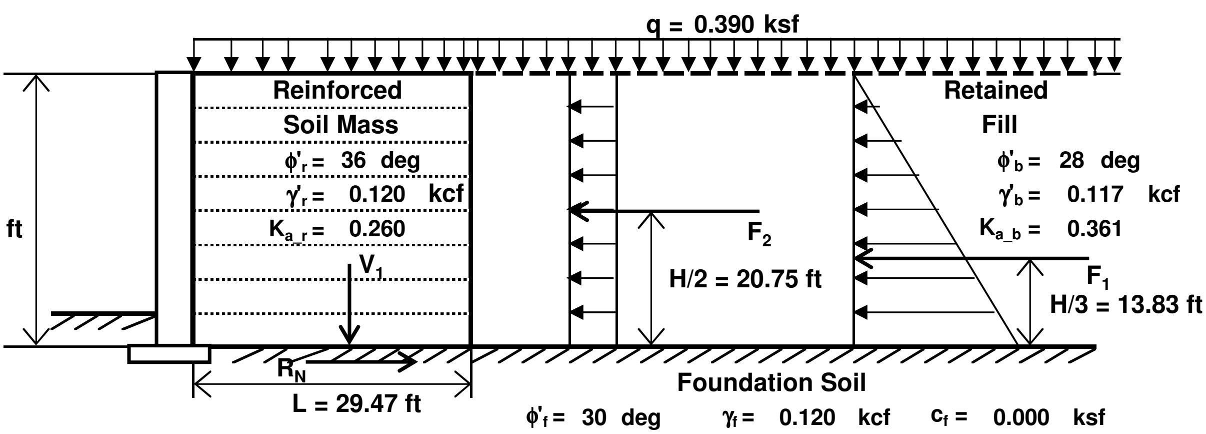
F_1 = Total Force Generated from Lateral Earth Pressure = $0.5(\gamma'_b)(H^2)(K_{ab})$ — FHWA Eqn. 4-5
= (0.5)(0.117 kcf)(41.50 ft)^2(0.361) = 36.371 kips

Horizontal Force from Traffic Surcharge

F_2 = Force Generated from Traffic Surcharge = $(q)(H)(K_{ab})$ — *FHWA Eqn. 4-6*
= (0.390 ksf)(41.50 ft)(0.361) = 5.843 kips

Sliding Stability - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

The passive resistance at the toe due to embedment is ignored due to the potential for soil to be removed through natural or manmade processes.
(per FHWA 4.4.6.a)



External Stability for MSE Walls: Sliding Stability - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Factored Sliding Resistance (R_R)

$R_R = \varphi R_N = \varphi_\tau R_\tau$ — *AASHTO Eqn. 10.6.3.4-1*

Sliding Stability Continued - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

φ_τ = *Resistance Factor for Sliding* = 1.00 — *AASHTO Table 11.5.6-1*

R_τ = *Nominal Sliding Resistance between Reinforced Soil Mass and Foundation Soil*

$= \Psi_{EV}(V_1)\mu + (c_f)(L)$ — *FHWA Eqn. 4-12 and AASHTO 10.6.3.4*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 — *AASHTO Table 3.4.1-1*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

V_1 = Total Vertical Force from the Reinforced Soil Mass = 146.761 kips

μ = Coefficent of Friction between Reinforced Soil Mass and Foundation Soil = 0.58 — *AASHTO 11.10.5.3*

c_f = Cohesion for Foundation Soil = 0.000 ksf

L = Reinforcement Length = 29.47 ft

R_τ = (1.00)(146.76 kips)(0.58) + (0.000 ksf)(29.47 ft) = 85.12 kips

R_R = (1.00)(85.12 kips) = 85.12 kips

Calculate Factored Horizontal Driving Force (P_d)

$P_d = (\Psi_{EHA})(F_1) + (\Psi_{LS})(F_2)$ — *FHWA Eqn. 4-9*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 — *AASHTO Table 3.4.1-1*

F_1 = Force Generated from Lateral Earth Pressure = 36.371 kips — *FHWA Eqn. 4-5*

Ψ_{LS} = Load Factor for Horizontal (Active) Earth Pressure = 1.75 — *AASHTO Table 3.4.1-1*

F_2 = Force Generated from Traffic Surcharge = 5.843 kips — *FHWA Eqn. 4-6*

P_d = (1.50)(36.371 kips) + (1.75)(5.843 kips) = 64.782 kips

Check Sliding

R_R must be greater than or equal to P_d

85.121 kips ≥ 64.782 kips

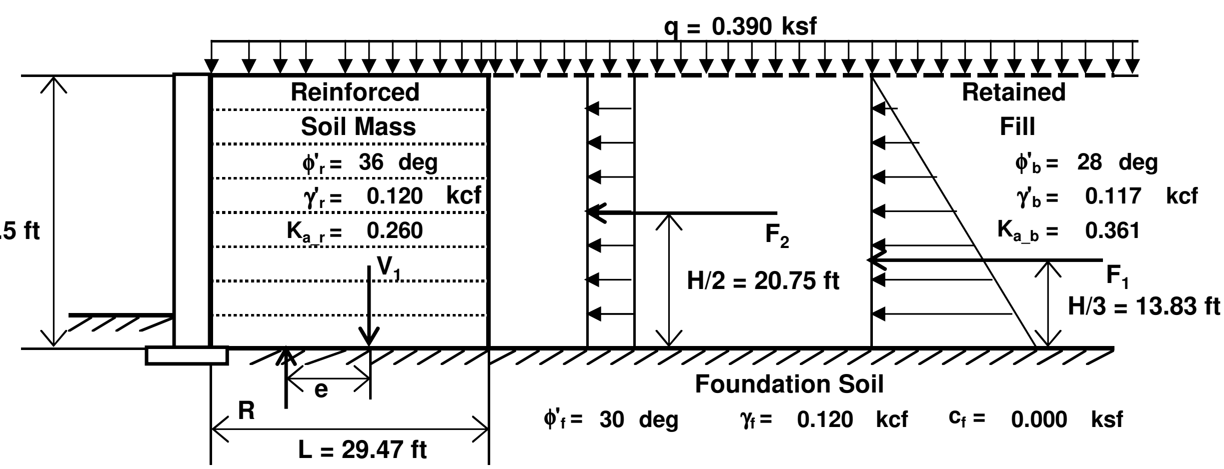
OK

Calculated Resistance Factor

$P_d/(Rr/\varphi_t)$ = **0.76**

Overturning (Limiting Eccentricity) - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Eccentricity (e) = the distance between the resultant foundation load (R) and the center of the reinforced zone



External Stability for MSE Walls: Overturning - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
Figure Not Drawn to Scale - All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity (e)

$$e = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1}$$ — *FHWA Eqn. 4-15*

Overturning (Limiting Eccentricity) Continued - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00
(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75
F_1 = Force Generated from Lateral Earth Pressure = 36.371 kips
F_2 = Force Generated from Traffic Surcharge = 5.843 kips
V_1 = Total Vertical Force from the Reinforced Soil Mass = 146.761 kips
H = MSE Wall Height = 41.50 ft

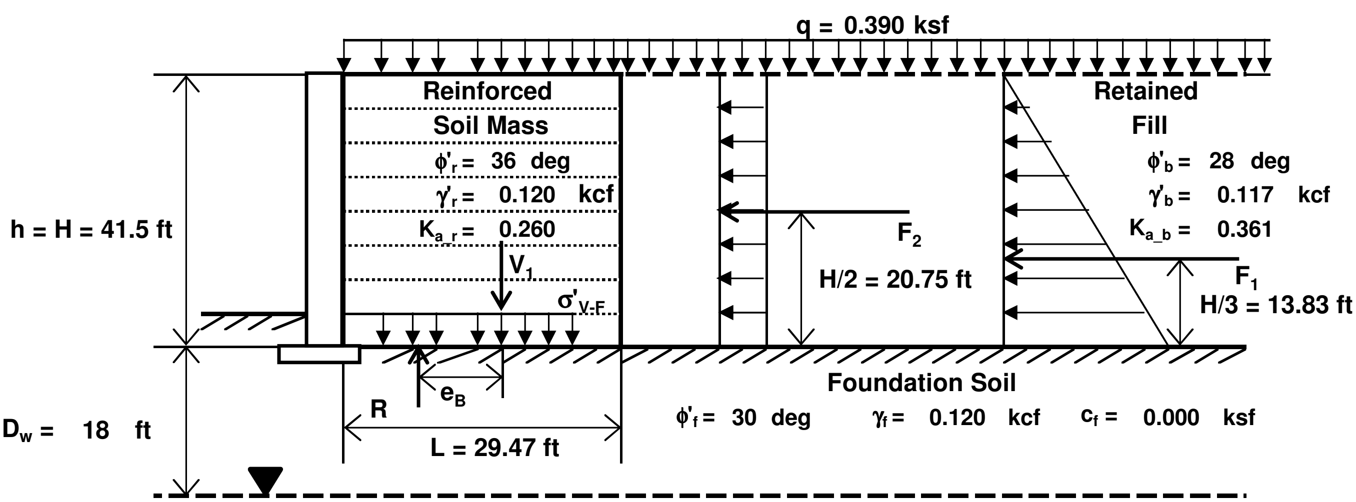
$$e = \frac{(1.50)(36.371\ \text{kips})(13.83\ \text{ft}) + (1.75)(5.843\ \text{kips})(20.75\ \text{ft})}{(1.00)(146.761\ \text{kips})}$$

= 6.59 ft

Check Eccentricity

e must be less than or equal to L/4 per AASHTO 11.6.3.3
6.59 ft ≤ 7.37 ft
OK

Bearing Resistance (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c



External Stability for MSE Walls: Bearing Resistance - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1 + \Psi_{LS}qL}$$ *FHWA Eqn. 4-19*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 *AASHTO Table 3.4.1-1*
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75 *AASHTO Table 3.4.1-1*
F_1 = Force Generated from Lateral Earth Pressure = 36.371 kips *FHWA Eqn. 4-5*
F_2 = Force Generated from Traffic Surcharge = 5.843 kips *FHWA Eqn. 4-6*
V_1 = Total Vertical Force from the Reinforced Soil Mass = 146.761 kips

Bearing Resistance Continued (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c

q = Live Load Traffic Surcharge = 0.390 ksf
H = MSE Wall Height = 41.50 ft
L = Reinforcement Length = 29.47 ft

$$e_B = \frac{(1.50)(36.371 \text{ kips})(13.83 \text{ ft}) + (1.75)(5.843 \text{ kips})(20.75 \text{ ft})}{(1.35)(146.8 \text{ kips}) + (1.75)(0.390 \text{ ksf})(29.47 \text{ ft})}$$

= 4.43 ft

Calculate Nominal Bearing Resistance, (q_n) — *AASHTO Eqn. 10.6.3.1.2a-1*

$q_n = c_f N_c + 0.5\gamma B' N_\gamma C_{w\gamma}$ — *AASHTO Eqn. 10.6.3.1.2a-1*

c_f = Cohesion for Foundation Soil = 0.000 ksf
N_c = Bearing Capacity Factor (based on ϕ'_f) = 30.10 — *AASHTO Table 10.6.3.1.2a-1*
γ_f = Total Unit Weight for Foundation Soil = 0.120 kcf
B' = Effective Foundation Width = L - 2e_B — *AASHTO C11.10.5.4*
= 29.5 ft - 2(4.43 ft) = 20.61 ft
N_γ = Bearing Capacity Factor (based on ϕ'_f) = 22.40 — *AASHTO Table 10.6.3.1.2a-1*
$C_{w\gamma}$ = Correction Factor to Account for Location of Groundwater Table = 0.7 — *AASHTO Table 10.6.3.1.2a-2*

q_n = (0.000 ksf)(30.10) + (0.5)(0.120 kcf)(20.61 ft)(22.40)(0.70)

= 19.390 ksf

Calculate Factored Bearing Resistance, (q_r)

$q_r = \varphi_b q_n$ — *AASHTO Eqn. 10.6.3.1.1-1*

φ_b = Resistance Factor for Bearing = 0.65 — *AASHTO Table 11.5.6-1*
q_n = Nominal Bearing Resistance = 19.390 ksf — *AASHTO Eqn. 10.6.3.1.2a-1*

q_r = (0.65)(19.390 ksf) = 12.604 ksf

Calculate Factored Vertical Bearing Pressure at the base, (q_{V-F})

$$\sigma_{V-F} = \frac{\Psi_{EV} V_1 + \Psi_{LS} qL}{L - 2e_B}$$ — *FHWA Eqn. 4-20*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 — *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.c, AASHTO C3.4.1, and AASHTO C11.5.5)
V_1 = Total Vertical Force from the Reinforced Soil Mass = 146.761 kips
Ψ_{LS} = Load Factor for Surcharge = 1.75 — *AASHTO Table 3.4.1-1*
q = Live Load Traffic Surcharge = 0.390 ksf
L = Reinforcement Length = 29.47 ft
e_B = Eccentricity for Bearing = 4.43 ft — *FHWA Eqn. 4-19*

$$\sigma_{V-F} = \frac{(1.35)(146.76 \text{ kips ft}) + (1.75)(0.390 \text{ ksf})(29.47 \text{ ft})}{29.47 \text{ ft} - 2(4.43 \text{ ft})}$$

= 10.589 ksf

Check Bearing

q_R must be greater than or equal to q_{V-F}
12.604 ksf ≥ 10.589 ksf
OK

Calculated Resistance Factor

σ_{V-F}/q_n = **0.55**

Bearing Resistance (Local/Punching Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1.2b, and FHWA 4.4.6.c

Local and Punching shear failure occurs in loose or compressible soils and in weak soils under slow (drained) loading. This mode of failure will only be considered for foundation material that is cohesive.

The Foundation Material for this Project is not Cohesive.

Seismic Stablity - SCDOT GDM Section 14.12

Calculate Wave Scattering Effects

Wave Scattering Coefficient, α_w =1+0.01H((0.5β)-1<1.0 SCDOT Equation 13-103

α_w = 0.7303

Ground Motion Index, $\beta = k_{max}/S_{d1}$ = 0.70 SCDOT Equation 13-104

Average seismic horizontal coefficient due to wave scattering

$k_h = \alpha_w * k_{max}$ = 0.146 SCDOT Equation 13-102

Calculate Seismic Active Earth Pressure Coefficicinet (Mononobe -Kobe Method) SCDOT GDM Section 14.4.1

Seismic Active Earth Pressure Coefficient Reinforced Soils, K_{AEr} = 0.531

Seismic Active Earth Pressure Coefficient Retained, K_{AEb} = 0.654

$$K_{ae} = \frac{\cos^2(\phi - \Psi - \theta)}{\cos(\Psi)\cos^2(\theta)\cos(\delta+\theta+\Psi)\left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\Psi-\beta)}{\cos(\delta+\theta+\Psi)\cos(\beta-\theta)}}\right]^2} \quad \text{Equation 14-2}$$

Where,

γ	=	unit weight of soil
H	=	height of wall or effective height of wall (h_{eff})
ϕ	=	angle of internal friction of soil
Ψ	=	$\tan^{-1}[k_h/(1-k_v)]$
δ	=	angle of friction between soil and wall
k_h	=	horizontal acceleration coefficient
k_v	=	vertical acceleration coefficient, typically set to zero.
β	=	backfill slope angle
θ	=	angle of backface of the wall with the vertical

Reinforced Soil				Retained Soil			
φ	=	36.0	deg	φ	=	28.0	deg
Ψ	=	8.3	deg	Ψ	=	8.3	deg
θ	=	0	deg	θ	=	0	deg
δ	=	0	deg	δ	=	0.00	deg
β	=	0	deg	β	=	0	deg

Calculate Inertial Wall Width, $B_{inertial} = \omega H$ 29

coefficient, ω = 0.70

Calculate Active Earth Thrust Force, $P_{AE} = \gamma_p * 0.5 K_{AEr} * \gamma_p * H^2$ = 65.9 kips GDM Eq. 14-40

Calculate Intertial Reinforced Soil Mass Force, $P_{IR} = \gamma_p * k_{avg} * B_{inertial} * H_{wall} *$ = 0.51 kips GDM Eq. 14-41

Dead Load Surcharge Force, P_{DC} = = 3.798 kips GDM Eq. 14-45

Live Load Surcharge Force, P_{LL} = = 3.391 kips GDM Eq. 14-46

Total Seismic Driving Force, F_H = 73.6 kip

Calculated Resistance Factor, $\varphi = F_H/R_t$ = **0.86**

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EQ\text{-}P}F_{1s}(H/2) + \Psi_{EQ\text{-}LL}F_{2s}(H/2)}{\Psi_{EV}V_1 + \Psi_{EQ\text{-}LL}qL}$$ *FHWA Eqn. 4-19*

Ψ_{EHAeq} = $\Psi_{EQ\text{-}p}$ = Load Factor for Horizontal (Active) Earth Pressure = 1.00 *AASHTO Table 3.4.1-1*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

Ψ_{LSeq} = $\Psi_{EQ\text{-}p}$ = Load Factor for Surcharge = 1.00 *AASHTO Table 3.4.1-1*

F_{1s} = Force Generated from Lateral Earth Pressure = 70.162 kips *FHWA Eqn. 4-5*

F_{2s} = Force Generated from Traffic Surcharge = 3.391 kips *FHWA Eqn. 4-6*

V_1 = Total Vertical Force from the Reinforced Soil Mass = 146.761 kips

q = Live Load Traffic Surcharge = 0.250 ksf *FHWA Eqn. 4-19*

H = MSE Wall Height = 41.50 ft

L = Reinforcement Length = 29.47 ft

$$e_B = \frac{(\ 1.00\ )(\ 70.162\ \text{kips})(\ 20.75\ \text{ft}) + (\ 1.00\ )(\ 3.391\ \text{kips})(\ 20.75\ \text{ft})}{(\ 1.00\ )(\ 146.8\ \text{kips}) + (\ 1.00\ )(\ 0.250\ \text{ksf})(\ 29.47\ \text{ft})}$$

= 9.90 ft

Calculate Factored Vertical Bearing Pressure at the base, ($q_{V\text{-}F}$)

$$\sigma_{V\text{-}F} = \frac{\Psi_{EQ\text{-}P}V_1 + \Psi_{EQ\text{-}LS}qL}{L - 2e_B}$$ *FHWA Eqn. 4-20*

$\Psi_{EQ\text{-}p}$ = Load Factor for Dead Load of Earth Fill = 1.00

V_1 = Total Vertical Force from the Reinforced Soil Mass = 146.761 kips

Ψ_{LSeq} = $\Psi_{EQ\text{-}ll}$ = Load Factor for Surcharge = 1.00

q = Live Load Traffic Surcharge = 0.250 ksf

L = Reinforcement Length = 29.47 ft

e_B = Eccentricity for Bearing = 9.90 ft

$$\sigma_{V\text{-}F} = \frac{(\ 1.00\ )(\ 146.76\ \text{kips})(\ \text{ft}) + (\ 1.00\ )(\ 0.250\ \text{ksf})(\ 29.47\ \text{ft})}{29.5\ \text{ft} - 2(\ 9.90\ \text{ft})}$$

= 16.365 ksf

Calculated Resistance Factor

$\sigma_{V\text{-}F}/q_n$ = **0.84**

Input Traffic Surcharge, Backslope, Wall Geometry, and Soil Parameters

Traffic and Overlay Surcharge Surcharge

q =	390	psf	*Live Load Traffic Surcharge and Pavement Overlay*
	35.9	% Surcharge due to overlay	
q_{ol} =	140	psf	*Pavement overlay surcharge*

Backslope

Horizontal Backslope

(d = horizontal distance from back of wall face to top of backslope)

Wall Geometry

H =	21.50	ft	*Wall Height*
L/H =	0.74		*Ratio of Reinforcement Length to Wall Height*
			(L/H ≥ 0.7 per NCDOT MSE Wall Standard Provision)
L =	16.00	ft	*Reinforcement Length*
			(L ≥ 6 ft per NCDOT MSE Wall Standard Provision)
h =	21.50	ft	*Height of Wall & Slope at the back of Reinforced Zone*
D_w =	20.00	ft	*Distance of Water Table below the Bottom of the Wall*

Soil Parameters for Reinforced Zone

ϕ'_r =	36	deg	*Effective Friction Angle*
γ'_r =	120	pcf	*Effective Unit Weight*
K_{a_r} =	0.260		*Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

Soil Parameters for Retained Backfill

ϕ'_b =	26	deg	*Effective Friction Angle*
γ'_b =	105	pcf	*Effective Unit Weight*
K_{a_b} =	0.390		*Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

Soil Parameters for Foundation Soil

ϕ'_f =	32	deg	*Effective Friction Angle*
γ_f =	110	pcf	*Total Unit Weight*
c_f =	0	psf	*Undrained Shear Strength (Cohesion)*
μ =	0.62		*Coefficient of Friction (AASHTO 11.10.5.3)*

The coefficient of friction shall be based on the lesser of ϕ'_r and ϕ'_f.

Input Load and Resistance Factors

Load Factors (See AASHTO Table 3.4.1-1 and 2)

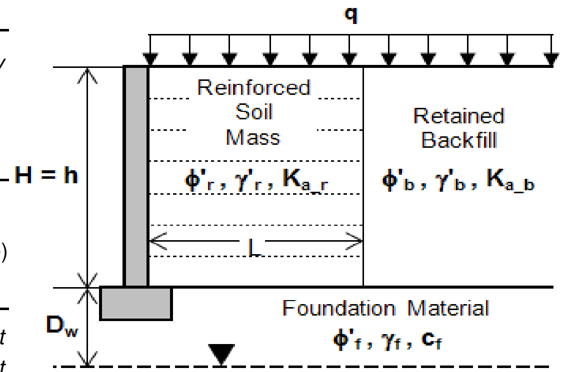
Ψ_{LS} =	1.75		*Lilve Load Surcharge*
$\Psi_{EH(A)}$ =	1.50		*Horizontal (Active) Earth Pressure Load*
Ψ_{EV} =	1.00	min	Vertical Dead Load Generated from Earth Fill
	1.35	max	
$\Psi_{EQ\text{-}p}$ =	1.00		
$\Psi_{EQ\text{-}LL}$ =	0.50		

Resistance Factors (See AASHTO Table 11.5.6-1)

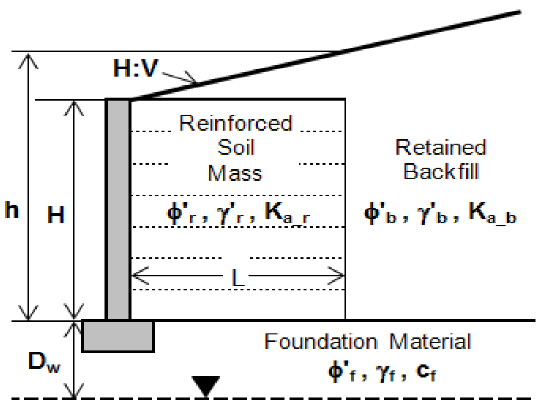
φ_b =	0.65	*Bearing Resistance for MSE Walls*
φ_τ =	1.00	*Sliding Resistance for MSE Walls*

Seismic Design Acceleration Parameters

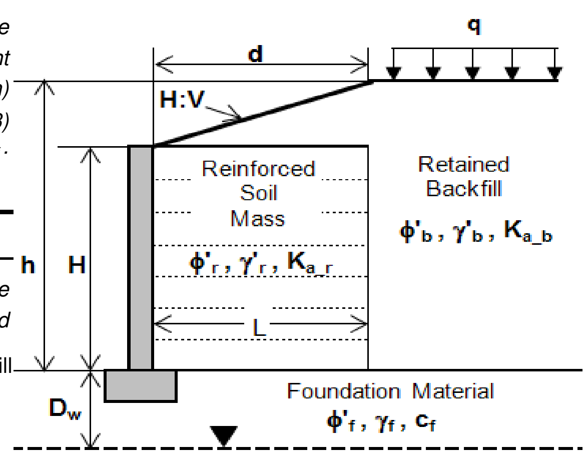
k_{max} =	0.20	*Maximum Horizontal Ground Acceration (PGA)*
S_{d1}=	0.14	*Peak spectral acceleration at 1 second*



Typical MSE Wall with Level Backslope and Traffic Surcharge



Typical MSE Wall with Infinite Backslope

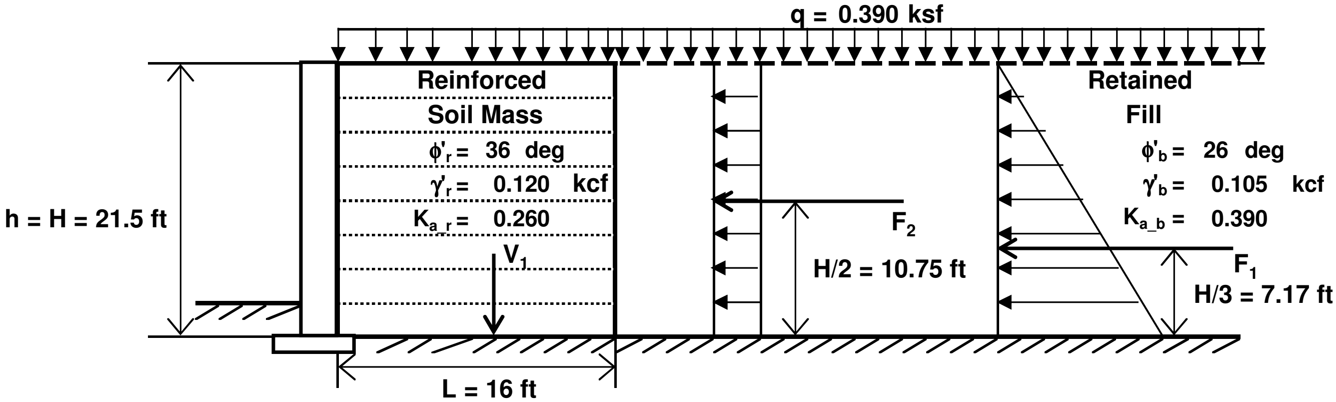


Typical MSE Wall with Broken Backslope and Traffic Surcharge

References:

1. *AASHTO LRFD Bridge Design Specifications, 5th Edition, 2010*
2. *FHWA-NHI-10-024 Design and Construction of MSE Walls and Reinforced Soil Slopes - Vol I, 2009*
3. *SCDOT Geotechnical Design Manual version 1.1, 2010*

Calculate Forces acting on Wall



External Stability for MSE Walls: Earth Pressure - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Forces from Vertical Earth Loads

V_1 = Total Vertical Force from the Reinforced Soil Mass = $(\gamma_r)(H)(L)$
= (0.120 kcf)(21.50 ft)(16.00 ft) = 41.280 kips

Forces from Lateral Earth Pressure

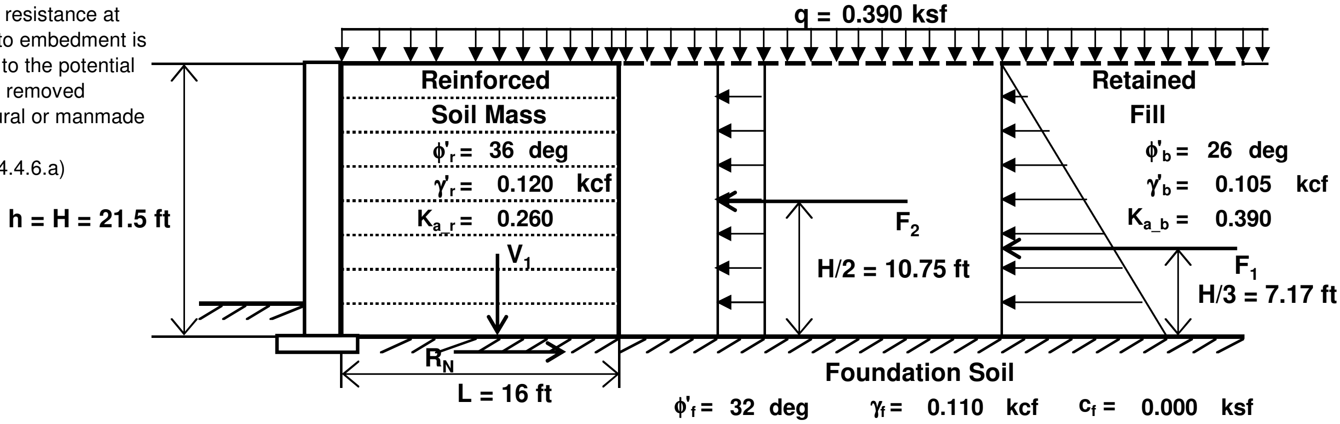
F_1 = Total Force Generated from Lateral Earth Pressure = $0.5(\gamma'_b)(H^2)(K_{ab})$ FHWA Eqn. 4-5
= (0.5)(0.105 kcf)(21.50 ft)^2(0.390) = 9.465 kips

Horizontal Force from Traffic Surcharge

F_2 = Force Generated from Traffic Surcharge = $(q)(H)(K_{ab})$ *FHWA Eqn. 4-6*
= (0.390 ksf)(21.50 ft)(0.390) = 3.270 kips

Sliding Stability - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

The passive resistance at the toe due to embedment is ignored due to the potential for soil to be removed through natural or manmade processes.
(per FHWA 4.4.6.a)



External Stability for MSE Walls: Sliding Stability - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Factored Sliding Resistance (R_R)

$R_R = \varphi R_N = \varphi_\tau R_\tau$ *AASHTO Eqn. 10.6.3.4-1*

Sliding Stability Continued - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

φ_τ = *Resistance Factor for Sliding* = 1.00 — *AASHTO Table 11.5.6-1*

R_τ = *Nominal Sliding Resistance between Reinforced Soil Mass and Foundation Soil*

= $\Psi_{EV}(V_1)\mu + (c_f)(L)$ — *FHWA Eqn. 4-12 and AASHTO 10.6.3.4*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 — *AASHTO Table 3.4.1-1*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

V_1 = Total Vertical Force from the Reinforced Soil Mass = 41.280 kips

μ = Coefficent of Friction between Reinforced Soil Mass and Foundation Soil = 0.62 — *AASHTO 11.10.5.3*

c_f = Cohesion for Foundation Soil = 0.000 ksf

L = Reinforcement Length = 16.00 ft

R_τ = (1.00)(41.28 kips)(0.62) + (0.000 ksf)(16.00 ft) = 25.59 kips

R_R = (1.00)(25.59 kips) = 25.59 kips

Calculate Factored Horizontal Driving Force (P_d)

$P_d = (\Psi_{EHA})(F_1) + (\Psi_{LS})(F_2)$ — *FHWA Eqn. 4-9*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 — *AASHTO Table 3.4.1-1*

F_1 = Force Generated from Lateral Earth Pressure = 9.465 kips — *FHWA Eqn. 4-5*

Ψ_{LS} = Load Factor for Horizontal (Active) Earth Pressure = 1.75 — *AASHTO Table 3.4.1-1*

F_2 = Force Generated from Traffic Surcharge = 3.270 kips — *FHWA Eqn. 4-6*

P_d = (1.50)(9.465 kips) + (1.75)(3.270 kips) = 19.920 kips

Check Sliding

R_R must be greater than or equal to P_d

25.594 kips ≥ 19.92 kips

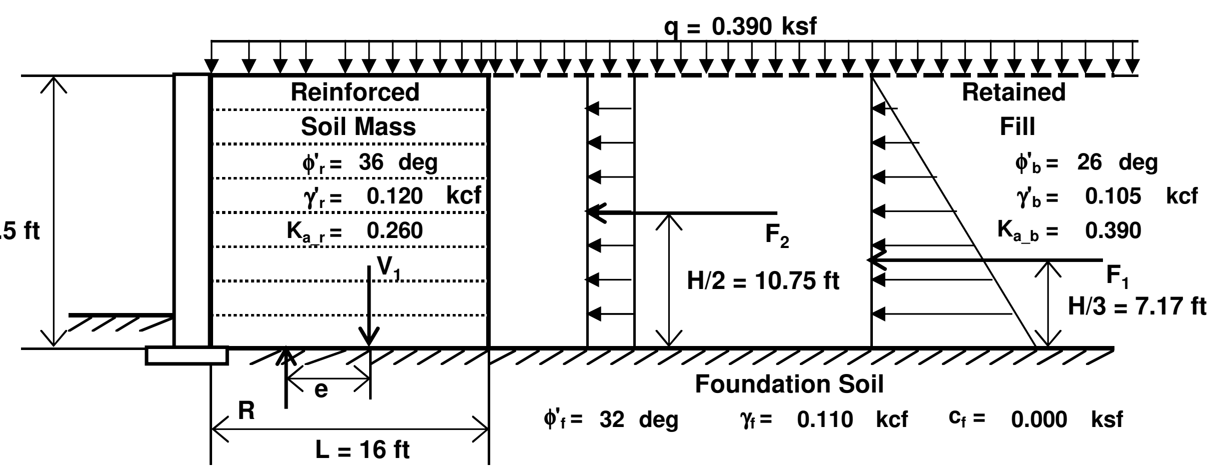
OK

Calculated Resistance Factor

$P_d/(Rr/\varphi_t)$ = **0.78**

Overturning (Limiting Eccentricity) - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Eccentricity (e) = the distance between the resultant foundation load (R) and the center of the reinforced zone



External Stability for MSE Walls: Overturning - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
Figure Not Drawn to Scale - All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity (e)

$$e = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1}$$ — *FHWA Eqn. 4-15*

Overturning (Limiting Eccentricity) Continued - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00
(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75
F_1 = Force Generated from Lateral Earth Pressure = 9.465 kips
F_2 = Force Generated from Traffic Surcharge = 3.270 kips
V_1 = Total Vertical Force from the Reinforced Soil Mass = 41.280 kips
H = MSE Wall Height = 21.50 ft

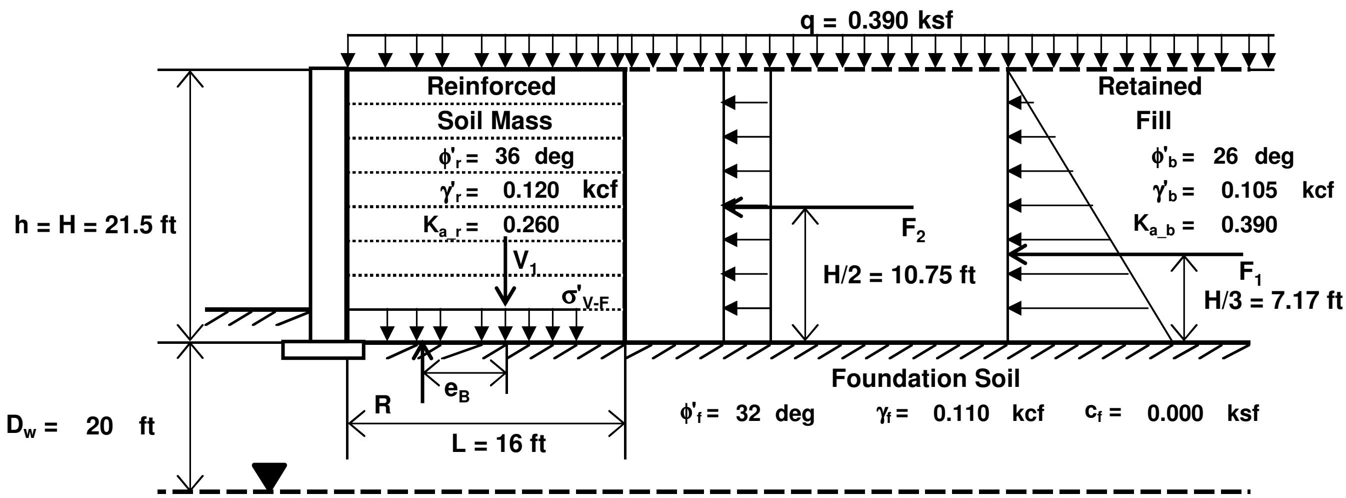
$$e = \frac{(1.50)(9.465 \text{ kips})(7.17 \text{ ft}) + (1.75)(3.270 \text{ kips})(10.75 \text{ ft})}{(1.00)(41.280 \text{ kips})}$$

= 3.96 ft

Check Eccentricity

e must be less than or equal to L/4 per AASHTO 11.6.3.3
3.96 ft ≤ 4 ft
OK

Bearing Resistance (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c



External Stability for MSE Walls: Bearing Resistance - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1 + \Psi_{LS}qL}$$ *FHWA Eqn. 4-19*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 *AASHTO Table 3.4.1-1*
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75 *AASHTO Table 3.4.1-1*
F_1 = Force Generated from Lateral Earth Pressure = 9.465 kips *FHWA Eqn. 4-5*
F_2 = Force Generated from Traffic Surcharge = 3.270 kips *FHWA Eqn. 4-6*
V_1 = Total Vertical Force from the Reinforced Soil Mass = 41.280 kips

Bearing Resistance Continued (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c

q = Live Load Traffic Surcharge = 0.390 ksf
H = MSE Wall Height = 21.50 ft
L = Reinforcement Length = 16.00 ft

$$e_B = \frac{(1.50)(9.465\ \text{kips})(7.17\ \text{ft}) + (1.75)(3.270\ \text{kips})(10.75\ \text{ft})}{(1.35)(41.3\ \text{kips}) + (1.75)(0.390\ \text{ksf})(16.00\ \text{ft})}$$

= 2.45 ft

Calculate Nominal Bearing Resistance, (q_n) — *AASHTO Eqn. 10.6.3.1.2a-1*

$q_n = c_f N_c + 0.5\gamma B' N_\gamma C_{w\gamma}$ — *AASHTO Eqn. 10.6.3.1.2a-1*

c_f = Cohesion for Foundation Soil = 0.000 ksf
N_c = Bearing Capacity Factor (based on ϕ'_f) = 35.50 — *AASHTO Table 10.6.3.1.2a-1*
γ_f = Total Unit Weight for Foundation Soil = 0.110 kcf
B' = Effective Foundation Width = L - 2e_B — *AASHTO C11.10.5.4*
= 16.0 ft - 2(2.45 ft) = 11.10 ft
N_γ = Bearing Capacity Factor (based on ϕ'_f) = 30.20 — *AASHTO Table 10.6.3.1.2a-1*
$C_{w\gamma}$ = Correction Factor to Account for Location of Groundwater Table = 0.9 — *AASHTO Table 10.6.3.1.2a-2*

q_n = (0.000 ksf)(35.50) + (0.5)(0.110 kcf)(11.10 ft)(30.20)(0.90)

= 16.593 ksf

Calculate Factored Bearing Resistance, (q_r)

$q_r = \varphi_b q_n$ — *AASHTO Eqn. 10.6.3.1.1-1*

φ_b = Resistance Factor for Bearing = 0.65 — *AASHTO Table 11.5.6-1*
q_n = Nominal Bearing Resistance = 16.593 ksf — *AASHTO Eqn. 10.6.3.1.2a-1*

q_r = (0.65)(16.593 ksf) = 10.785 ksf

Calculate Factored Vertical Bearing Pressure at the base, (q_{V-F})

$$\sigma_{V-F} = \frac{\Psi_{EV} V_1 + \Psi_{LS} q L}{L - 2e_B}$$ — *FHWA Eqn. 4-20*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 — *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.c, AASHTO C3.4.1, and AASHTO C11.5.5)
V_1 = Total Vertical Force from the Reinforced Soil Mass = 41.280 kips
Ψ_{LS} = Load Factor for Surcharge = 1.75 — *AASHTO Table 3.4.1-1*
q = Live Load Traffic Surcharge = 0.390 ksf
L = Reinforcement Length = 16.00 ft
e_B = Eccentricity for Bearing = 2.45 ft — *FHWA Eqn. 4-19*

$$\sigma_{V-F} = \frac{(1.35)(41.28\ \text{kips ft}) + (1.75)(0.390\ \text{ksf})(16.00\ \text{ft})}{16.00\ \text{ft} - 2(2.45\ \text{ft})}$$

= 6.004 ksf

Check Bearing

q_R must be greater than or equal to q_{V-F}
10.785 ksf ≥ 6.004 ksf
OK

Calculated Resistance Factor

σ_{V-F}/q_n = **0.36**

Bearing Resistance (Local/Punching Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1.2b, and FHWA 4.4.6.c

Local and Punching shear failure occurs in loose or compressible soils and in weak soils under slow (drained) loading. This mode of failure will only be considered for foundation material that is cohesive.

The Foundation Material for this Project is not Cohesive.

Seismic Stablity - SCDOT GDM Section 14.12

Calculate Wave Scattering Effects

Wave Scattering Coefficient, α_w =1+0.01H((0.5β)-1<1.0 — SCDOT Equation 13-103

α_w = 0.8603

Ground Motion Index, $\beta = k_{max}/S_{d1}$ = 0.70 — SCDOT Equation 13-104

Average seismic horizontal coefficient due to wave scattering

$k_h = \alpha_w * k_{max}$ = 0.172 — SCDOT Equation 13-102

Calculate Seismic Active Earth Pressure Coefficinet (Mononobe -Kobe Method) SCDOT GDM Section 14.4.1

Seismic Active Earth Pressure Coefficient Reinforced Soils, K_{AEr} = 0.555

Seismic Active Earth Pressure Coefficient Retained, K_{AEb} = 0.712

$$K_{ae} = \frac{\cos^2(\phi - \Psi - \theta)}{\cos(\Psi)\cos^2(\theta)\cos(\delta + \theta + \Psi)\left[1 + \sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \Psi - \beta)}{\cos(\delta + \theta + \Psi)\cos(\beta - \theta)}}\right]^2} \quad \text{Equation 14-2}$$

Where,

γ	=	unit weight of soil
H	=	height of wall or effective height of wall (h_{eff})
ϕ	=	angle of internal friction of soil
Ψ	=	$\tan^{-1}[k_h/(1-k_v)]$
δ	=	angle of friction between soil and wall
k_h	=	horizontal acceleration coefficient
k_v	=	vertical acceleration coefficient, typically set to zero.
β	=	backfill slope angle
θ	=	angle of backface of the wall with the vertical

	Reinforced Soil		Retained Soil	
φ =	36.0	deg	26.0	deg
Ψ =	9.8	deg	9.8	deg
θ =	0	deg	0	deg
δ =	0	deg	0.00	deg
β =	0	deg	0	deg

Calculate Inertial Wall Width, $B_{inertial} = \omega H$ 15

coefficient, ω = 0.70

Calculate Active Earth Thrust Force, $P_{AE} = \gamma_p * 0.5 K_{AEr} * \gamma_p * H^2$ = 17.3 kips — GDM Eq. 14-40

Calculate Intertial Reinforced Soil Mass Force, $P_{IR} = \gamma_p * k_{avg} * B_{inertial} * H_{wall} *$ = 0.31 kips — GDM Eq. 14-41

Dead Load Surcharge Force, P_{DC} = = 2.143 kips — GDM Eq. 14-45

Live Load Surcharge Force, P_{LL} = = 1.913 kips — GDM Eq. 14-46

Total Seismic Driving Force, F_H = 21.6 kip

Calculated Resistance Factor, $\varphi = F_H/R_t$ = **0.85**

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EQ\text{-}P}F_{1s}(H/2) + \Psi_{EQ\text{-}LL}F_{2s}(H/2)}{\Psi_{EV}V_1 + \Psi_{EQ\text{-}LL}qL}$$ *FHWA Eqn. 4-19*

$\Psi_{EHAeq} = \Psi_{EQ\text{-}p}$ = Load Factor for Horizontal (Active) Earth Pressure = 1.00 *AASHTO Table 3.4.1-1*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

$\Psi_{LSeq} = \Psi_{EQ\text{-}p}$ = Load Factor for Surcharge = 1.00 *AASHTO Table 3.4.1-1*

F_{1s} = Force Generated from Lateral Earth Pressure = 19.732 kips *FHWA Eqn. 4-5*

F_{2s} = Force Generated from Traffic Surcharge = 1.913 kips *FHWA Eqn. 4-6*

V_1 = Total Vertical Force from the Reinforced Soil Mass = 41.280 kips

q = Live Load Traffic Surcharge = 0.250 ksf *FHWA Eqn. 4-19*

H = MSE Wall Height = 21.50 ft

L = Reinforcement Length = 16.00 ft

$$e_B = \frac{(\ 1.00\ )(\ 19.732 \text{ kips })(\ 10.75 \text{ ft }) + (\ 1.00\ )(\ 1.913 \text{ kips })(\ 10.75 \text{ ft })}{(\ 1.00\ )(\ 41.3 \text{ kips }) + (\ 1.00\ )(\ 0.250 \text{ ksf })(\ 16.00 \text{ ft })}$$

= 5.14 ft

Calculate Factored Vertical Bearing Pressure at the base, ($q_{V\text{-}F}$)

$$\sigma_{V\text{-}F} = \frac{\Psi_{EQ\text{-}P}V_1 + \Psi_{EQ\text{-}LS}qL}{L - 2e_B}$$ *FHWA Eqn. 4-20*

$\Psi_{EQ\text{-}p}$ = Load Factor for Dead Load of Earth Fill = 1.00

V_1 = Total Vertical Force from the Reinforced Soil Mass = 41.280 kips

$\Psi_{LSeq} = \Psi_{EQ\text{-}ll}$ = Load Factor for Surcharge = 1.00

q = Live Load Traffic Surcharge = 0.250 ksf

L = Reinforcement Length = 16.00 ft

e_B = Eccentricity for Bearing = 5.14 ft

$$\sigma_{V\text{-}F} = \frac{(\ 1.00\ )(\ 41.28 \text{ kips })(\text{ ft }) + (\ 1.00\ )(\ 0.250 \text{ ksf })(\ 16.00 \text{ ft })}{16.0 \text{ ft } - 2(\ 5.14 \text{ ft })}$$

= 8.308 ksf

Calculated Resistance Factor

$\sigma_{V\text{-}F}/q_n$ = **0.50**

TIP NO.: COUNTY:

LRFD External Stability Analysis for MSE Walls

Wall 33 - Ramp 2B

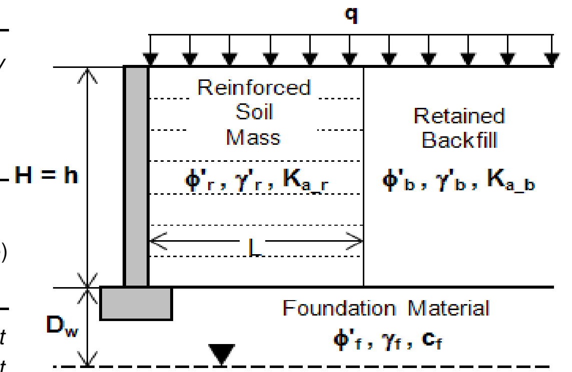
PREPARED BY: CLB DATE: 09/11/15 STATION: 44+00

CHECKED BY: DATE: STR. NO.: SHEET: 1 OF 8

Input Traffic Surcharge, Backslope, Wall Geometry, and Soil Parameters

Traffic and Overlay Surcharge Surcharge

q =	390	psf	*Live Load Traffic Surcharge and Pavement Overlay*
	35.9	% Surcharge due to overlay	
q_{ol} =	140	psf	*Pavement overlay surcharge*



Typical MSE Wall with Level Backslope and Traffic Surcharge

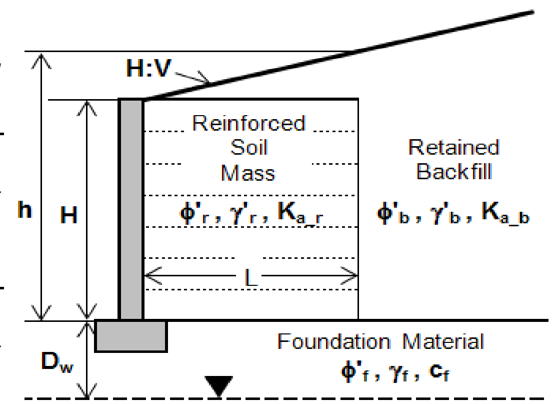
Backslope

Horizontal Backslope

(d = horizontal distance from back of wall face to top of backslope)

Wall Geometry

H =	58.00	ft	*Wall Height*
L/H =	0.85		*Ratio of Reinforcement Length to Wall Height*
			(L/H ≥ 0.7 per NCDOT MSE Wall Standard Provision)
L =	49.47	ft	*Reinforcement Length*
			(L ≥ 6 ft per NCDOT MSE Wall Standard Provision)
h =	58.00	ft	*Height of Wall & Slope at the back of Reinforced Zone*
D_w =	12.00	ft	*Distance of Water Table below the Bottom of the Wall*



Typical MSE Wall with Infinite Backslope

Soil Parameters for Reinforced Zone

ϕ'_r =	36	deg	*Effective Friction Angle*
γ'_r =	120	pcf	*Effective Unit Weight*
K_{a_r} =	0.260		*Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

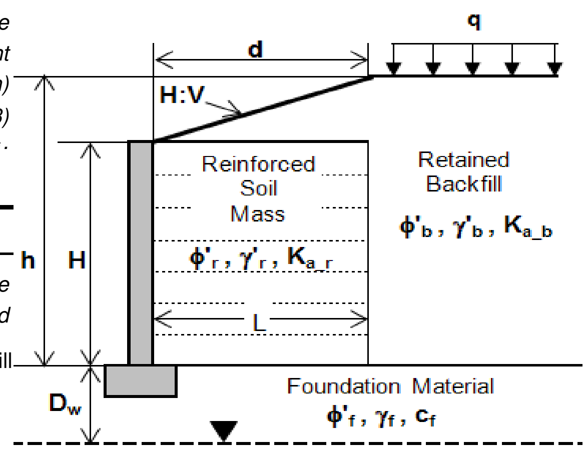
Soil Parameters for Retained Backfill

ϕ'_b =	28	deg	*Effective Friction Angle*
γ'_b =	117	pcf	*Effective Unit Weight*
K_{a_b} =	0.361		*Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

Soil Parameters for Foundation Soil

ϕ'_f =	32	deg	*Effective Friction Angle*
γ_f =	110	pcf	*Total Unit Weight*
c_f =	0	psf	*Undrained Shear Strength (Cohesion)*
μ =	0.62		*Coefficient of Friction (AASHTO 11.10.5.3)*

The coefficient of friction shall be based on the lesser of ϕ'_r and ϕ'_f.



Typical MSE Wall with Broken Backslope and Traffic Surcharge

Input Load and Resistance Factors

Load Factors (See AASHTO Table 3.4.1-1 and 2)

Ψ_{LS} =	1.75		*Lilve Load Surcharge*
$\Psi_{EH(A)}$ =	1.50		*Horizontal (Active) Earth Pressure Load*
Ψ_{EV} =	1.00	min	Vertical Dead Load Generated from Earth Fill
	1.35	max	
$\Psi_{EQ\text{-}p}$ =	1.00		
$\Psi_{EQ\text{-}LL}$ =	0.50		

Resistance Factors (See AASHTO Table 11.5.6-1)

φ_b =	0.65	*Bearing Resistance for MSE Walls*
φ_τ =	1.00	*Sliding Resistance for MSE Walls*

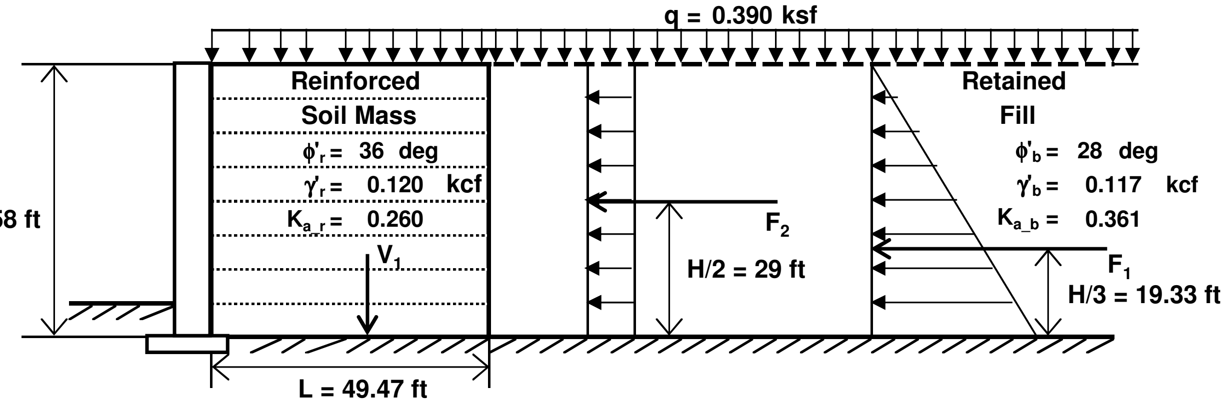
Seismic Design Acceleration Parameters

k_{max} =	0.20	*Maximum Horizontal Ground Acceleration (PGA)*
S_{d1}=	0.14	*Peak spectral acceleration at 1 second*

References:

1. *AASHTO LRFD Bridge Design Specifications, 5th Edition, 2010*
2. *FHWA-NHI-10-024 Design and Construction of MSE Walls and Reinforced Soil Slopes - Vol I, 2009*
3. *SCDOT Geotechnical Design Manual version 1.1, 2010*

Calculate Forces acting on Wall



External Stability for MSE Walls: Earth Pressure - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Forces from Vertical Earth Loads

V_1 = Total Vertical Force from the Reinforced Soil Mass = $(\gamma_r)(H)(L)$
= (0.120 kcf)(58.00 ft)(49.47 ft) = 344.311 kips

Forces from Lateral Earth Pressure

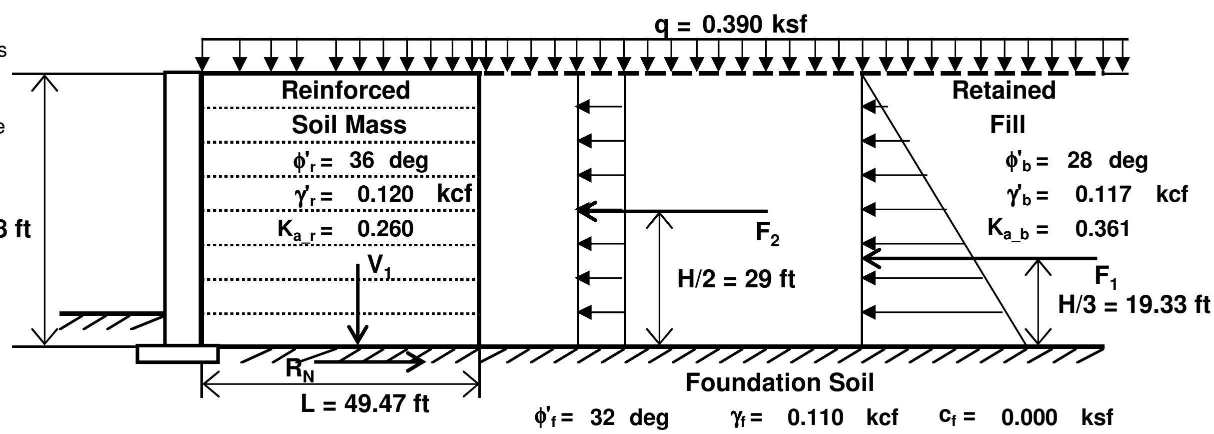
F_1 = Total Force Generated from Lateral Earth Pressure = $0.5(\gamma'_b)(H^2)(K_{ab})$ — FHWA Eqn. 4-5
= (0.5)(0.117 kcf)(58.00 ft $)^2$(0.361) = 71.043 kips

Horizontal Force from Traffic Surcharge

F_2 = Force Generated from Traffic Surcharge = $(q)(H)(K_{ab})$ — *FHWA Eqn. 4-6*
= (0.390 ksf)(58.00 ft) (0.361) = 8.166 kips

Sliding Stability - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

The passive resistance at the toe due to embedment is ignored due to the potential for soil to be removed through natural or manmade processes.
(per FHWA 4.4.6.a)



External Stability for MSE Walls: Sliding Stability - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Factored Sliding Resistance (R_R)

$R_R = \varphi R_N = \varphi_\tau R_\tau$ — *AASHTO Eqn. 10.6.3.4-1*

Sliding Stability Continued - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

φ_τ = *Resistance Factor for Sliding* = 1.00 — *AASHTO Table 11.5.6-1*

R_τ = *Nominal Sliding Resistance between Reinforced Soil Mass and Foundation Soil*

= $\Psi_{EV}(V_1)\mu + (c_f)(L)$ — *FHWA Eqn. 4-12 and AASHTO 10.6.3.4*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 — *AASHTO Table 3.4.1-1*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

V_1 = Total Vertical Force from the Reinforced Soil Mass = 344.311 kips

μ = Coefficent of Friction between Reinforced Soil Mass and Foundation Soil = 0.62 — *AASHTO 11.10.5.3*

c_f = Cohesion for Foundation Soil = 0.000 ksf

L = Reinforcement Length = 49.47 ft

R_τ = (1.00)(344.31 kips)(0.62) + (0.000 ksf)(49.47 ft) = 213.47 kips

R_R = (1.00)(213.47 kips) = 213.47 kips

Calculate Factored Horizontal Driving Force (P_d)

$P_d = (\Psi_{EHA})(F_1) + (\Psi_{LS})(F_2)$ — *FHWA Eqn. 4-9*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 — *AASHTO Table 3.4.1-1*

F_1 = Force Generated from Lateral Earth Pressure = 71.043 kips — *FHWA Eqn. 4-5*

Ψ_{LS} = Load Factor for Horizontal (Active) Earth Pressure = 1.75 — *AASHTO Table 3.4.1-1*

F_2 = Force Generated from Traffic Surcharge = 8.166 kips — *FHWA Eqn. 4-6*

P_d = (1.50)(71.043 kips) + (1.75)(8.166 kips) = 120.854 kips

Check Sliding

R_R must be greater than or equal to P_d

213.473 kips ≥ 120.854 kips

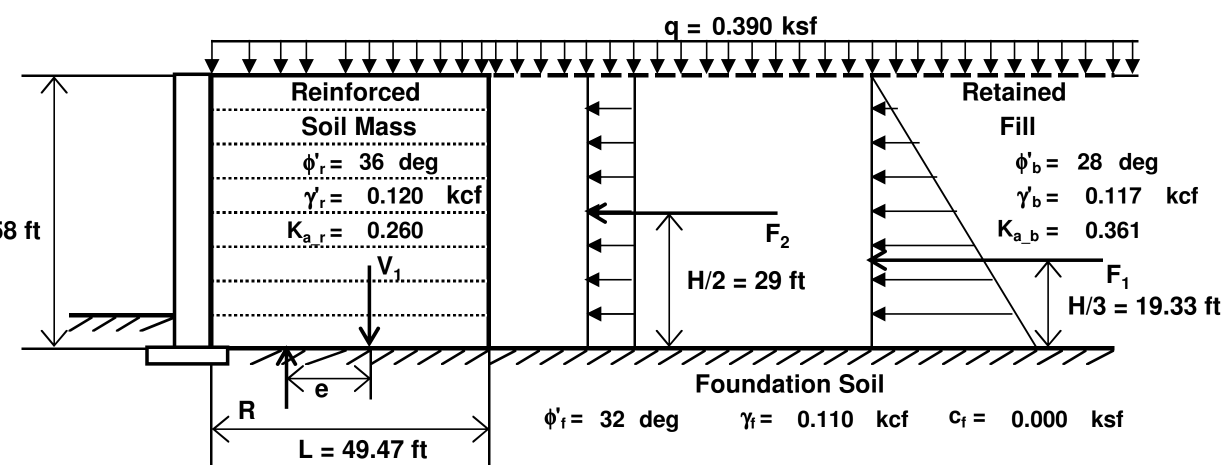
OK

Calculated Resistance Factor

$P_d/(Rr/\varphi_t)$ = **0.57**

Overturning (Limiting Eccentricity) - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Eccentricity (e) = the distance between the resultant foundation load (R) and the center of the reinforced zone



External Stability for MSE Walls: Overturning - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
Figure Not Drawn to Scale - All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity (e)

$$e = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1}$$ — *FHWA Eqn. 4-15*

Overturning (Limiting Eccentricity) Continued - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00
(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75
F_1 = Force Generated from Lateral Earth Pressure = 71.043 kips
F_2 = Force Generated from Traffic Surcharge = 8.166 kips
V_1 = Total Vertical Force from the Reinforced Soil Mass = 344.311 kips
H = MSE Wall Height = 58.00 ft

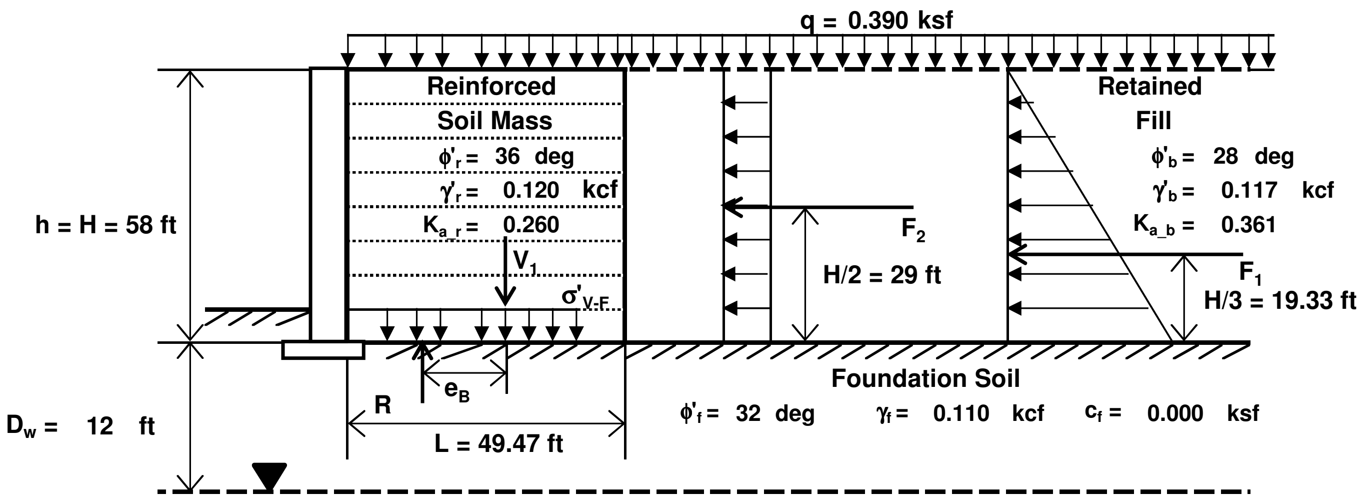
$$e = \frac{(1.50)(71.043\text{ kips})(19.33\text{ ft}) + (1.75)(8.166\text{ kips})(29.00\text{ ft})}{(1.00)(344.311\text{ kips})}$$

$= 7.19$ ft

Check Eccentricity

e must be less than or equal to L/4 per AASHTO 11.6.3.3
7.19 ft ≤ 12.37 ft
OK

Bearing Resistance (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c



External Stability for MSE Walls: Bearing Resistance - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1 + \Psi_{LS}qL}$$ *FHWA Eqn. 4-19*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 *AASHTO Table 3.4.1-1*
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75 *AASHTO Table 3.4.1-1*
F_1 = Force Generated from Lateral Earth Pressure = 71.043 kips *FHWA Eqn. 4-5*
F_2 = Force Generated from Traffic Surcharge = 8.166 kips *FHWA Eqn. 4-6*
V_1 = Total Vertical Force from the Reinforced Soil Mass = 344.311 kips

Bearing Resistance Continued (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c

q = Live Load Traffic Surcharge = 0.390 ksf
H = MSE Wall Height = 58.00 ft
L = Reinforcement Length = 49.47 ft

$$e_B = \frac{(1.50)(71.043\ \text{kips})(19.33\ \text{ft}) + (1.75)(8.166\ \text{kips})(29.00\ \text{ft})}{(1.35)(344.3\ \text{kips}) + (1.75)(0.390\ \text{ksf})(49.47\ \text{ft})}$$

= 4.96 ft

Calculate Nominal Bearing Resistance, (q_n) — *AASHTO Eqn. 10.6.3.1.2a-1*

$q_n = c_f N_c + 0.5\gamma B' N_\gamma C_{w\gamma}$ — *AASHTO Eqn. 10.6.3.1.2a-1*

c_f = Cohesion for Foundation Soil = 0.000 ksf
N_c = Bearing Capacity Factor (based on ϕ'_f) = 0.00 — *AASHTO Table 10.6.3.1.2a-1*
γ_f = Total Unit Weight for Foundation Soil = 0.110 kcf
B' = Effective Foundation Width = L - 2e_B — *AASHTO C11.10.5.4*
= 49.5 ft - 2(4.96 ft) = 39.55 ft
N_γ = Bearing Capacity Factor (based on ϕ'_f) = 15.00 — *AASHTO Table 10.6.3.1.2a-1*
$C_{w\gamma}$ = Correction Factor to Account for Location of Groundwater Table = 0.6 — *AASHTO Table 10.6.3.1.2a-2*

q_n = (0.000 ksf)(0.00) + (0.5)(0.110 kcf)(39.55 ft)(15.00)(0.60)

= 19.577 ksf

Calculate Factored Bearing Resistance, (q_r)

$q_r = \varphi_b q_n$ — *AASHTO Eqn. 10.6.3.1.1-1*

φ_b = Resistance Factor for Bearing = 0.65 — *AASHTO Table 11.5.6-1*
q_n = Nominal Bearing Resistance = 19.577 ksf — *AASHTO Eqn. 10.6.3.1.2a-1*

q_r = (0.65)(19.577 ksf) = 12.725 ksf

Calculate Factored Vertical Bearing Pressure at the base, (q_{V-F})

$$\sigma_{V-F} = \frac{\Psi_{EV}V_1 + \Psi_{LS}qL}{L - 2e_B}$$ — *FHWA Eqn. 4-20*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 — *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.c, AASHTO C3.4.1, and AASHTO C11.5.5)
V_1 = Total Vertical Force from the Reinforced Soil Mass = 344.311 kips
Ψ_{LS} = Load Factor for Surcharge = 1.75 — *AASHTO Table 3.4.1-1*
q = Live Load Traffic Surcharge = 0.390 ksf
L = Reinforcement Length = 49.47 ft
e_B = Eccentricity for Bearing = 4.96 ft — *FHWA Eqn. 4-19*

$$\sigma_{V-F} = \frac{(1.35)(344.31\ \text{kips ft}) + (1.75)(0.390\ \text{ksf})(49.47\ \text{ft})}{49.47\ \text{ft} - 2(4.96\ \text{ft})}$$

= 12.606 ksf

Check Bearing

q_R must be greater than or equal to q_{V-F}
12.725 ksf ≥ 12.606 ksf
OK

Calculated Resistance Factor

σ_{V-F}/q_n = **0.64**

Bearing Resistance (Local/Punching Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1.2b, and FHWA 4.4.6.c

Local and Punching shear failure occurs in loose or compressible soils and in weak soils under slow (drained) loading. This mode of failure will only be considered for foundation material that is cohesive.

The Foundation Material for this Project is not Cohesive.

Seismic Stablity - SCDOT GDM Section 14.12

Calculate Wave Scattering Effects

Wave Scattering Coefficient, α_w =1+0.01H((0.5β)-1<1.0 — SCDOT Equation 13-103

α_w = 0.623

Ground Motion Index, $\beta = k_{max}/S_{d1}$ = 0.70 — SCDOT Equation 13-104

Average seismic horizontal coefficient due to wave scattering

$k_h = \alpha_w * k_{max}$ = 0.125 — SCDOT Equation 13-102

Calculate Seismic Active Earth Pressure Coefficicinet (Mononobe -Kobe Method) SCDOT GDM Section 14.4.1

Seismic Active Earth Pressure Coefficient Reinforced Soils, K_{AEr} = 0.511

Seismic Active Earth Pressure Coefficient Retained, K_{AEb} = 0.633

$$K_{ae} = \frac{\cos^2(\phi-\Psi-\theta)}{\cos(\Psi)\cos^2(\theta)\cos(\delta+\theta+\Psi)\left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\Psi-\beta)}{\cos(\delta+\theta+\Psi)\cos(\beta-\theta)}}\right]^2} \quad \text{Equation 14-2}$$

Where,

γ	=	unit weight of soil
H	=	height of wall or effective height of wall (h_{eff})
ϕ	=	angle of internal friction of soil
Ψ	=	$\tan^{-1}[k_h/(1-k_v)]$
δ	=	angle of friction between soil and wall
k_h	=	horizontal acceleration coefficient
k_v	=	vertical acceleration coefficient, typically set to zero.
β	=	backfill slope angle
θ	=	angle of backface of the wall with the vertical

	Reinforced Soil	Retained Soil
φ =	36.0 deg	28.0 deg
Ψ =	7.1 deg	7.1 deg
θ =	0 deg	0 deg
δ =	0 deg	0.00 deg
β =	0 deg	0 deg

Calculate Inertial Wall Width, $B_{inertial} = \omega H$ 41

coefficient, ω = 0.70

Calculate Active Earth Thrust Force, $P_{AE} = \gamma_p * 0.5 K_{AEr} * \gamma_p * H^2$ = 124.6 kips — GDM Eq. 14-40

Calculate Intertial Reinforced Soil Mass Force, $P_{IR} = \gamma_p * k_{avg} * B_{inertial} * H_{wall} *$ = 0.61 kips — GDM Eq. 14-41

Dead Load Surcharge Force, P_{DC} = = 5.141 kips — GDM Eq. 14-45

Live Load Surcharge Force, P_{LL} = = 4.59 kips — GDM Eq. 14-46

Total Seismic Driving Force, F_H = #### kip

Calculated Resistance Factor, $\varphi = F_H/R_t$ = **0.63**

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EQ\text{-}P}F_{1s}(H/2) + \Psi_{EQ\text{-}LL}F_{2s}(H/2)}{\Psi_{EV}V_1 + \Psi_{EQ\text{-}LL}qL}$$ *FHWA Eqn. 4-19*

Ψ_{EHAeq} = $\Psi_{EQ\text{-}p}$ = Load Factor for Horizontal (Active) Earth Pressure = 1.00 *AASHTO Table 3.4.1-1*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

Ψ_{LSeq} = $\Psi_{EQ\text{-}p}$ = Load Factor for Surcharge = 1.00 *AASHTO Table 3.4.1-1*

F_{1s} = Force Generated from Lateral Earth Pressure = 130.338 kips *FHWA Eqn. 4-5*

F_{2s} = Force Generated from Traffic Surcharge = 4.590 kips *FHWA Eqn. 4-6*

V_1 = Total Vertical Force from the Reinforced Soil Mass = 344.311 kips

q = Live Load Traffic Surcharge = 0.250 ksf *FHWA Eqn. 4-19*

H = MSE Wall Height = 58.00 ft

L = Reinforcement Length = 49.47 ft

$$e_B = \frac{(\ 1.00\ )(\ 130.338 \text{ kips})(\ 29.00 \text{ ft}) + (\ 1.00\ )(\ 4.590 \text{ kips})(\ 29.00 \text{ ft})}{(\ 1.00\ )(\ 344.3 \text{ kips}) + (\ 1.00\ )(\ 0.250 \text{ ksf})(\ 49.47 \text{ ft})}$$

= 10.97 ft

Calculate Factored Vertical Bearing Pressure at the base, ($q_{V\text{-}F}$)

$$\sigma_{V\text{-}F} = \frac{\Psi_{EQ\text{-}P}V_1 + \Psi_{EQ\text{-}LS}qL}{L - 2e_B}$$ *FHWA Eqn. 4-20*

$\Psi_{EQ\text{-}p}$ = Load Factor for Dead Load of Earth Fill = 1.00

V_1 = Total Vertical Force from the Reinforced Soil Mass = 344.311 kips

Ψ_{LSeq} = $\Psi_{EQ\text{-}ll}$ = Load Factor for Surcharge = 1.00

q = Live Load Traffic Surcharge = 0.250 ksf

L = Reinforcement Length = 49.47 ft

e_B = Eccentricity for Bearing = 10.97 ft

$$\sigma_{V\text{-}F} = \frac{(\ 1.00\ )(\ 344.31 \text{ kips})(\text{ ft}) + (\ 1.00\ )(\ 0.250 \text{ ksf})(\ 49.47 \text{ ft})}{49.5 \text{ ft} - 2(\ 10.97 \text{ ft})}$$

= 13.208 ksf

Calculated Resistance Factor

$\sigma_{V\text{-}F}/q_n$ = **0.67**

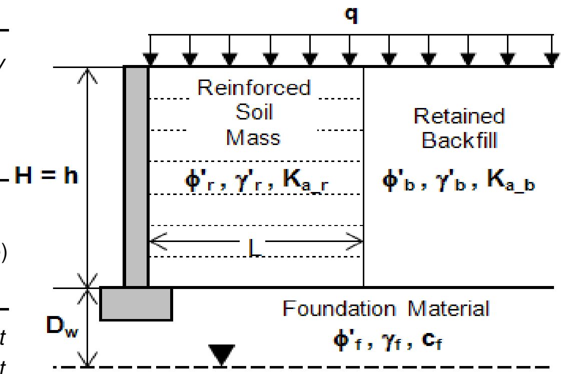
Input Traffic Surcharge, Backslope, Wall Geometry, and Soil Parameters

Traffic and Overlay Surcharge Surcharge

q = 390 psf *Live Load Traffic Surcharge and Pavement Overlay*

35.9 % Surcharge due to overlay

q_{ol} = 140 psf *Pavement overlay surcharge*



Typical MSE Wall with Level Backslope and Traffic Surcharge

Backslope

Horizontal Backslope

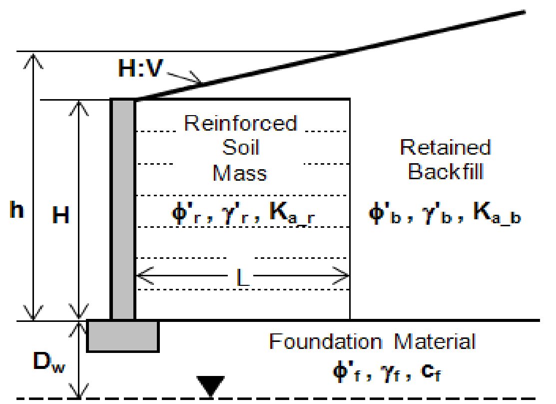
(d = horizontal distance from back of wall face to top of backslope)

Wall Geometry

H =	27.00	ft	*Wall Height*
L/H =	0.78		*Ratio of Reinforcement Length to Wall Height*
			(L/H ≥ 0.7 per NCDOT MSE Wall Standard Provision)
L =	20.98	ft	*Reinforcement Length*
			(L ≥ 6 ft per NCDOT MSE Wall Standard Provision)
h =	27.00	ft	*Height of Wall & Slope at the back of Reinforced Zone*
D_w =	40.00	ft	*Distance of Water Table below the Bottom of the Wall*

Soil Parameters for Reinforced Zone

ϕ'_r =	36	deg	*Effective Friction Angle*
γ'_r =	120	pcf	*Effective Unit Weight*
K_{a_r} =	0.260		*Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*



Typical MSE Wall with Infinite Backslope

Soil Parameters for Retained Backfill

ϕ'_b =	30	deg	*Effective Friction Angle*
γ'_b =	110	pcf	*Effective Unit Weight*
K_{a_b} =	0.333		*Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

Soil Parameters for Foundation Soil

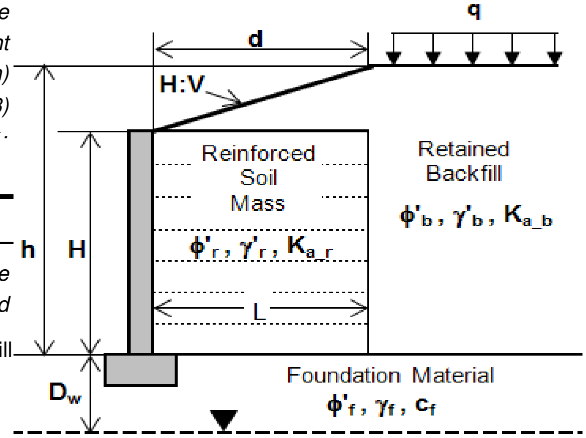
ϕ'_f =	26	deg	*Effective Friction Angle*
γ_f =	105	pcf	*Total Unit Weight*
c_f =	0	psf	*Undrained Shear Strength (Cohesion)*
μ =	0.49		*Coefficient of Friction (AASHTO 11.10.5.3)*

The coefficient of friction shall be based on the lesser of ϕ'_r and ϕ'_f.

Input Load and Resistance Factors

Load Factors (See AASHTO Table 3.4.1-1 and 2)

Ψ_{LS} =	1.75		*Lilve Load Surcharge*
$\Psi_{EH(A)}$ =	1.50		*Horizontal (Active) Earth Pressure Load*
Ψ_{EV} =	1.00	min	Vertical Dead Load Generated from Earth Fill
	1.35	max	
$\Psi_{EQ\text{-}p}$ =	1.00		
$\Psi_{EQ\text{-}LL}$ =	0.50		



Typical MSE Wall with Broken Backslope and Traffic Surcharge

Resistance Factors (See AASHTO Table 11.5.6-1)

φ_b =	0.65	*Bearing Resistance for MSE Walls*
φ_τ =	1.00	*Sliding Resistance for MSE Walls*

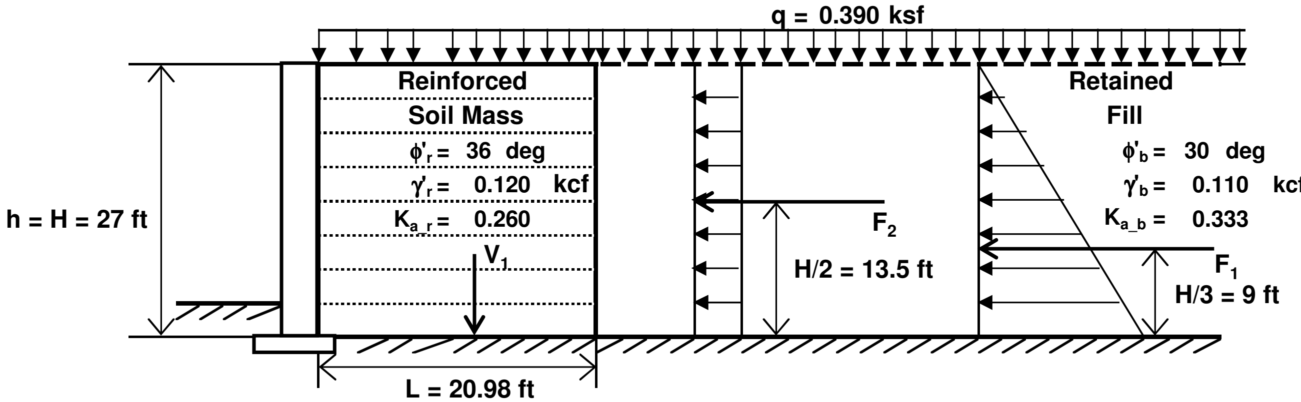
Seismic Design Acceleration Parameters

k_{max} =	0.20	*Maximum Horizontal Ground Acceleration (PGA)*
S_{d1}=	0.14	*Peak spectral acceleration at 1 second*

References:

1. *AASHTO LRFD Bridge Design Specifications, 5th Edition, 2010*
2. *FHWA-NHI-10-024 Design and Construction of MSE Walls and Reinforced Soil Slopes - Vol I, 2009*
3. *SCDOT Geotechnical Design Manual version 1.1, 2010*

Calculate Forces acting on Wall



External Stability for MSE Walls: Earth Pressure - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Forces from Vertical Earth Loads

V_1 = Total Vertical Force from the Reinforced Soil Mass = $(\gamma_r)(H)(L)$
= (0.120 kcf)(27.00 ft)(20.98 ft) = 67.975 kips

Forces from Lateral Earth Pressure

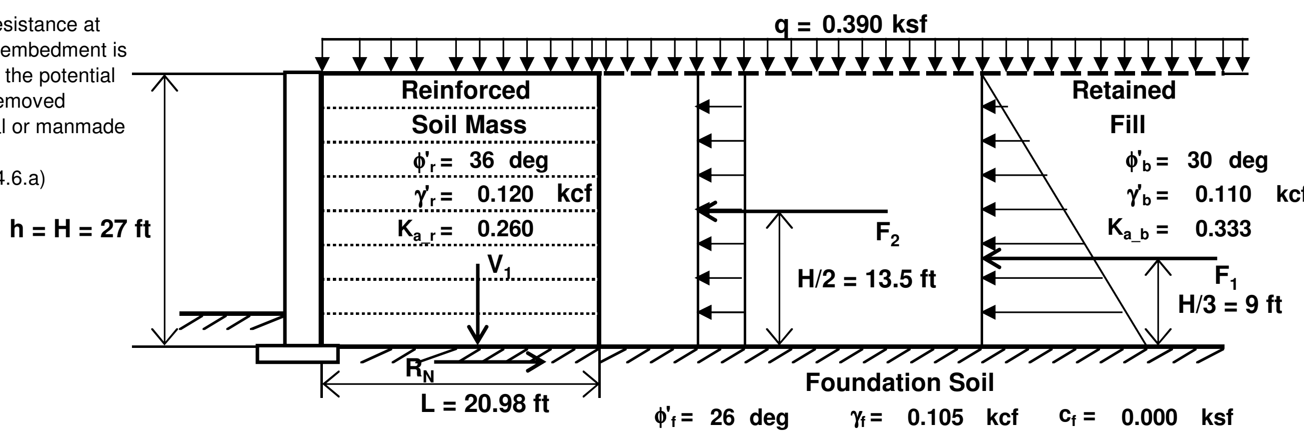
F_1 = Total Force Generated from Lateral Earth Pressure = $0.5(\gamma'_b)(H^2)(K_{ab})$ — FHWA Eqn. 4-5
= (0.5)(0.110 kcf)(27.00 ft)^2(0.333) = 13.352 kips

Horizontal Force from Traffic Surcharge

F_2 = Force Generated from Traffic Surcharge = $(q)(H)(K_{ab})$ — *FHWA Eqn. 4-6*
= (0.390 ksf)(27.00 ft)(0.333) = 3.506 kips

Sliding Stability - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

The passive resistance at the toe due to embedment is ignored due to the potential for soil to be removed through natural or manmade processes.
(per FHWA 4.4.6.a)



External Stability for MSE Walls: Sliding Stability - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Factored Sliding Resistance (R_R)

$R_R = \varphi R_N = \varphi_\tau R_\tau$ — *AASHTO Eqn. 10.6.3.4-1*

Sliding Stability Continued - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

φ_τ = *Resistance Factor for Sliding =* 1.00 — *AASHTO Table 11.5.6-1*

R_τ = *Nominal Sliding Resistance between Reinforced Soil Mass and Foundation Soil*

= $\Psi_{EV}(V_1)\mu + (c_f)(L)$ — *FHWA Eqn. 4-12 and AASHTO 10.6.3.4*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 — *AASHTO Table 3.4.1-1*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

V_1 = Total Vertical Force from the Reinforced Soil Mass = 67.975 kips

μ = Coefficent of Friction between Reinforced Soil Mass and Foundation Soil = 0.49 — *AASHTO 11.10.5.3*

c_f = Cohesion for Foundation Soil = 0.000 ksf

L = Reinforcement Length = 20.98 ft

R_τ = (1.00)(67.98 kips)(0.49) + (0.000 ksf)(20.98 ft) = 33.31 kips

R_R = (1.00)(33.31 kips) = 33.31 kips

Calculate Factored Horizontal Driving Force (P_d)

$P_d = (\Psi_{EHA})(F_1) + (\Psi_{LS})(F_2)$ — *FHWA Eqn. 4-9*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 — *AASHTO Table 3.4.1-1*

F_1 = Force Generated from Lateral Earth Pressure = 13.352 kips — *FHWA Eqn. 4-5*

Ψ_{LS} = Load Factor for Horizontal (Active) Earth Pressure = 1.75 — *AASHTO Table 3.4.1-1*

F_2 = Force Generated from Traffic Surcharge = 3.506 kips — *FHWA Eqn. 4-6*

P_d = (1.50)(13.352 kips) + (1.75)(3.506 kips) = 26.164 kips

Check Sliding

R_R must be greater than or equal to P_d

33.308 kips ≥ 26.164 kips

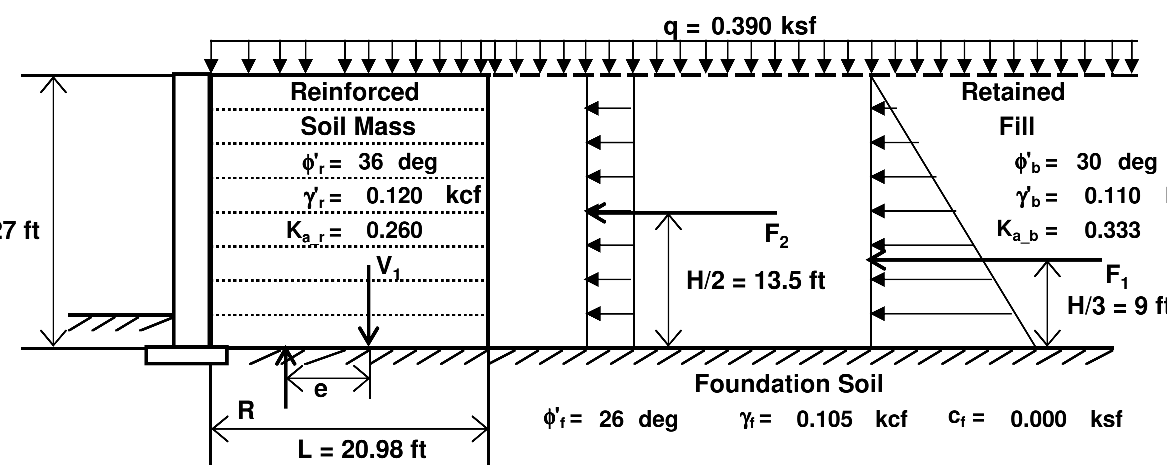
OK

Calculated Resistance Factor

$P_d/(Rr/\varphi_t)$ = **0.79**

Overturning (Limiting Eccentricity) - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Eccentricity (e) = the distance between the resultant foundation load (R) and the center of the reinforced zone



External Stability for MSE Walls: Overturning - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
Figure Not Drawn to Scale - All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity (e)

$$e = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1}$$ — *FHWA Eqn. 4-15*

Overturning (Limiting Eccentricity) Continued - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00
(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75
F_1 = Force Generated from Lateral Earth Pressure = 13.352 kips
F_2 = Force Generated from Traffic Surcharge = 3.506 kips
V_1 = Total Vertical Force from the Reinforced Soil Mass = 67.975 kips
H = MSE Wall Height = 27.00 ft

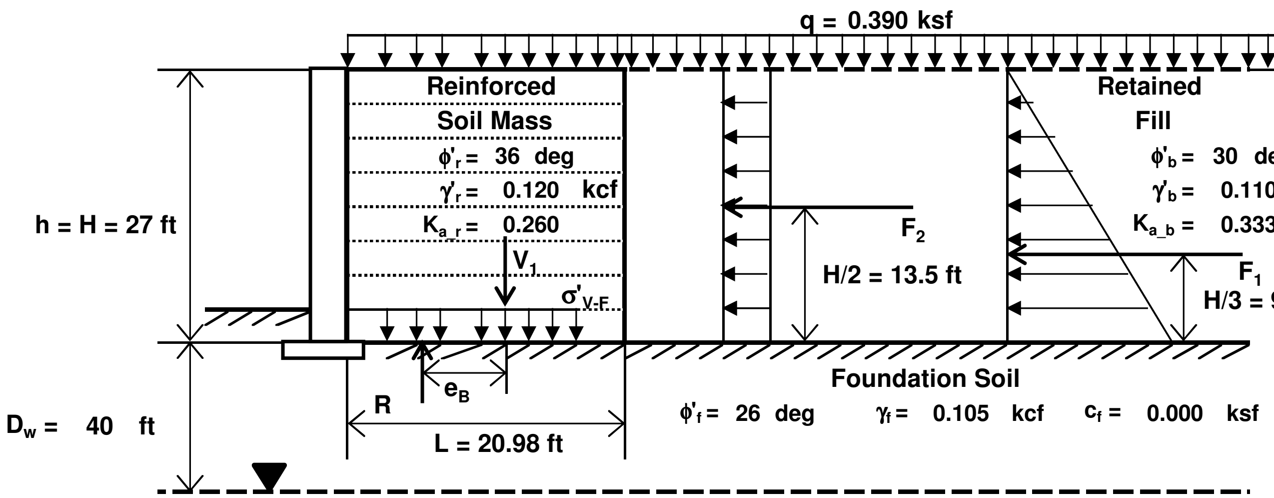
$$e = \frac{(1.50)(13.352\text{ kips})(9.00\text{ ft}) + (1.75)(3.506\text{ kips})(13.50\text{ ft})}{(1.00)(67.975\text{ kips})}$$

= 3.87 ft

Check Eccentricity

e must be less than or equal to L/4 per AASHTO 11.6.3.3
3.87 ft ≤ 5.25 ft
OK

Bearing Resistance (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c



External Stability for MSE Walls: Bearing Resistance - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1 + \Psi_{LS}qL}$$ *FHWA Eqn. 4-19*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 *AASHTO Table 3.4.1-1*
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75 *AASHTO Table 3.4.1-1*
F_1 = Force Generated from Lateral Earth Pressure = 13.352 kips *FHWA Eqn. 4-5*
F_2 = Force Generated from Traffic Surcharge = 3.506 kips *FHWA Eqn. 4-6*
V_1 = Total Vertical Force from the Reinforced Soil Mass = 67.975 kips

Bearing Resistance Continued (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c

q = Live Load Traffic Surcharge = 0.390 ksf
H = MSE Wall Height = 27.00 ft
L = Reinforcement Length = 20.98 ft

$$e_B = \frac{(1.50)(13.352 \text{ kips})(9.00 \text{ ft}) + (1.75)(3.506 \text{ kips})(13.50 \text{ ft})}{(1.35)(68.0 \text{ kips}) + (1.75)(0.390 \text{ ksf})(20.98 \text{ ft})}$$

= 2.48 ft

Calculate Nominal Bearing Resistance, (q_n) — *AASHTO Eqn. 10.6.3.1.2a-1*

$q_n = c_f N_c + 0.5\gamma B' N_\gamma C_{w\gamma}$ — *AASHTO Eqn. 10.6.3.1.2a-1*

c_f = Cohesion for Foundation Soil = 0.000 ksf
N_c = Bearing Capacity Factor (based on ϕ'_f) = 22.30 — *AASHTO Table 10.6.3.1.2a-1*
γ_f = Total Unit Weight for Foundation Soil = 0.105 kcf
B' = Effective Foundation Width = L - $2e_B$ — *AASHTO C11.10.5.4*
= 21.0 ft - 2(2.48 ft) = 16.02 ft
N_γ = Bearing Capacity Factor (based on ϕ'_f) = 12.50 — *AASHTO Table 10.6.3.1.2a-1*
$C_{w\gamma}$ = Correction Factor to Account for Location of Groundwater Table = 1.0 — *AASHTO Table 10.6.3.1.2a-2*

q_n = (0.000 ksf)(22.30) + (0.5)(0.105 kcf)(16.02 ft)(12.50)(1.00)

= 10.513 ksf

Calculate Factored Bearing Resistance, (q_r)

$q_r = \varphi_b q_n$ — *AASHTO Eqn. 10.6.3.1.1-1*

φ_b = Resistance Factor for Bearing = 0.65 — *AASHTO Table 11.5.6-1*
q_n = Nominal Bearing Resistance = 10.513 ksf — *AASHTO Eqn. 10.6.3.1.2a-1*

q_r = (0.65)(10.513 ksf) = 6.833 ksf

Calculate Factored Vertical Bearing Pressure at the base, (q_{V-F})

$$\sigma_{V-F} = \frac{\Psi_{EV} V_1 + \Psi_{LS} qL}{L - 2e_B}$$ — *FHWA Eqn. 4-20*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 — *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.c, AASHTO C3.4.1, and AASHTO C11.5.5)
V_1 = Total Vertical Force from the Reinforced Soil Mass = 67.975 kips
Ψ_{LS} = Load Factor for Surcharge = 1.75 — *AASHTO Table 3.4.1-1*
q = Live Load Traffic Surcharge = 0.390 ksf
L = Reinforcement Length = 20.98 ft
e_B = Eccentricity for Bearing = 2.48 ft — *FHWA Eqn. 4-19*

$$\sigma_{V-F} = \frac{(1.35)(67.98 \text{ kips ft}) + (1.75)(0.390 \text{ ksf})(20.98 \text{ ft})}{20.98 \text{ ft} - 2(2.48 \text{ ft})}$$

= 6.622 ksf

Check Bearing

q_R must be greater than or equal to q_{V-F}
6.833 ksf ≥ 6.622 ksf
OK

Calculated Resistance Factor

σ_{V-F}/q_n = **0.63**

Bearing Resistance (Local/Punching Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1.2b, and FHWA 4.4.6.c

Local and Punching shear failure occurs in loose or compressible soils and in weak soils under slow (drained) loading. This mode of failure will only be considered for foundation material that is cohesive.

The Foundation Material for this Project is not Cohesive.

Seismic Stablity - SCDOT GDM Section 14.12

Calculate Wave Scattering Effects

Wave Scattering Coefficient, α_w =1+0.01H((0.5β)-1<1.0 — SCDOT Equation 13-103

α_w = 0.8245

Ground Motion Index, $\beta = k_{max}/S_{d1}$ = 0.70 — SCDOT Equation 13-104

Average seismic horizontal coefficient due to wave scattering

$k_h = \alpha_w * k_{max}$ = 0.165 — SCDOT Equation 13-102

Calculate Seismic Active Earth Pressure Coefficicnet (Mononobe -Kobe Method) SCDOT GDM Section 14.4.1

Seismic Active Earth Pressure Coefficient Reinforced Soils, K_{AEr} = 0.548

Seismic Active Earth Pressure Coefficient Retained, K_{AEb} = 0.641

$$K_{ae} = \frac{\cos^2(\phi - \Psi - \theta)}{\cos(\Psi)\cos^2(\theta)\cos(\delta + \theta + \Psi)\left[1 + \sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \Psi - \beta)}{\cos(\delta + \theta + \Psi)\cos(\beta - \theta)}}\right]^2} \quad \text{Equation 14-2}$$

Where,

- γ = unit weight of soil
- H = height of wall or effective height of wall (h_{eff})
- ϕ = angle of internal friction of soil
- Ψ = $\tan^{-1}[k_h/(1-k_v)]$
- δ = angle of friction between soil and wall
- k_h = horizontal acceleration coefficient
- k_v = vertical acceleration coefficient, typically set to zero.
- β = backfill slope angle
- θ = angle of backface of the wall with the vertical

Reinforced Soil			Retained Soil		
φ =	36.0	deg	φ =	30.0	deg
Ψ =	9.4	deg	Ψ =	9.4	deg
θ =	0	deg	θ =	0	deg
δ =	0	deg	δ =	0.00	deg
β =	0	deg	β =	0	deg

Calculate Inertial Wall Width, $B_{inertial} = \omega H$ 19

coefficient, ω = 0.70

Calculate Active Earth Thrust Force, $P_{AE} = \gamma_p * 0.5 K_{AEr} * \gamma_p * H^2$ = 25.7 kips — GDM Eq. 14-40

Calculate Intertial Reinforced Soil Mass Force, $P_{IR} = \gamma_p * k_{avg} * B_{inertial} * H_{wall} *$ = 0.37 kips — GDM Eq. 14-41

Dead Load Surcharge Force, P_{DC} = = 2.423 kips — GDM Eq. 14-45

Live Load Surcharge Force, P_{LL} = = 2.163 kips — GDM Eq. 14-46

Total Seismic Driving Force, F_H = 30.7 kip

Calculated Resistance Factor, $\varphi = F_H/R_t$ = **0.92**

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EQ\text{-}P}F_{1s}(H/2) + \Psi_{EQ\text{-}LL}F_{2s}(H/2)}{\Psi_{EV}V_1 + \Psi_{EQ\text{-}LL}qL}$$ *FHWA Eqn. 4-19*

Ψ_{EHAeq} = $\Psi_{EQ\text{-}p}$ = Load Factor for Horizontal (Active) Earth Pressure = 1.00 — *AASHTO Table 3.4.1-1*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 — *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

Ψ_{LSeq} = $\Psi_{EQ\text{-}p}$ = Load Factor for Surcharge = 1.00 — *AASHTO Table 3.4.1-1*

F_{1s} = Force Generated from Lateral Earth Pressure = 28.494 kips — *FHWA Eqn. 4-5*

F_{2s} = Force Generated from Traffic Surcharge = 2.163 kips — *FHWA Eqn. 4-6*

V_1 = Total Vertical Force from the Reinforced Soil Mass = 67.975 kips

q = Live Load Traffic Surcharge = 0.250 ksf — *FHWA Eqn. 4-19*

H = MSE Wall Height = 27.00 ft

L = Reinforcement Length = 20.98 ft

$$e_B = \frac{(1.00)(28.494\text{ kips})(13.50\text{ ft}) + (1.00)(2.163\text{ kips})(13.50\text{ ft})}{(1.00)(68.0\text{ kips}) + (1.00)(0.250\text{ ksf})(20.98\text{ ft})}$$

= 5.65 ft

Calculate Factored Vertical Bearing Pressure at the base, ($q_{V\text{-}F}$)

$$\sigma_{V\text{-}F} = \frac{\Psi_{EQ\text{-}P}V_1 + \Psi_{EQ\text{-}LS}qL}{L - 2e_B}$$ *FHWA Eqn. 4-20*

$\Psi_{EQ\text{-}p}$ = Load Factor for Dead Load of Earth Fill = 1.00

V_1 = Total Vertical Force from the Reinforced Soil Mass = 67.975 kips

Ψ_{LSeq} = $\Psi_{EQ\text{-}ll}$ = Load Factor for Surcharge = 1.00

q = Live Load Traffic Surcharge = 0.250 ksf

L = Reinforcement Length = 20.98 ft

e_B = Eccentricity for Bearing = 5.65 ft

$$\sigma_{V\text{-}F} = \frac{(1.00)(67.98\text{ kips})(\text{ ft}) + (1.00)(0.250\text{ ksf})(20.98\text{ ft})}{21.0\text{ ft} - 2(5.65\text{ ft})}$$

= 7.868 ksf

Calculated Resistance Factor

$\sigma_{V\text{-}F}/q_n$ = **0.75**

Input Traffic Surcharge, Backslope, Wall Geometry, and Soil Parameters

Traffic and Overlay Surcharge Surcharge

q = 390 psf *Live Load Traffic Surcharge and Pavement Overlay*
35.9 % Surcharge due to overlay
q_{ol} = 140 psf *Pavement overlay surcharge*

Backslope

Horizontal Backslope

(d = horizontal distance from back of wall face to top of backslope)

Wall Geometry

H = 56.00 ft *Wall Height*
L/H = 0.88 *Ratio of Reinforcement Length to Wall Height*
(L/H ≥ 0.7 per NCDOT MSE Wall Standard Provision)
L = 49.00 ft *Reinforcement Length*
(L ≥ 6 ft per NCDOT MSE Wall Standard Provision)
h = 56.00 ft *Height of Wall & Slope at the back of Reinforced Zone*

D_w = 0.00 ft *Distance of Water Table below the Bottom of the Wall*

Soil Parameters for Reinforced Zone

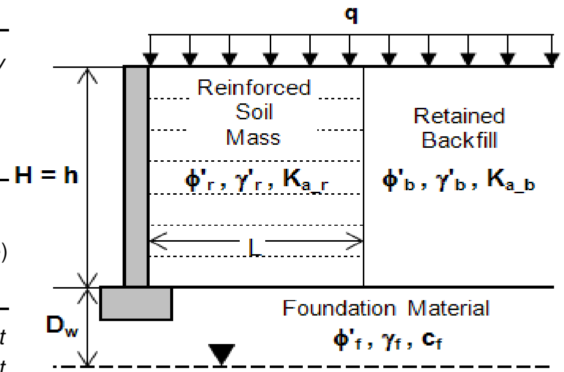
ϕ'_r = 36 deg *Effective Friction Angle*
γ'_r = 120 pcf *Effective Unit Weight*
K_{a_r} = 0.260 *Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

Soil Parameters for Retained Backfill

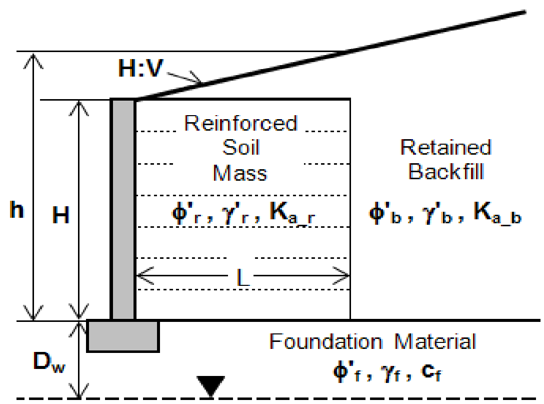
ϕ'_b = 28 deg *Effective Friction Angle*
γ'_b = 117 pcf *Effective Unit Weight*
K_{a_b} = 0.361 *Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

Soil Parameters for Foundation Soil

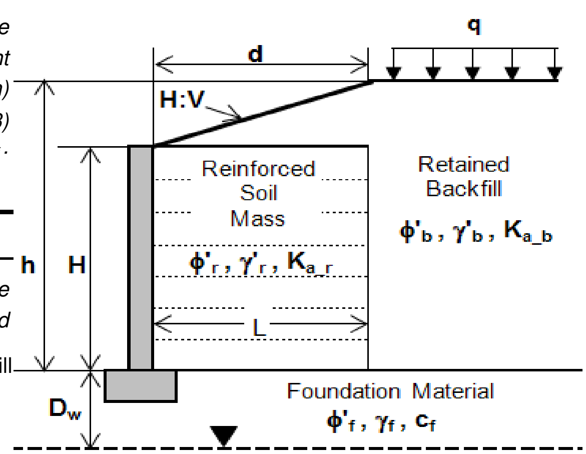
ϕ'_f = 30 deg *Effective Friction Angle*
γ_f = 120 pcf *Total Unit Weight*
c_f = 0 psf *Undrained Shear Strength (Cohesion)*
μ = 0.58 *Coefficient of Friction (AASHTO 11.10.5.3)*
The coefficient of friction shall be based on the lesser of ϕ'_r and ϕ'_f.



Typical MSE Wall with Level Backslope and Traffic Surcharge



Typical MSE Wall with Infinite Backslope



Typical MSE Wall with Broken Backslope and Traffic Surcharge

Input Load and Resistance Factors

Load Factors (See AASHTO Table 3.4.1-1 and 2)

Ψ_{LS} = 1.75 *Lilve Load Surcharge*
$\Psi_{EH(A)}$ = 1.50 *Horizontal (Active) Earth Pressure Load*
Ψ_{EV} = 1.00 min, 1.35 max Vertical Dead Load Generated from Earth Fill
$\Psi_{EQ\text{-}p}$ = 1.00
$\Psi_{EQ\text{-}LL}$ = 0.50

Resistance Factors (See AASHTO Table 11.5.6-1)

φ_b = 0.65 *Bearing Resistance for MSE Walls*
φ_τ = 1.00 *Sliding Resistance for MSE Walls*

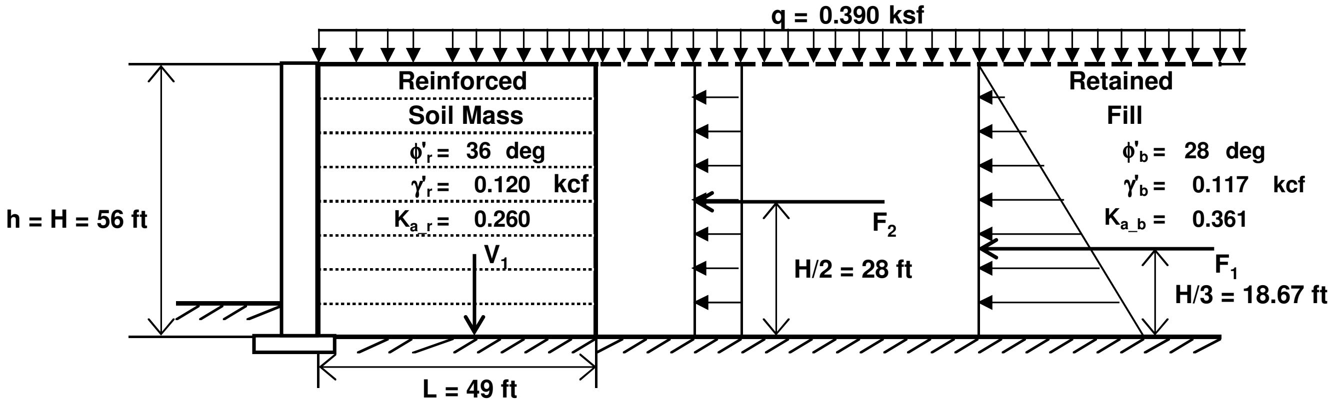
Seismic Design Acceleration Parameters

k_{max} = 0.20 *Maximum Horizontal Ground Acceration (PGA)*
S_{d1}= 0.14 *Peak spectral acceleration at 1 second*

References:

1. *AASHTO LRFD Bridge Design Specifications, 5th Edition, 2010*
2. *FHWA-NHI-10-024 Design and Construction of MSE Walls and Reinforced Soil Slopes - Vol I, 2009*
3. *SCDOT Geotechnical Design Manual version 1.1, 2010*

Calculate Forces acting on Wall



External Stability for MSE Walls: Earth Pressure - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Forces from Vertical Earth Loads

V_1 = Total Vertical Force from the Reinforced Soil Mass = $(\gamma_r)(H)(L)$
= (0.120 kcf)(56.00 ft)(49.00 ft) = 329.280 kips

Forces from Lateral Earth Pressure

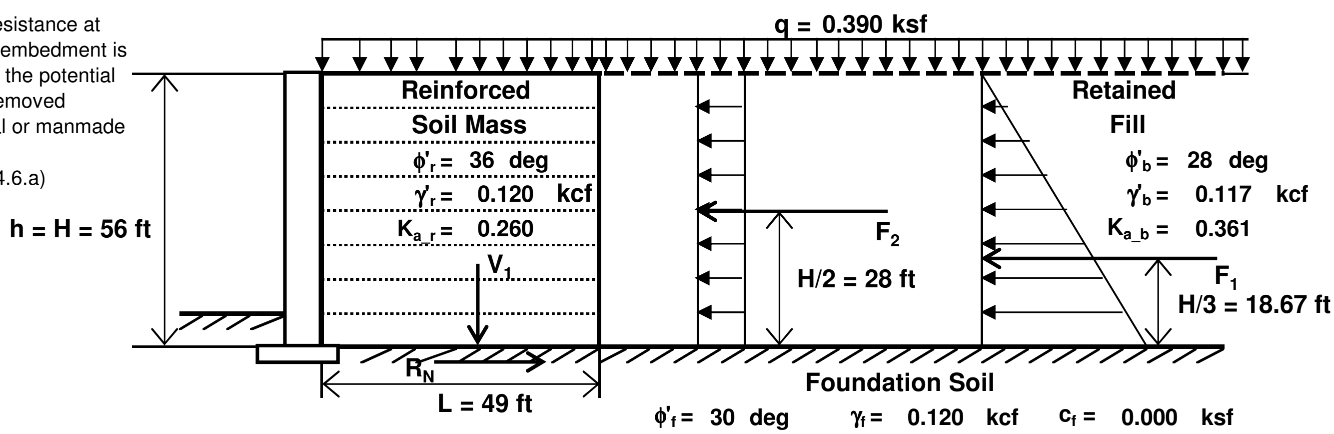
F_1 = Total Force Generated from Lateral Earth Pressure = $0.5(\gamma_b)(H^2)(K_{ab})$ FHWA Eqn. 4-5
= (0.5)(0.117 kcf)(56.00 ft)^2(0.361) = 66.228 kips

Horizontal Force from Traffic Surcharge

F_2 = Force Generated from Traffic Surcharge = $(q)(H)(K_{ab})$ *FHWA Eqn. 4-6*
= (0.390 ksf)(56.00 ft) (0.361) = 7.884 kips

Sliding Stability - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

The passive resistance at the toe due to embedment is ignored due to the potential for soil to be removed through natural or manmade processes.
(per FHWA 4.4.6.a)



External Stability for MSE Walls: Sliding Stability - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Factored Sliding Resistance (R_R)

$R_R = \varphi R_N = \varphi_\tau R_\tau$ *AASHTO Eqn. 10.6.3.4-1*

Sliding Stability Continued - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

φ_τ = *Resistance Factor for Sliding* = 1.00 — *AASHTO Table 11.5.6-1*

R_τ = *Nominal Sliding Resistance between Reinforced Soil Mass and Foundation Soil*

$= \Psi_{EV}(V_1)\mu + (c_f)(L)$ — *FHWA Eqn. 4-12 and AASHTO 10.6.3.4*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 — *AASHTO Table 3.4.1-1*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

V_1 = Total Vertical Force from the Reinforced Soil Mass = 329.280 kips

μ = Coefficent of Friction between Reinforced Soil Mass and Foundation Soil = 0.58 — *AASHTO 11.10.5.3*

c_f = Cohesion for Foundation Soil = 0.000 ksf

L = Reinforcement Length = 49.00 ft

R_τ = (1.00)(329.28 kips)(0.58) + (0.000 ksf)(49.00 ft) = 190.98 kips

R_R = (1.00)(190.98 kips) = 190.98 kips

Calculate Factored Horizontal Driving Force (P_d)

$P_d = (\Psi_{EHA})(F_1) + (\Psi_{LS})(F_2)$ — *FHWA Eqn. 4-9*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 — *AASHTO Table 3.4.1-1*

F_1 = Force Generated from Lateral Earth Pressure = 66.228 kips — *FHWA Eqn. 4-5*

Ψ_{LS} = Load Factor for Horizontal (Active) Earth Pressure = 1.75 — *AASHTO Table 3.4.1-1*

F_2 = Force Generated from Traffic Surcharge = 7.884 kips — *FHWA Eqn. 4-6*

P_d = (1.50)(66.228 kips) + (1.75)(7.884 kips) = 113.139 kips

Check Sliding

R_R must be greater than or equal to P_d

190.982 kips ≥ 113.139 kips

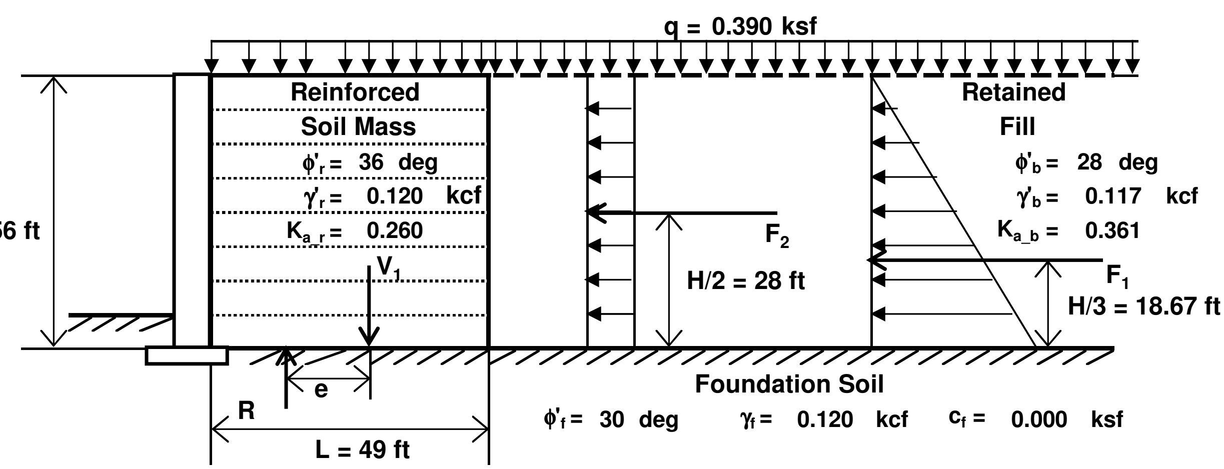
OK

Calculated Resistance Factor

$P_d/(Rr/\varphi_t)$ = **0.59**

Overturning (Limiting Eccentricity) - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Eccentricity (e) = the distance between the resultant foundation load (R) and the center of the reinforced zone



External Stability for MSE Walls: Overturning - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
Figure Not Drawn to Scale - All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity (e)

$$e = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1}$$ — *FHWA Eqn. 4-15*

Overturning (Limiting Eccentricity) Continued - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00
(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75
F_1 = Force Generated from Lateral Earth Pressure = 66.228 kips
F_2 = Force Generated from Traffic Surcharge = 7.884 kips
V_1 = Total Vertical Force from the Reinforced Soil Mass = 329.280 kips
H = MSE Wall Height = 56.00 ft

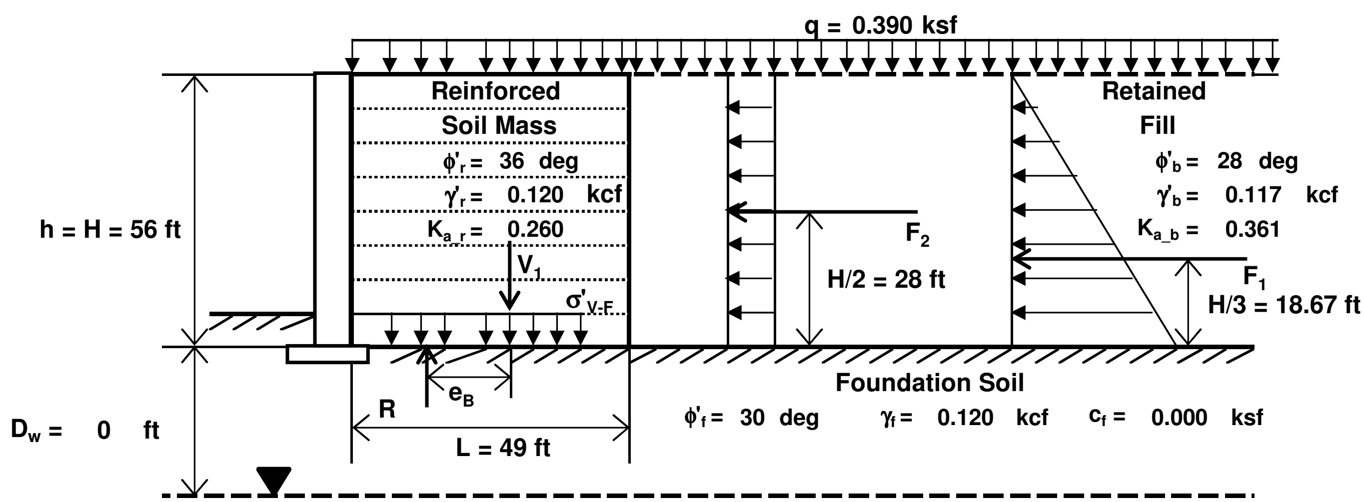
$$e = \frac{(1.50)(66.228\text{ kips})(18.67\text{ ft}) + (1.75)(7.884\text{ kips})(28.00\text{ ft})}{(1.00)(329.280\text{ kips})}$$

= 6.80 ft

Check Eccentricity

e must be less than or equal to L/4 per AASHTO 11.6.3.3
6.8 ft ≤ 12.25 ft
OK

Bearing Resistance (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c



External Stability for MSE Walls: Bearing Resistance - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1 + \Psi_{LS}qL}$$ *FHWA Eqn. 4-19*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 — *AASHTO Table 3.4.1-1*
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 — *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75 — *AASHTO Table 3.4.1-1*
F_1 = Force Generated from Lateral Earth Pressure = 66.228 kips — *FHWA Eqn. 4-5*
F_2 = Force Generated from Traffic Surcharge = 7.884 kips — *FHWA Eqn. 4-6*
V_1 = Total Vertical Force from the Reinforced Soil Mass = 329.280 kips

Bearing Resistance Continued (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c

q = Live Load Traffic Surcharge = 0.390 ksf
H = MSE Wall Height = 56.00 ft
L = Reinforcement Length = 49.00 ft

$$e_B = \frac{(1.50)(66.228\ \text{kips})(18.67\ \text{ft}) + (1.75)(7.884\ \text{kips})(28.00\ \text{ft})}{(1.35)(329.3\ \text{kips}) + (1.75)(0.390\ \text{ksf})(49.00\ \text{ft})}$$

= 4.69 ft

Calculate Nominal Bearing Resistance, (q_n) — *AASHTO Eqn. 10.6.3.1.2a-1*

$q_n = c_f N_c + 0.5\gamma B' N_\gamma C_{w\gamma}$ — *AASHTO Eqn. 10.6.3.1.2a-1*

c_f = Cohesion for Foundation Soil = 0.000 ksf
N_c = Bearing Capacity Factor (based on ϕ'_f) = 30.10 — *AASHTO Table 10.6.3.1.2a-1*
γ_f = Total Unit Weight for Foundation Soil = 0.120 kcf
B' = Effective Foundation Width = L - $2e_B$ — *AASHTO C11.10.5.4*
= 49.0 ft - 2(4.69 ft) = 39.62 ft
N_γ = Bearing Capacity Factor (based on ϕ'_f) = 22.40 — *AASHTO Table 10.6.3.1.2a-1*
$C_{w\gamma}$ = Correction Factor to Account for Location of Groundwater Table = 0.5 — *AASHTO Table 10.6.3.1.2a-2*

q_n = (0.000 ksf)(30.10) + (0.5)(0.120 kcf)(39.62 ft)(22.40)(0.50)

= 26.625 ksf

Calculate Factored Bearing Resistance, (q_r)

$q_r = \varphi_b q_n$ — *AASHTO Eqn. 10.6.3.1.1-1*

φ_b = Resistance Factor for Bearing = 0.65 — *AASHTO Table 11.5.6-1*
q_n = Nominal Bearing Resistance = 26.625 ksf — *AASHTO Eqn. 10.6.3.1.2a-1*

q_r = (0.65)(26.625 ksf) = 17.306 ksf

Calculate Factored Vertical Bearing Pressure at the base, (q_{V-F})

$$\sigma_{V-F} = \frac{\Psi_{EV} V_1 + \Psi_{LS} qL}{L - 2e_B}$$ — *FHWA Eqn. 4-20*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 — *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.c, AASHTO C3.4.1, and AASHTO C11.5.5)
V_1 = Total Vertical Force from the Reinforced Soil Mass = 329.280 kips
Ψ_{LS} = Load Factor for Surcharge = 1.75 — *AASHTO Table 3.4.1-1*
q = Live Load Traffic Surcharge = 0.390 ksf
L = Reinforcement Length = 49.00 ft
e_B = Eccentricity for Bearing = 4.69 ft — *FHWA Eqn. 4-19*

$$\sigma_{V-F} = \frac{(1.35)(329.28\ \text{kips ft}) + (1.75)(0.390\ \text{ksf})(49.00\ \text{ft})}{49.00\ \text{ft} - 2(4.69\ \text{ft})}$$

= 12.064 ksf

Check Bearing

q_R must be greater than or equal to q_{V-F}
17.306 ksf ≥ 12.064 ksf
OK

Calculated Resistance Factor

σ_{V-F}/q_n = **0.45**

Bearing Resistance (Local/Punching Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1.2b, and FHWA 4.4.6.c

Local and Punching shear failure occurs in loose or compressible soils and in weak soils under slow (drained) loading. This mode of failure will only be considered for foundation material that is cohesive.

The Foundation Material for this Project is not Cohesive.

Seismic Stablity - SCDOT GDM Section 14.12

Calculate Wave Scattering Effects

Wave Scattering Coefficient, α_w =1+0.01H((0.5β)-1<1.0 — SCDOT Equation 13-103

α_w = 0.636

Ground Motion Index, $\beta = k_{max}/S_{d1}$ = 0.70 — SCDOT Equation 13-104

Average seismic horizontal coefficient due to wave scattering

$k_h = \alpha_w * k_{max}$ = 0.127 — SCDOT Equation 13-102

Calculate Seismic Active Earth Pressure Coefficicinet (Mononobe -Kobe Method) SCDOT GDM Section 14.4.1

Seismic Active Earth Pressure Coefficient Reinforced Soils, K_{AEr} = 0.513

Seismic Active Earth Pressure Coefficient Retained, K_{AEb} = 0.636

$$K_{ae} = \frac{\cos^2(\phi - \Psi - \theta)}{\cos(\Psi)\cos^2(\theta)\cos(\delta + \theta + \Psi)\left[1 + \sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \Psi - \beta)}{\cos(\delta + \theta + \Psi)\cos(\beta - \theta)}}\right]^2} \quad \text{Equation 14-2}$$

Where,

γ	=	unit weight of soil
H	=	height of wall or effective height of wall (h_{eff})
φ	=	angle of internal friction of soil
Ψ	=	$\tan^{-1}[k_h/(1-k_v)]$
δ	=	angle of friction between soil and wall
k_h	=	horizontal acceleration coefficient
k_v	=	vertical acceleration coefficient, typically set to zero.
β	=	backfill slope angle
θ	=	angle of backface of the wall with the vertical

	Reinforced Soil		Retained Soil	
φ =	36.0	deg	28.0	deg
Ψ =	7.2	deg	7.2	deg
θ =	0	deg	0	deg
δ =	0	deg	0.00	deg
β =	0	deg	0	deg

Calculate Inertial Wall Width, $B_{inertial} = \omega H$ 39

coefficient, ω = 0.70

Calculate Active Earth Thrust Force, $P_{AE} = \gamma_p * 0.5 K_{AEr} * \gamma_p * H^2$ = 116.6 kips — GDM Eq. 14-40

Calculate Intertial Reinforced Soil Mass Force, $P_{IR} = \gamma_p * k_{avg} * B_{inertial} * H_{wall} *$ = 0.6 kips — GDM Eq. 14-41

Dead Load Surcharge Force, P_{DC} = 4.983 kips — GDM Eq. 14-45

Live Load Surcharge Force, P_{LL} = 4.449 kips — GDM Eq. 14-46

Total Seismic Driving Force, F_H = #### kip

Calculated Resistance Factor, $\varphi = F_H/R_t$ = **0.66**

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EQ\text{-}P}F_{1s}(H/2) + \Psi_{EQ\text{-}LL}F_{2s}(H/2)}{\Psi_{EV}V_1 + \Psi_{EQ\text{-}LL}qL}$$ *FHWA Eqn. 4-19*

Ψ_{EHAeq} = $\Psi_{EQ\text{-}p}$ = Load Factor for Horizontal (Active) Earth Pressure = 1.00 *AASHTO Table 3.4.1-1*
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LSeq} = $\Psi_{EQ\text{-}p}$ = Load Factor for Surcharge = 1.00 *AASHTO Table 3.4.1-1*
F_{1s} = Force Generated from Lateral Earth Pressure = 122.174 kips *FHWA Eqn. 4-5*
F_{2s} = Force Generated from Traffic Surcharge = 4.449 kips *FHWA Eqn. 4-6*
V_1 = Total Vertical Force from the Reinforced Soil Mass = 329.280 kips
q = Live Load Traffic Surcharge = 0.250 ksf *FHWA Eqn. 4-19*
H = MSE Wall Height = 56.00 ft
L = Reinforcement Length = 49.00 ft

$$e_B = \frac{(1.00)(122.174\text{ kips})(28.00\text{ ft}) + (1.00)(4.449\text{ kips})(28.00\text{ ft})}{(1.00)(329.3\text{ kips}) + (1.00)(0.250\text{ ksf})(49.00\text{ ft})}$$

= 10.38 ft

Calculate Factored Vertical Bearing Pressure at the base, ($q_{V\text{-}F}$)

$$\sigma_{V\text{-}F} = \frac{\Psi_{EQ\text{-}P}V_1 + \Psi_{EQ\text{-}LS}qL}{L - 2e_B}$$ *FHWA Eqn. 4-20*

$\Psi_{EQ\text{-}p}$ = Load Factor for Dead Load of Earth Fill = 1.00

V_1 = Total Vertical Force from the Reinforced Soil Mass = 329.280 kips
Ψ_{LSeq} = $\Psi_{EQ\text{-}ll}$ = Load Factor for Surcharge = 1.00
q = Live Load Traffic Surcharge = 0.250 ksf
L = Reinforcement Length = 49.00 ft
e_B = Eccentricity for Bearing = 10.38 ft

$$\sigma_{V\text{-}F} = \frac{(1.00)(329.28\text{ kips})(\text{ft}) + (1.00)(0.250\text{ ksf})(49.00\text{ ft})}{49.0\text{ ft} - 2(10.38\text{ ft})}$$

= 12.337 ksf

Calculated Resistance Factor

$\sigma_{V\text{-}F}/q_n$ = **0.46**

STATE OF NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION
GEOTECHNICAL ENGINEERING UNIT
1589 MAIL SERVICE CENTER

WBS NO.: TIP NO.: COUNTY:
SUBJECT: LRFD External Stability Analysis for MSE Walls
Wall 32 - Ramp 4
PREPARED BY: CLB DATE: 09/11/15 STATION: 43+50
CHECKED BY: DATE: STR. NO.: SHEET: 1 OF 8

Input Traffic Surcharge, Backslope, Wall Geometry, and Soil Parameters

Traffic and Overlay Surcharge Surcharge

q = 390 psf *Live Load Traffic Surcharge and Pavement Overlay*
35.9 % Surcharge due to overlay
q_{ol} = 140 psf *Pavement overlay surcharge*

Backslope

Horizontal Backslope

(d = horizontal distance from back of wall face to top of backslope)

Wall Geometry

H = 49.00 ft *Wall Height*
L/H = 1.00 *Ratio of Reinforcement Length to Wall Height*
(L/H ≥ 0.7 per NCDOT MSE Wall Standard Provision)
L = 49.00 ft *Reinforcement Length*
(L ≥ 6 ft per NCDOT MSE Wall Standard Provision)
h = 49.00 ft *Height of Wall & Slope at the back of Reinforced Zone*

D_w = 0.00 ft *Distance of Water Table below the Bottom of the Wall*

Soil Parameters for Reinforced Zone

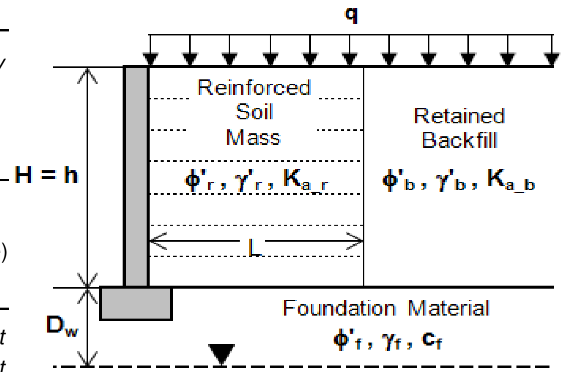
ϕ'_r = 36 deg *Effective Friction Angle*
γ'_r = 120 pcf *Effective Unit Weight*
K_{a_r} = 0.260 *Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

Soil Parameters for Retained Backfill

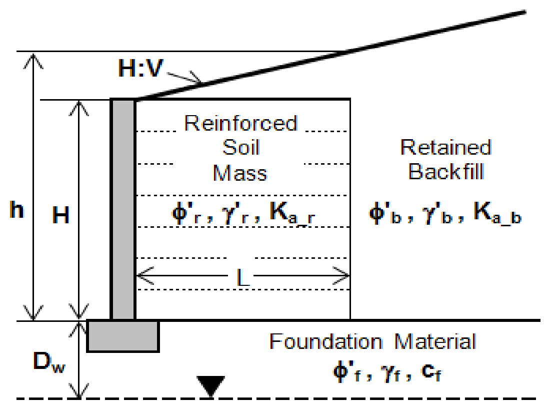
ϕ'_b = 28 deg *Effective Friction Angle*
γ'_b = 117 pcf *Effective Unit Weight*
K_{a_b} = 0.361 *Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

Soil Parameters for Foundation Soil

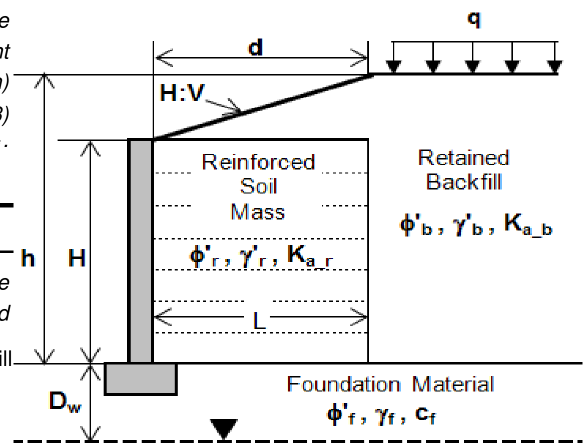
ϕ'_f = 30 deg *Effective Friction Angle*
γ_f = 120 pcf *Total Unit Weight*
c_f = 0 psf *Undrained Shear Strength (Cohesion)*
μ = 0.58 *Coefficient of Friction (AASHTO 11.10.5.3)*
The coefficient of friction shall be based on the lesser of ϕ'_r and ϕ'_f.



Typical MSE Wall with Level Backslope and Traffic Surcharge



Typical MSE Wall with Infinite Backslope



Typical MSE Wall with Broken Backslope and Traffic Surcharge

Input Load and Resistance Factors

Load Factors (See AASHTO Table 3.4.1-1 and 2)

Ψ_{LS} = 1.75 *Lilve Load Surcharge*
$\Psi_{EH(A)}$ = 1.50 *Horizontal (Active) Earth Pressure Load*
Ψ_{EV} = 1.00 min / 1.35 max Vertical Dead Load Generated from Earth Fill
$\Psi_{EQ\text{-}p}$ = 1.00
$\Psi_{EQ\text{-}LL}$ = 0.50

Resistance Factors (See AASHTO Table 11.5.6-1)

φ_b = 0.65 *Bearing Resistance for MSE Walls*
φ_τ = 1.00 *Sliding Resistance for MSE Walls*

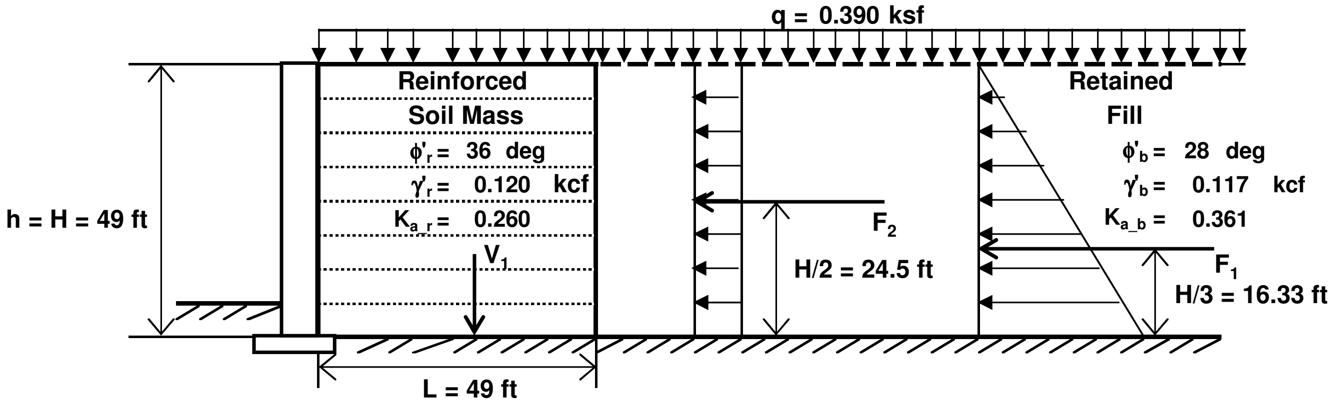
Seismic Design Acceleration Parameters

k_{max} = 0.20 *Maximum Horizontal Ground Acceration (PGA)*
S_{d1} = 0.14 *Peak spectral acceleration at 1 second*

References:

1. *AASHTO LRFD Bridge Design Specifications, 5th Edition, 2010*
2. *FHWA-NHI-10-024 Design and Construction of MSE Walls and Reinforced Soil Slopes - Vol I, 2009*
3. *SCDOT Geotechnical Design Manual version 1.1, 2010*

Calculate Forces acting on Wall



External Stability for MSE Walls: Earth Pressure - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Forces from Vertical Earth Loads

V_1 = Total Vertical Force from the Reinforced Soil Mass = $(\gamma_r)(H)(L)$
= (0.120 kcf)(49.00 ft)(49.00 ft) = 288.120 kips

Forces from Lateral Earth Pressure

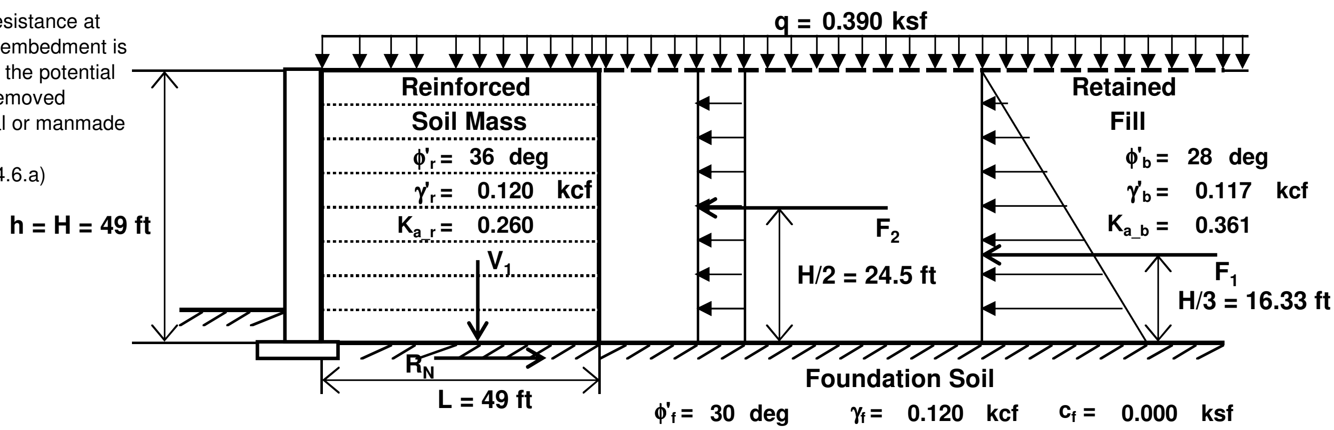
F_1 = Total Force Generated from Lateral Earth Pressure = $0.5(\gamma'_b)(H^2)(K_{ab})$ — FHWA Eqn. 4-5
= (0.5)(0.117 kcf)(49.00 ft)^2(0.361) = 50.706 kips

Horizontal Force from Traffic Surcharge

F_2 = Force Generated from Traffic Surcharge = $(q)(H)(K_{ab})$ — *FHWA Eqn. 4-6*
= (0.390 ksf)(49.00 ft) (0.361) = 6.899 kips

Sliding Stability - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

The passive resistance at the toe due to embedment is ignored due to the potential for soil to be removed through natural or manmade processes.
(per FHWA 4.4.6.a)



External Stability for MSE Walls: Sliding Stability - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Factored Sliding Resistance (R_R)

$R_R = \varphi R_N = \varphi_\tau R_\tau$ — *AASHTO Eqn. 10.6.3.4-1*

Sliding Stability Continued - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

φ_τ = *Resistance Factor for Sliding* = 1.00 — *AASHTO Table 11.5.6-1*

R_τ = *Nominal Sliding Resistance between Reinforced Soil Mass and Foundation Soil*

$= \Psi_{EV}(V_1)\mu + (c_f)(L)$ — *FHWA Eqn. 4-12 and AASHTO 10.6.3.4*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 — *AASHTO Table 3.4.1-1*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

V_1 = Total Vertical Force from the Reinforced Soil Mass = 288.120 kips

μ = Coefficent of Friction between Reinforced Soil Mass and Foundation Soil = 0.58 — *AASHTO 11.10.5.3*

c_f = Cohesion for Foundation Soil = 0.000 ksf

L = Reinforcement Length = 49.00 ft

R_τ = (1.00)(288.12 kips)(0.58) + (0.000 ksf)(49.00 ft) = 167.11 kips

R_R = (1.00)(167.11 kips) = 167.11 kips

Calculate Factored Horizontal Driving Force (P_d)

$P_d = (\Psi_{EHA})(F_1) + (\Psi_{LS})(F_2)$ — *FHWA Eqn. 4-9*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 — *AASHTO Table 3.4.1-1*

F_1 = Force Generated from Lateral Earth Pressure = 50.706 kips — *FHWA Eqn. 4-5*

Ψ_{LS} = Load Factor for Horizontal (Active) Earth Pressure = 1.75 — *AASHTO Table 3.4.1-1*

F_2 = Force Generated from Traffic Surcharge = 6.899 kips — *FHWA Eqn. 4-6*

P_d = (1.50)(50.706 kips) + (1.75)(6.899 kips) = 88.131 kips

Check Sliding

R_R must be greater than or equal to P_d

167.11 kips ≥ 88.131 kips

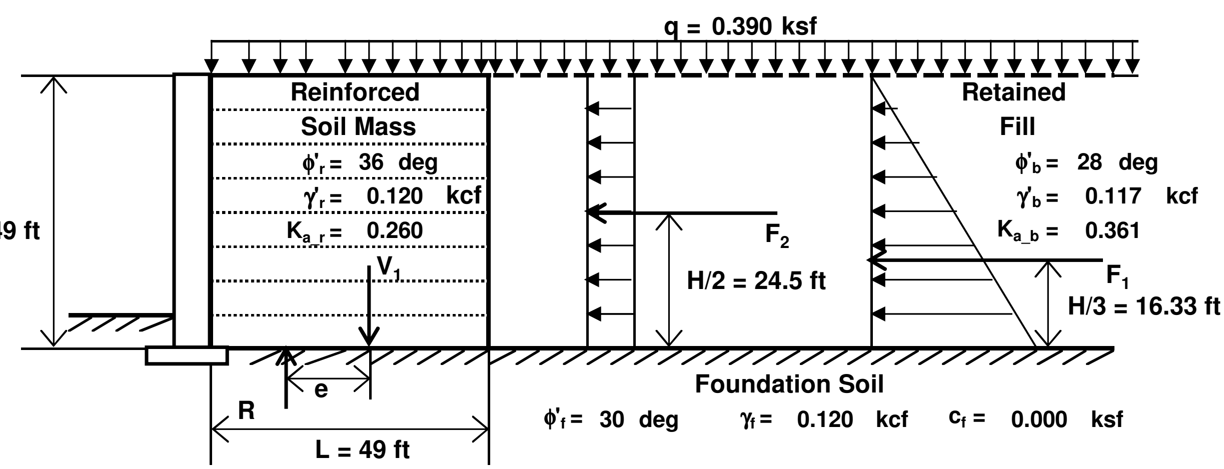
OK

Calculated Resistance Factor

$P_d/(Rr/\varphi_t)$ = **0.53**

Overturning (Limiting Eccentricity) - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Eccentricity (e) = the distance between the resultant foundation load (R) and the center of the reinforced zone



External Stability for MSE Walls: Overturning - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
Figure Not Drawn to Scale - All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity (e)

$$e = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1}$$ — *FHWA Eqn. 4-15*

Overturning (Limiting Eccentricity) Continued - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00
(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75
F_1 = Force Generated from Lateral Earth Pressure = 50.706 kips
F_2 = Force Generated from Traffic Surcharge = 6.899 kips
V_1 = Total Vertical Force from the Reinforced Soil Mass = 288.120 kips
H = MSE Wall Height = 49.00 ft

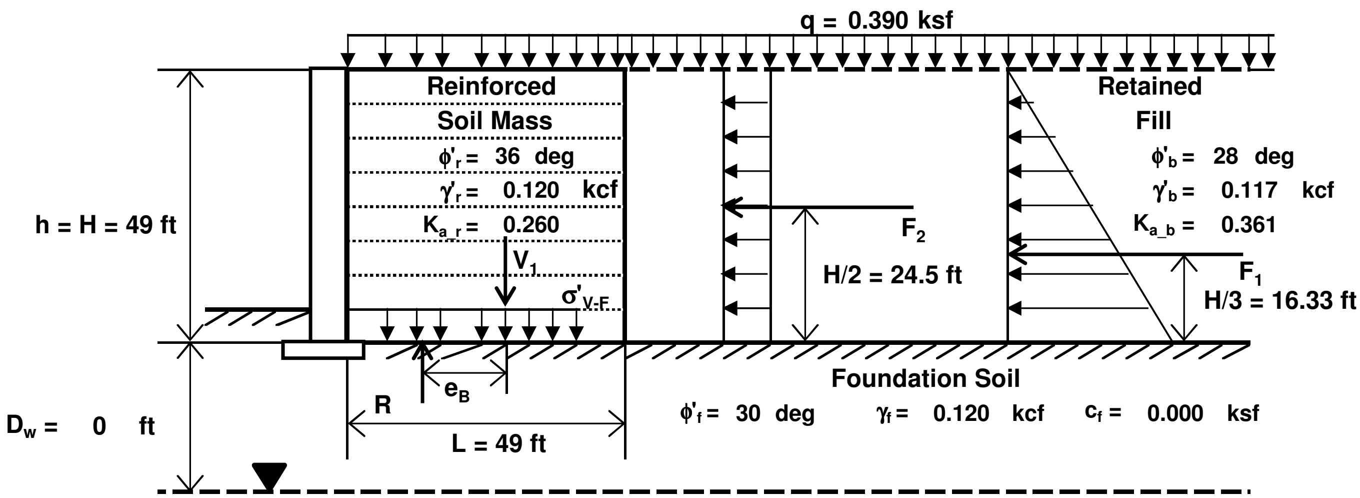
$$e = \frac{(1.50)(50.706\text{ kips})(16.33\text{ ft}) + (1.75)(6.899\text{ kips})(24.50\text{ ft})}{(1.00)(288.120\text{ kips})}$$

= 5.34 ft

Check Eccentricity

e must be less than or equal to L/4 per AASHTO 11.6.3.3
5.34 ft ≤ 12.25 ft
OK

Bearing Resistance (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c



External Stability for MSE Walls: Bearing Resistance - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1 + \Psi_{LS}qL}$$ *FHWA Eqn. 4-19*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 *AASHTO Table 3.4.1-1*
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75 *AASHTO Table 3.4.1-1*
F_1 = Force Generated from Lateral Earth Pressure = 50.706 kips *FHWA Eqn. 4-5*
F_2 = Force Generated from Traffic Surcharge = 6.899 kips *FHWA Eqn. 4-6*
V_1 = Total Vertical Force from the Reinforced Soil Mass = 288.120 kips

Bearing Resistance Continued (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c

q = Live Load Traffic Surcharge = 0.390 ksf
H = MSE Wall Height = 49.00 ft
L = Reinforcement Length = 49.00 ft

$$e_B = \frac{(1.50)(50.706\text{ kips})(16.33\text{ ft}) + (1.75)(6.899\text{ kips})(24.50\text{ ft})}{(1.35)(288.1\text{ kips}) + (1.75)(0.390\text{ ksf})(49.00\text{ ft})}$$

= 3.64 ft

Calculate Nominal Bearing Resistance, (q_n) — *AASHTO Eqn. 10.6.3.1.2a-1*

$q_n = c_f N_c + 0.5\gamma B' N_\gamma C_{w\gamma}$ — *AASHTO Eqn. 10.6.3.1.2a-1*

c_f = Cohesion for Foundation Soil = 0.000 ksf
N_c = Bearing Capacity Factor (based on ϕ'_f) = 30.10 — *AASHTO Table 10.6.3.1.2a-1*
γ_f = Total Unit Weight for Foundation Soil = 0.120 kcf
B' = Effective Foundation Width = L - $2e_B$ — *AASHTO C11.10.5.4*
= 49.0 ft - 2(3.64 ft) = 41.72 ft
N_γ = Bearing Capacity Factor (based on ϕ'_f) = 22.40 — *AASHTO Table 10.6.3.1.2a-1*
$C_{w\gamma}$ = Correction Factor to Account for Location of Groundwater Table = 0.5 — *AASHTO Table 10.6.3.1.2a-2*

q_n = (0.000 ksf)(30.10) + (0.5)(0.120 kcf)(41.72 ft)(22.40)(0.50)

= 28.036 ksf

Calculate Factored Bearing Resistance, (q_r)

$q_r = \varphi_b q_n$ — *AASHTO Eqn. 10.6.3.1.1-1*

φ_b = Resistance Factor for Bearing = 0.75 — *AASHTO Table 11.5.6-1*
q_n = Nominal Bearing Resistance = 28.036 ksf — *AASHTO Eqn. 10.6.3.1.2a-1*

q_r = (0.75)(28.036 ksf) = 21.027 ksf

Calculate Factored Vertical Bearing Pressure at the base, (q_{V-F})

$$\sigma_{V-F} = \frac{\Psi_{EV} V_1 + \Psi_{LS} q L}{L - 2e_B}$$ — *FHWA Eqn. 4-20*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 — *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.c, AASHTO C3.4.1, and AASHTO C11.5.5)
V_1 = Total Vertical Force from the Reinforced Soil Mass = 288.120 kips
Ψ_{LS} = Load Factor for Surcharge = 1.75 — *AASHTO Table 3.4.1-1*
q = Live Load Traffic Surcharge = 0.390 ksf
L = Reinforcement Length = 49.00 ft
e_B = Eccentricity for Bearing = 3.64 ft — *FHWA Eqn. 4-19*

$$\sigma_{V-F} = \frac{(1.35)(288.12\text{ kips ft}) + (1.75)(0.390\text{ ksf})(49.00\text{ ft})}{49.00\text{ ft} - 2(3.64\text{ ft})}$$

= 10.125 ksf

Check Bearing

q_R must be greater than or equal to q_{V-F}
21.027 ksf ≥ 10.125 ksf
OK

Calculated Resistance Factor

σ_{V-F}/q_n = **0.36**

Bearing Resistance (Local/Punching Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1.2b, and FHWA 4.4.6.c

Local and Punching shear failure occurs in loose or compressible soils and in weak soils under slow (drained) loading. This mode of failure will only be considered for foundation material that is cohesive.

The Foundation Material for this Project is not Cohesive.

Seismic Stablity - SCDOT GDM Section 14.12

Calculate Wave Scattering Effects

Wave Scattering Coefficient, α_w =1+0.01H((0.5β)-1<1.0 — SCDOT Equation 13-103

α_w = 0.6815

Ground Motion Index, $\beta = k_{max}/S_{d1}$ = 0.70 — SCDOT Equation 13-104

Average seismic horizontal coefficient due to wave scattering

$k_h = \alpha_w * k_{max}$ = 0.136 — SCDOT Equation 13-102

Calculate Seismic Active Earth Pressure Coefficinet (Mononobe -Kobe Method) SCDOT GDM Section 14.4.1

Seismic Active Earth Pressure Coefficient Reinforced Soils, K_{AEr} = 0.522

Seismic Active Earth Pressure Coefficient Retained, K_{AEb} = 0.644

$$K_{ae} = \frac{\cos^2(\phi - \Psi - \theta)}{\cos(\Psi)\cos^2(\theta)\cos(\delta + \theta + \Psi)\left[1 + \sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \Psi - \beta)}{\cos(\delta + \theta + \Psi)\cos(\beta - \theta)}}\right]^2} \quad \text{Equation 14-2}$$

Where,

γ	=	unit weight of soil
H	=	height of wall or effective height of wall (h_{eff})
ϕ	=	angle of internal friction of soil
Ψ	=	$\tan^{-1}[k_h/(1-k_v)]$
δ	=	angle of friction between soil and wall
k_h	=	horizontal acceleration coefficient
k_v	=	vertical acceleration coefficient, typically set to zero.
β	=	backfill slope angle
θ	=	angle of backface of the wall with the vertical

	Reinforced Soil	Retained Soil
φ =	36.0 deg	28.0 deg
Ψ =	7.8 deg	7.8 deg
θ =	0 deg	0 deg
δ =	0 deg	0.00 deg
β =	0 deg	0 deg

Calculate Inertial Wall Width, $B_{inertial} = \omega H$ 34

coefficient, ω = 0.70

Calculate Active Earth Thrust Force, $P_{AE} = \gamma_p * 0.5 K_{AEr} * \gamma_p * H^2$ = 90.5 kips — GDM Eq. 14-40

Calculate Intertial Reinforced Soil Mass Force, $P_{IR} = \gamma_p * k_{avg} * B_{inertial} * H_{wall} *$ = 0.56 kips — GDM Eq. 14-41

Dead Load Surcharge Force, P_{DC} = = 4.419 kips — GDM Eq. 14-45

Live Load Surcharge Force, P_{LL} = = 3.945 kips — GDM Eq. 14-46

Total Seismic Driving Force, F_H = 99.4 kip

Calculated Resistance Factor, $\varphi = F_H/R_t$ = **0.59**

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EQ\text{-}P}F_{1s}(H/2) + \Psi_{EQ\text{-}LL}F_{2s}(H/2)}{\Psi_{EV}V_1 + \Psi_{EQ\text{-}LL}qL}$$ *FHWA Eqn. 4-19*

Ψ_{EHAeq} = $\Psi_{EQ\text{-}p}$ = Load Factor for Horizontal (Active) Earth Pressure = 1.00 *AASHTO Table 3.4.1-1*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

Ψ_{LSeq} = $\Psi_{EQ\text{-}p}$ = Load Factor for Surcharge = 1.00 *AASHTO Table 3.4.1-1*

F_{1s} = Force Generated from Lateral Earth Pressure = 95.461 kips *FHWA Eqn. 4-5*

F_{2s} = Force Generated from Traffic Surcharge = 3.945 kips *FHWA Eqn. 4-6*

V_1 = Total Vertical Force from the Reinforced Soil Mass = 288.120 kips

q = Live Load Traffic Surcharge = 0.250 ksf *FHWA Eqn. 4-19*

H = MSE Wall Height = 49.00 ft

L = Reinforcement Length = 49.00 ft

$$e_B = \frac{(\ 1.00\ )(\ 95.461\ \text{kips})(\ 24.50\ \text{ft}) + (\ 1.00\ )(\ 3.945\ \text{kips})(\ 24.50\ \text{ft})}{(\ 1.00\ )(\ 288.1\ \text{kips}) + (\ 1.00\ )(\ 0.250\ \text{ksf})(\ 49.00\ \text{ft})}$$

= 8.11 ft

Calculate Factored Vertical Bearing Pressure at the base, ($q_{V\text{-}F}$)

$$\sigma_{V\text{-}F} = \frac{\Psi_{EQ\text{-}P}V_1 + \Psi_{EQ\text{-}LS}qL}{L - 2e_B}$$ *FHWA Eqn. 4-20*

$\Psi_{EQ\text{-}p}$ = Load Factor for Dead Load of Earth Fill = 1.00

V_1 = Total Vertical Force from the Reinforced Soil Mass = 288.120 kips

Ψ_{LSeq} = $\Psi_{EQ\text{-}ll}$ = Load Factor for Surcharge = 1.00

q = Live Load Traffic Surcharge = 0.250 ksf

L = Reinforcement Length = 49.00 ft

e_B = Eccentricity for Bearing = 8.11 ft

$$\sigma_{V\text{-}F} = \frac{(\ 1.00\ )(\ 288.12\ \text{kips})(\ \text{ft}) + (\ 1.00\ )(\ 0.250\ \text{ksf})(\ 49.00\ \text{ft})}{49.0\ \text{ft} - 2(\ 8.11\ \text{ft})}$$

= 9.372 ksf

Calculated Resistance Factor

$\sigma_{V\text{-}F}/q_n$ = **0.33**

STATE OF NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION
GEOTECHNICAL ENGINEERING UNIT
1589 MAIL SERVICE CENTER

WBS NO.: TIP NO.: COUNTY:
SUBJECT: LRFD External Stability Analysis for MSE Walls
Wall 36 -Ramp 4B
PREPARED BY: CLB DATE: 09/11/15 STATION: 388+00
CHECKED BY: DATE: STR. NO.: SHEET: 1 OF 8

Input Traffic Surcharge, Backslope, Wall Geometry, and Soil Parameters

Traffic and Overlay Surcharge Surcharge

q = 390 psf *Live Load Traffic Surcharge and Pavement Overlay*
35.9 % Surcharge due to overlay
q_{ol} = 140 psf *Pavement overlay surcharge*

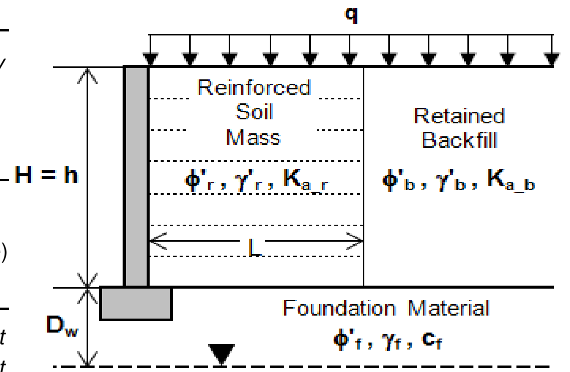
Backslope

Horizontal Backslope

(d = horizontal distance from back of wall face to top of backslope)

Wall Geometry

H =	23.50	ft	*Wall Height*
L/H =	0.77		*Ratio of Reinforcement Length to Wall Height*
			(L/H ≥ 0.7 per NCDOT MSE Wall Standard Provision)
L =	18.00	ft	*Reinforcement Length*
			(L ≥ 6 ft per NCDOT MSE Wall Standard Provision)
h =	23.50	ft	*Height of Wall & Slope at the back of Reinforced Zone*
D_w =	21.00	ft	*Distance of Water Table below the Bottom of the Wall*



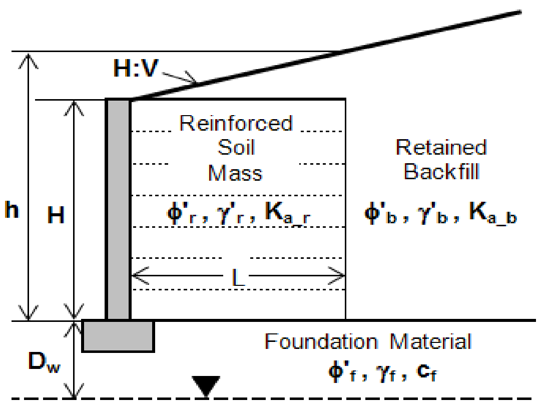
Typical MSE Wall with Level Backslope and Traffic Surcharge

Soil Parameters for Reinforced Zone

ϕ'_r =	36	deg	*Effective Friction Angle*
γ'_r =	120	pcf	*Effective Unit Weight*
K_{a_r} =	0.260		*Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

Soil Parameters for Retained Backfill

ϕ'_b =	32	deg	*Effective Friction Angle*
γ'_b =	117	pcf	*Effective Unit Weight*
K_{a_b} =	0.307		*Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*



Typical MSE Wall with Infinite Backslope

Soil Parameters for Foundation Soil

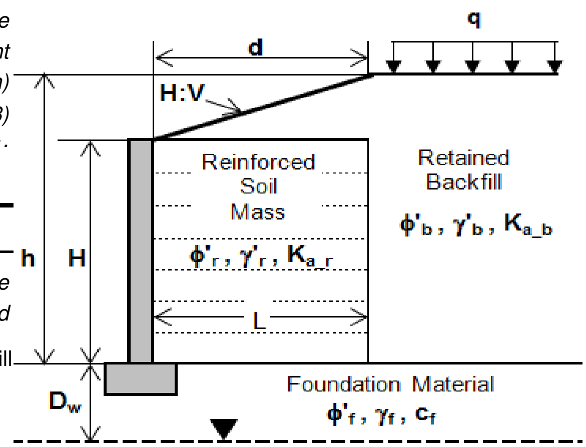
ϕ'_f =	26	deg	*Effective Friction Angle*
γ_f =	120	pcf	*Total Unit Weight*
c_f =	0	psf	*Undrained Shear Strength (Cohesion)*
μ =	0.49		*Coefficient of Friction (AASHTO 11.10.5.3)*

The coefficient of friction shall be based on the lesser of ϕ'_r and ϕ'_f.

Input Load and Resistance Factors

Load Factors (See AASHTO Table 3.4.1-1 and 2)

Ψ_{LS} =	1.75		*Lilve Load Surcharge*
$\Psi_{EH(A)}$ =	1.50		*Horizontal (Active) Earth Pressure Load*
Ψ_{EV} =	1.00	min	Vertical Dead Load Generated from Earth Fill
	1.35	max	
$\Psi_{EQ\text{-}p}$ =	1.00		
$\Psi_{EQ\text{-}LL}$ =	0.50		



Typical MSE Wall with Broken Backslope and Traffic Surcharge

Resistance Factors (See AASHTO Table 11.5.6-1)

φ_b =	0.65	*Bearing Resistance for MSE Walls*
φ_τ =	1.00	*Sliding Resistance for MSE Walls*

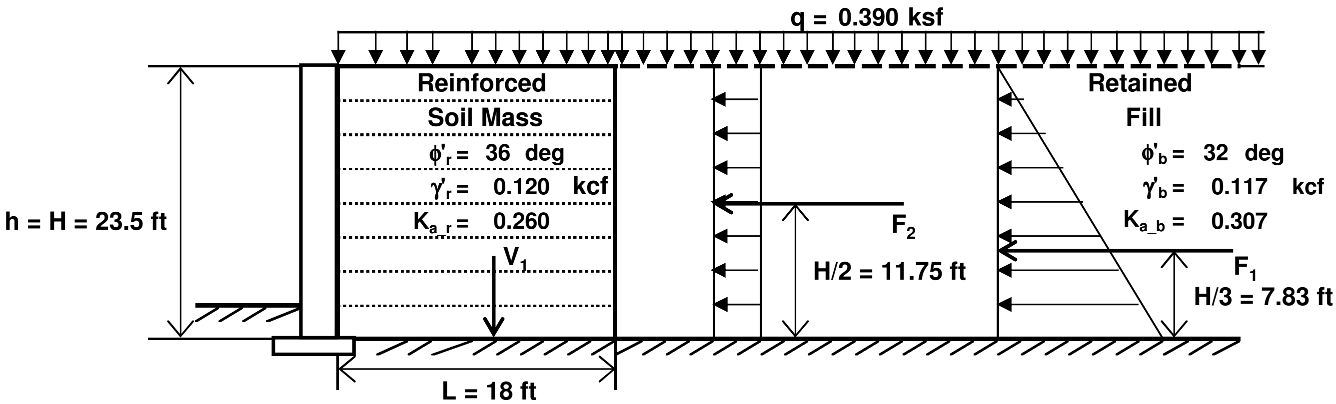
Seismic Design Acceleration Parameters

k_{max} =	0.20	*Maximum Horizontal Ground Acceration (PGA)*
S_{d1}=	0.14	*Peak spectral acceleration at 1 second*

References:

1. *AASHTO LRFD Bridge Design Specifications, 5th Edition, 2010*
2. *FHWA-NHI-10-024 Design and Construction of MSE Walls and Reinforced Soil Slopes - Vol I, 2009*
3. *SCDOT Geotechnical Design Manual version 1.1, 2010*

Calculate Forces acting on Wall



External Stability for MSE Walls: Earth Pressure - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Forces from Vertical Earth Loads

V_1 = Total Vertical Force from the Reinforced Soil Mass = $(\gamma_r)(H)(L)$

= (0.120 kcf)(23.50 ft)(18.00 ft) = 50.760 kips

Forces from Lateral Earth Pressure

F_1 = Total Force Generated from Lateral Earth Pressure = $0.5(\gamma'_b)(H^2)(K_{ab})$ — FHWA Eqn. 4-5

= (0.5)(0.117 kcf)(23.50 ft)^2(0.307) = 9.918 kips

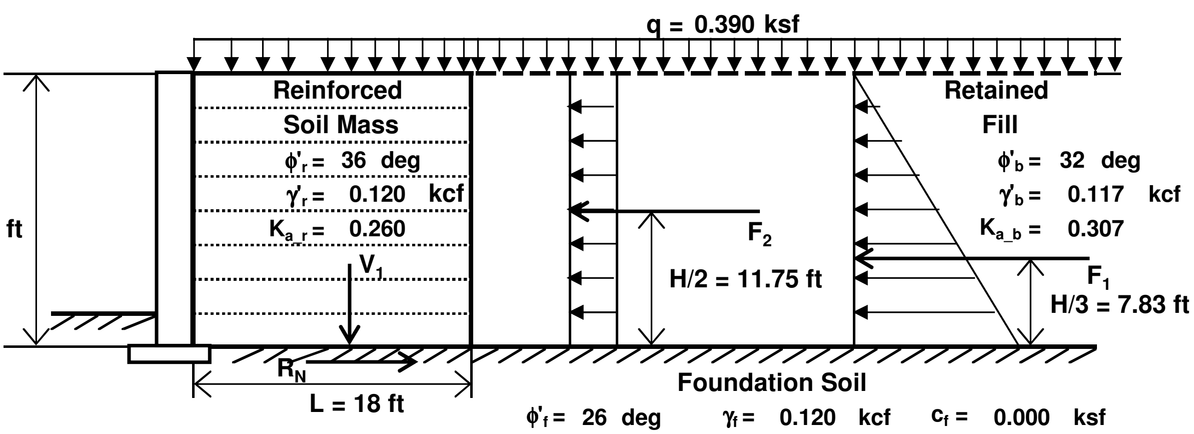
Horizontal Force from Traffic Surcharge

F_2 = Force Generated from Traffic Surcharge = $(q)(H)(K_{ab})$ — *FHWA Eqn. 4-6*

= (0.390 ksf)(23.50 ft) (0.307) = 2.814 kips

Sliding Stability - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

The passive resistance at the toe due to embedment is ignored due to the potential for soil to be removed through natural or manmade processes.
(per FHWA 4.4.6.a)



External Stability for MSE Walls: Sliding Stability - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Factored Sliding Resistance (R_R)

$R_R = \varphi R_N = \varphi_\tau R_\tau$ — *AASHTO Eqn. 10.6.3.4-1*

Sliding Stability Continued - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

φ_τ = *Resistance Factor for Sliding* = 1.00 — *AASHTO Table 11.5.6-1*

R_τ = *Nominal Sliding Resistance between Reinforced Soil Mass and Foundation Soil*

$= \Psi_{EV}(V_1)\mu + (c_f)(L)$ — *FHWA Eqn. 4-12 and AASHTO 10.6.3.4*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 — *AASHTO Table 3.4.1-1*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

V_1 = Total Vertical Force from the Reinforced Soil Mass = 50.760 kips

μ = Coefficent of Friction between Reinforced Soil Mass and Foundation Soil = 0.49 — *AASHTO 11.10.5.3*

c_f = Cohesion for Foundation Soil = 0.000 ksf

L = Reinforcement Length = 18.00 ft

R_τ = (1.00)(50.76 kips)(0.49) + (0.000 ksf)(18.00 ft) = 24.87 kips

R_R = (1.00)(24.87 kips) = 24.87 kips

Calculate Factored Horizontal Driving Force (P_d)

$P_d = (\Psi_{EHA})(F_1) + (\Psi_{LS})(F_2)$ — *FHWA Eqn. 4-9*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 — *AASHTO Table 3.4.1-1*

F_1 = Force Generated from Lateral Earth Pressure = 9.918 kips — *FHWA Eqn. 4-5*

Ψ_{LS} = Load Factor for Horizontal (Active) Earth Pressure = 1.75 — *AASHTO Table 3.4.1-1*

F_2 = Force Generated from Traffic Surcharge = 2.814 kips — *FHWA Eqn. 4-6*

P_d = (1.50)(9.918 kips) + (1.75)(2.814 kips) = 19.801 kips

Check Sliding

R_R must be greater than or equal to P_d

24.872 kips ≥ 19.801 kips

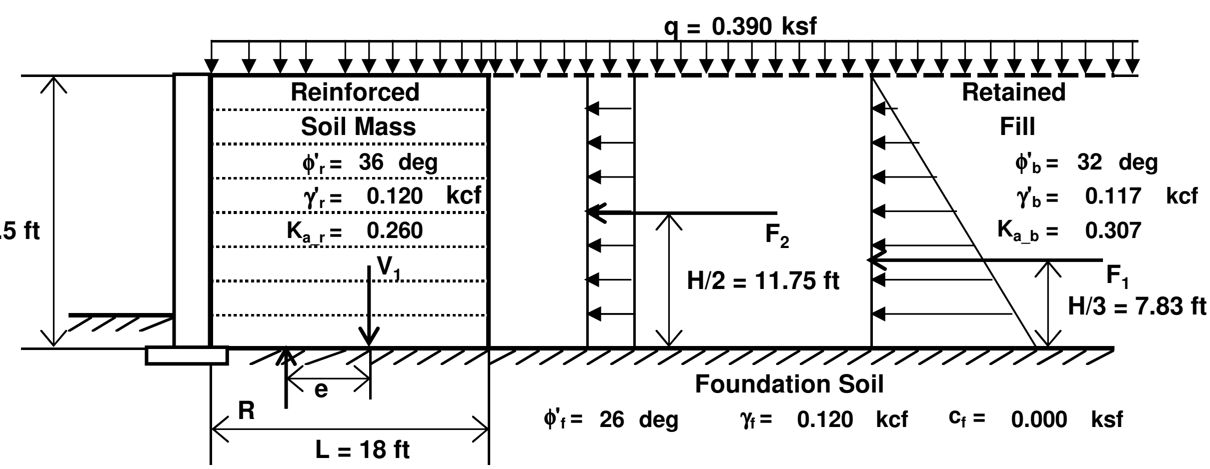
OK

Calculated Resistance Factor

$P_d/(Rr/\varphi_t)$ = **0.80**

Overturning (Limiting Eccentricity) - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Eccentricity (e) = the distance between the resultant foundation load (R) and the center of the reinforced zone



External Stability for MSE Walls: Overturning - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
Figure Not Drawn to Scale - All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity (e)

$$e = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1}$$ — *FHWA Eqn. 4-15*

Overturning (Limiting Eccentricity) Continued - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00
(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75
F_1 = Force Generated from Lateral Earth Pressure = 9.918 kips
F_2 = Force Generated from Traffic Surcharge = 2.814 kips
V_1 = Total Vertical Force from the Reinforced Soil Mass = 50.760 kips
H = MSE Wall Height = 23.50 ft

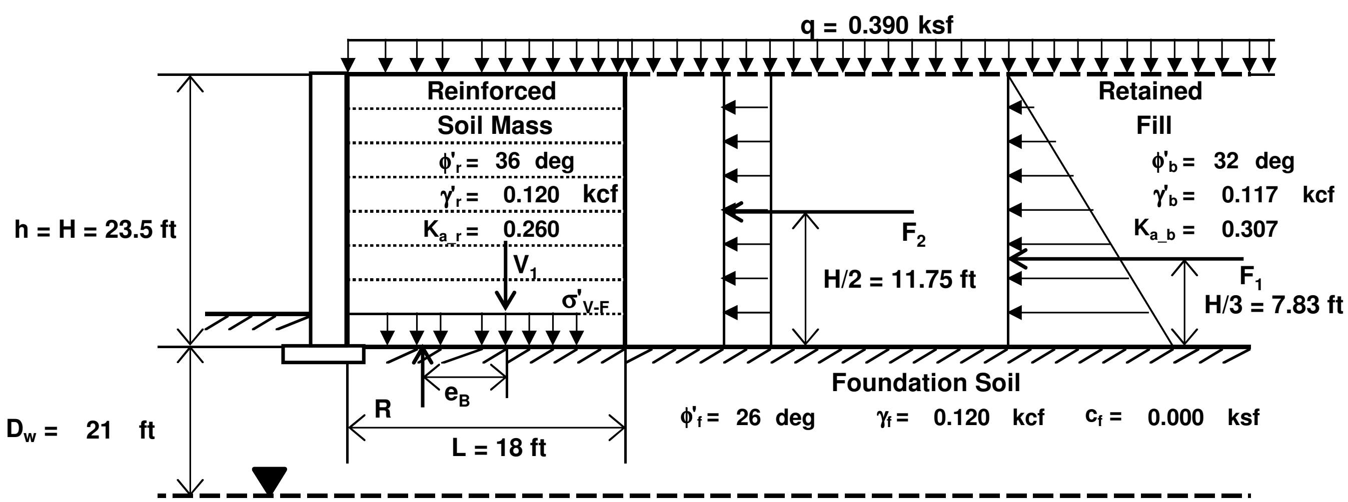
$$e = \frac{(1.50)(9.918 \text{ kips})(7.83 \text{ ft}) + (1.75)(2.814 \text{ kips})(11.75 \text{ ft})}{(1.00)(50.760 \text{ kips})}$$

= 3.44 ft

Check Eccentricity

e must be less than or equal to L/4 per AASHTO 11.6.3.3
3.44 ft ≤ 4.5 ft
OK

Bearing Resistance (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c



External Stability for MSE Walls: Bearing Resistance - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1 + \Psi_{LS}qL}$$ *FHWA Eqn. 4-19*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 *AASHTO Table 3.4.1-1*
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75 *AASHTO Table 3.4.1-1*
F_1 = Force Generated from Lateral Earth Pressure = 9.918 kips *FHWA Eqn. 4-5*
F_2 = Force Generated from Traffic Surcharge = 2.814 kips *FHWA Eqn. 4-6*
V_1 = Total Vertical Force from the Reinforced Soil Mass = 50.760 kips

Bearing Resistance Continued (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c

q = Live Load Traffic Surcharge = 0.390 ksf
H = MSE Wall Height = 23.50 ft
L = Reinforcement Length = 18.00 ft

$$e_B = \frac{(1.50)(9.918 \text{ kips})(7.83 \text{ ft}) + (1.75)(2.814 \text{ kips})(11.75 \text{ ft})}{(1.35)(50.8 \text{ kips}) + (1.75)(0.390 \text{ ksf})(18.00 \text{ ft})}$$

= 2.16 ft

Calculate Nominal Bearing Resistance, (q_n) — *AASHTO Eqn. 10.6.3.1.2a-1*

$q_n = c_f N_c + 0.5\gamma B' N_\gamma C_{w\gamma}$ — *AASHTO Eqn. 10.6.3.1.2a-1*

c_f = Cohesion for Foundation Soil = 0.000 ksf
N_c = Bearing Capacity Factor (based on ϕ'_f) = 22.30 — *AASHTO Table 10.6.3.1.2a-1*
γ_f = Total Unit Weight for Foundation Soil = 0.120 kcf
B' = Effective Foundation Width = L - $2e_B$ — *AASHTO C11.10.5.4*
= 18.0 ft - 2(2.16 ft) = 13.68 ft
N_γ = Bearing Capacity Factor (based on ϕ'_f) = 12.50 — *AASHTO Table 10.6.3.1.2a-1*
$C_{w\gamma}$ = Correction Factor to Account for Location of Groundwater Table = 0.9 — *AASHTO Table 10.6.3.1.2a-2*

q_n = (0.000 ksf)(22.30) + (0.5)(0.120 kcf)(13.68 ft)(12.50)(0.90)

= 9.234 ksf

Calculate Factored Bearing Resistance, (q_r)

$q_r = \varphi_b q_n$ — *AASHTO Eqn. 10.6.3.1.1-1*

φ_b = Resistance Factor for Bearing = 0.65 — *AASHTO Table 11.5.6-1*
q_n = Nominal Bearing Resistance = 9.234 ksf — *AASHTO Eqn. 10.6.3.1.2a-1*

q_r = (0.65)(9.234 ksf) = 6.002 ksf

Calculate Factored Vertical Bearing Pressure at the base, ($q_{V\text{-}F}$)

$$\sigma_{V\text{-}F} = \frac{\Psi_{EV} V_1 + \Psi_{LS} q L}{L - 2e_B}$$ — *FHWA Eqn. 4-20*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 — *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.c, AASHTO C3.4.1, and AASHTO C11.5.5)
V_1 = Total Vertical Force from the Reinforced Soil Mass = 50.760 kips
Ψ_{LS} = Load Factor for Surcharge = 1.75 — *AASHTO Table 3.4.1-1*
q = Live Load Traffic Surcharge = 0.390 ksf
L = Reinforcement Length = 18.00 ft
e_B = Eccentricity for Bearing = 2.16 ft — *FHWA Eqn. 4-19*

$$\sigma_{V\text{-}F} = \frac{(1.35)(50.76 \text{ kips ft}) + (1.75)(0.390 \text{ ksf})(18.00 \text{ ft})}{18.00 \text{ ft} - 2(2.16 \text{ ft})}$$

= 5.907 ksf

Check Bearing

q_R must be greater than or equal to $q_{V\text{-}F}$
6.002 ksf ≥ 5.907 ksf
OK

Calculated Resistance Factor

$\sigma_{V\text{-}F}/q_n$ = **0.64**

Bearing Resistance (Local/Punching Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1.2b, and FHWA 4.4.6.c

Local and Punching shear failure occurs in loose or compressible soils and in weak soils under slow (drained) loading. This mode of failure will only be considered for foundation material that is cohesive.

The Foundation Material for this Project is not Cohesive.

Seismic Stablity - SCDOT GDM Section 14.12

Calculate Wave Scattering Effects

Wave Scattering Coefficient, α_w =1+0.01H((0.5β)-1<1.0 — SCDOT Equation 13-103

α_w = 0.8473

Ground Motion Index, $\beta = k_{max}/S_{d1}$ = 0.70 — SCDOT Equation 13-104

Average seismic horizontal coefficient due to wave scattering

$k_h = \alpha_w * k_{max}$ = 0.169 — SCDOT Equation 13-102

Calculate Seismic Active Earth Pressure Coefficicnet (Mononobe -Kobe Method) SCDOT GDM Section 14.4.1

Seismic Active Earth Pressure Coefficient Reinforced Soils, K_{AEr} = 0.553

Seismic Active Earth Pressure Coefficient Retained, K_{AEb} = 0.614

$$K_{ae} = \frac{\cos^2(\phi - \Psi - \theta)}{\cos(\Psi)\cos^2(\theta)\cos(\delta + \theta + \Psi)\left[1 + \sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \Psi - \beta)}{\cos(\delta + \theta + \Psi)\cos(\beta - \theta)}}\right]^2} \quad \text{Equation 14-2}$$

Where,

- γ = unit weight of soil
- H = height of wall or effective height of wall (h_{eff})
- ϕ = angle of internal friction of soil
- Ψ = $\tan^{-1}[k_h/(1-k_v)]$
- δ = angle of friction between soil and wall
- k_h = horizontal acceleration coefficient
- k_v = vertical acceleration coefficient, typically set to zero.
- β = backfill slope angle
- θ = angle of backface of the wall with the vertical

	Reinforced Soil		Retained Soil	
φ =	36.0	deg	32.0	deg
Ψ =	9.6	deg	9.6	deg
θ =	0	deg	0	deg
δ =	0	deg	0.00	deg
β =	0	deg	0	deg

Calculate Inertial Wall Width, $B_{inertial} = \omega H$ 16

coefficient, ω = 0.70

Calculate Active Earth Thrust Force, $P_{AE} = \gamma_p * 0.5 K_{AEr} * \gamma_p * H^2$ = 19.8 kips — GDM Eq. 14-40

Calculate Intertial Reinforced Soil Mass Force, $P_{IR} = \gamma_p * k_{avg} * B_{inertial} * H_{wall} *$ = 0.33 kips — GDM Eq. 14-41

Dead Load Surcharge Force, P_{DC} = 2.021 kips — GDM Eq. 14-45

Live Load Surcharge Force, P_{LL} = 1.804 kips — GDM Eq. 14-46

Total Seismic Driving Force, F_H = 24.0 kip

Calculated Resistance Factor, $\varphi = F_H/R_t$ = **0.97**

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EQ\text{-}P} F_{1s}(H/2) + \Psi_{EQ\text{-}LL} F_{2s}(H/2)}{\Psi_{EV} V_1 + \Psi_{EQ\text{-}LL} qL}$$ *FHWA Eqn. 4-19*

Ψ_{EHAeq} = $\Psi_{EQ\text{-}p}$ = Load Factor for Horizontal (Active) Earth Pressure = 1.00 *AASHTO Table 3.4.1-1*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

Ψ_{LSeq} = $\Psi_{EQ\text{-}p}$ = Load Factor for Surcharge = 1.00 *AASHTO Table 3.4.1-1*

F_{1s} = Force Generated from Lateral Earth Pressure = 22.199 kips *FHWA Eqn. 4-5*

F_{2s} = Force Generated from Traffic Surcharge = 1.804 kips *FHWA Eqn. 4-6*

V_1 = Total Vertical Force from the Reinforced Soil Mass = 50.760 kips

q = Live Load Traffic Surcharge = 0.250 ksf *FHWA Eqn. 4-19*

H = MSE Wall Height = 23.50 ft

L = Reinforcement Length = 18.00 ft

$$e_B = \frac{(1.00)(22.199 \text{ kips})(11.75 \text{ ft}) + (1.00)(1.804 \text{ kips})(11.75 \text{ ft})}{(1.00)(50.8 \text{ kips}) + (1.00)(0.250 \text{ ksf})(18.00 \text{ ft})}$$

= 5.10 ft

Calculate Factored Vertical Bearing Pressure at the base, ($q_{V\text{-}F}$)

$$\sigma_{V\text{-}F} = \frac{\Psi_{EQ\text{-}P} V_1 + \Psi_{EQ\text{-}LS} qL}{L - 2e_B}$$ *FHWA Eqn. 4-20*

$\Psi_{EQ\text{-}p}$ = Load Factor for Dead Load of Earth Fill = 1.00

V_1 = Total Vertical Force from the Reinforced Soil Mass = 50.760 kips

Ψ_{LSeq} = $\Psi_{EQ\text{-}ll}$ = Load Factor for Surcharge = 1.00

q = Live Load Traffic Surcharge = 0.250 ksf

L = Reinforcement Length = 18.00 ft

e_B = Eccentricity for Bearing = 5.10 ft

$$\sigma_{V\text{-}F} = \frac{(1.00)(50.76 \text{ kips})(\text{ ft}) + (1.00)(0.250 \text{ ksf})(18.00 \text{ ft})}{18.0 \text{ ft} - 2(5.10 \text{ ft})}$$

= 7.408 ksf

Calculated Resistance Factor

$\sigma_{V\text{-}F}/q_n$ = **0.80**

Purpose: Example for determining seismic active earth pressure coefficient for infinite slope MSE Wall external stability calculations

Define Terms

Horizontal acceleration coefficient: $k_h := 0.20$

Vertical acceleration coefficient: $k_v := 0$

Internal angle of friction: $\phi_s := 26\ deg$

Unit Weight of Wall Backfill: $\gamma_s := 105\ pcf$

Soil Cohesion: $c_s := 0\ psf$

Soi/Wall Adhesion: $c_a := 0\ psf$

Angle of Friction between soil and wall: $\delta := 0.67 \cdot \phi_s$

Wall angle: $\omega_w := 0\ deg$

Wall Height $H := 8.5\ ft$

Backfill inclination: $\beta := 27\ deg$

Itterate in one degree incremenents for failure wedge surface, let:

Failure surface inclination: $\alpha := 55\ deg$

Determine Area of Failure Wedge:

Determine Length of Failure Surface (Law of Sines):

$$L_n := H \cdot \frac{\sin(90\ deg + \beta)}{\sin(180\ deg - \beta - \alpha)} = 7.648\ ft$$

The depth of the failure wedge is:

$$h := L_n \cdot \cos(\alpha) = 4.387\ ft$$

The Area of the failure wedge is: $A_w := \frac{1}{2} \cdot L_n \cdot h = 16.775\ ft^2$

The weight of the wedge per foot of wall is: $W_w := \gamma_s \cdot A_w = 1.761\ \frac{kip}{ft}$

The dead load surcharge is: $W_{dl} := 0.140\ \frac{kip}{ft}$

The live load surcharge is: $W_{ll} := 0.250\ \frac{kip}{ft}$

The total weight is: $W_t := W_w + W_{dl} + W_{ll}$

The active thrust force is:

$$P_{AE} := \frac{W_t \cdot \left(\left(1 - k_v\right) \cdot \tan\left(\alpha - \phi_s\right) + k_h\right) - c_s \cdot L_n \cdot \left(\sin(\alpha) \cdot \tan\left(\alpha - \phi_s\right) + \cos(\alpha)\right) - c_a \cdot H \cdot \left(\tan\left(\alpha - \phi_s\right) \cdot \cos\left(\omega_w\right) + \sin\left(\omega_w\right)\right)}{\left(1 + \tan\left(\delta + \omega_w\right) \cdot \tan\left(\alpha - \phi_s\right)\right)^{\cos\left(\delta + \omega_w\right)}}$$

$$P_{AE} = 1.393\ \frac{kip}{ft}$$

STATE OF NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION
GEOTECHNICAL ENGINEERING UNIT
1589 MAIL SERVICE CENTER

WBS NO.: TIP NO.: COUNTY:
SUBJECT: LRFD External Stability Analysis for MSE Walls
Wall 31 B - Ramp 4 Sta 383+50
PREPARED BY: CLB DATE: 08/17/15 STATION: 383+50
CHECKED BY: DATE: STR. NO.: SHEET: 1 OF 8

Input Traffic Surcharge, Backslope, Wall Geometry, and Soil Parameters

Traffic and Overlay Surcharge Surcharge

q = 390 psf *Live Load Traffic Surcharge and Pavement Overlay*
35.9 % Surcharge due to overlay
q_{ol} = 140 psf *Pavement overlay surcharge*

Backslope

Broken Backslope H : V = 2 : 1 d = 5.00 ft
(d = horizontal distance from back of wall face to top of backslope)

Wall Geometry

H = 10.00 ft *Wall Height*
L/H = 1.10 *Ratio of Reinforcement Length to Wall Height*
(L/H ≥ 0.7 per NCDOT MSE Wall Standard Provision)
L = 11.00 ft *Reinforcement Length*
(L ≥ 6 ft per NCDOT MSE Wall Standard Provision)
h = 12.50 ft *Height of Wall & Slope at the back of Reinforced Zone*

D_w = 47.00 ft *Distance of Water Table below the Bottom of the Wall*

Soil Parameters for Reinforced Zone

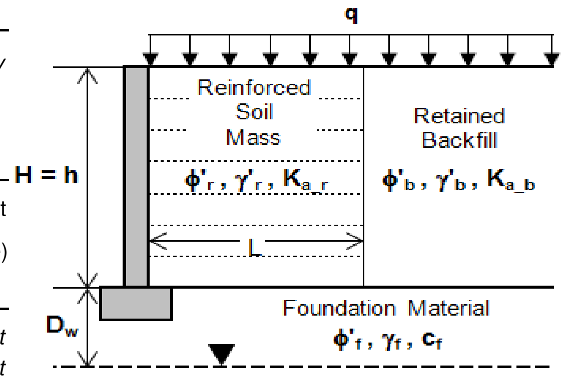
ϕ'_r = 36 deg *Effective Friction Angle*
γ'_r = 105 pcf *Effective Unit Weight*
K_{a_r} = 0.265 *Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

Soil Parameters for Retained Backfill

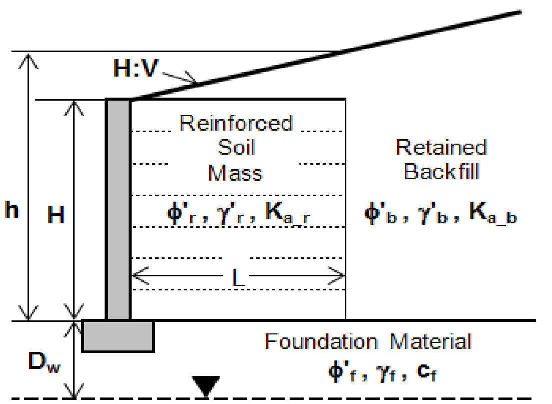
ϕ'_b = 30 deg *Effective Friction Angle*
γ'_b = 105 pcf *Effective Unit Weight*
K_{a_b} = 0.341 *Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

Soil Parameters for Foundation Soil

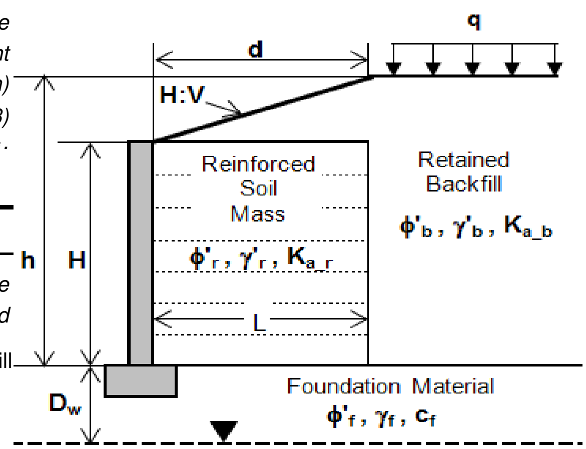
ϕ'_f = 30 deg *Effective Friction Angle*
γ_f = 110 pcf *Total Unit Weight*
c_f = 0 psf *Undrained Shear Strength (Cohesion)*
μ = 0.58 *Coefficient of Friction (AASHTO 11.10.5.3)*
The coefficient of friction shall be based on the lesser of ϕ'_r and ϕ'_f.



Typical MSE Wall with Level Backslope and Traffic Surcharge



Typical MSE Wall with Infinite Backslope



Typical MSE Wall with Broken Backslope and Traffic Surcharge

Input Load and Resistance Factors

Load Factors (See AASHTO Table 3.4.1-1 and 2)

Ψ_{LS} = 1.75 *Lilve Load Surcharge*
$\Psi_{EH(A)}$ = 1.50 *Horizontal (Active) Earth Pressure Load*
Ψ_{EV} = 1.00 min, 1.35 max Vertical Dead Load Generated from Earth Fill
$\Psi_{EQ\text{-}p}$ = 1.00
$\Psi_{EQ\text{-}LL}$ = 0.50

Resistance Factors (See AASHTO Table 11.5.6-1)

φ_b = 0.65 *Bearing Resistance for MSE Walls*
φ_τ = 1.00 *Sliding Resistance for MSE Walls*

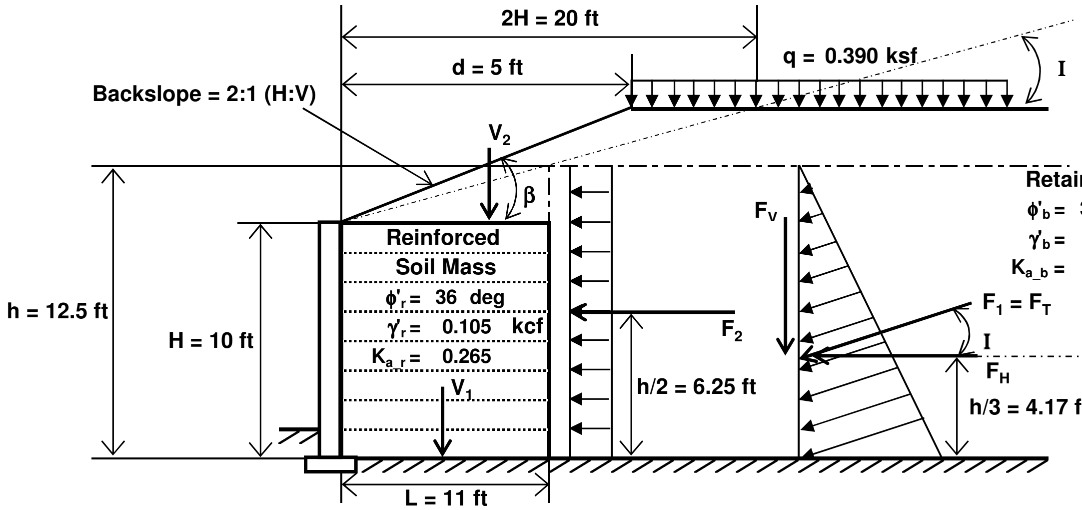
Seismic Design Acceleration Parameters

k_{max} = 0.20 *Maximum Horizontal Ground Acceration (PGA)*
S_{d1}= 0.14 *Peak spectral acceleration at 1 second*

References:

1. *AASHTO LRFD Bridge Design Specifications, 5th Edition, 2010*
2. *FHWA-NHI-10-024 Design and Construction of MSE Walls and Reinforced Soil Slopes - Vol I, 2009*
3. *SCDOT Geotechnical Design Manual version 1.1, 2010*

Calculate Forces acting on Wall



External Stability for MSE Walls: Earth Pressure - Broken Backslope Case
(Based on FHWA Figure 4-4 and AASHTO Figure 3.11.5.8.1-3)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Angle of β and I

β = Inclination Angle of Backslope
= $\tan^{-1}$ ($V_{Backslope}$ / $H_{Backslope}$)
= $\tan^{-1}$(1.0 / 2.0) = 26.57 degrees

I = Inclination Angle of an Imaginary Plane that starts at the top of the wall and intersects the top of the backslope at a distance of 2H from the face of the wall. (Must be lees than or equal to the inclination angle of the backslope, β)
= $\tan^{-1}$[(d x tan β) / (2H)] ≤ β
= $\tan^{-1}$ [(5.00 x tan 26.57 deg) / (2 x 10.00 ft)] = 7.13 degrees

Forces from Vertical Earth Loads

V_1 = Total Vertical Force from the Reinforced Soil Mass = (γ_r)(H)(L)
= (0.105 kcf)(10.00 ft)(11.00 ft) = 11.550 kips

V_2 = Total Vertical Force from the Retained Fill above the Reinforced Soil Mass = 0.5(γ_b)(h - H)(L)
= (0.5)(0.105 kcf)(12.50 ft - 10.00 ft)(11.00 ft) = 1.444 kips

Forces from Lateral Earth Pressure

F_1 = F_T = Total Force Generated from Lateral Earth Pressure = 0.5(γ_b)(h^2)(K_{ab}) FHWA Eqn. 4-7
= (0.5)(0.105 kcf)(12.50 ft $)^2$(0.341) = 2.797 kips

F_H = Horizontal Force Generated from Lateral Earth Pressure = (F_1)(cos I) FHWA Eqn. 4-10
= (2.797 kips)(cos 7.13 deg) = 2.776 kips

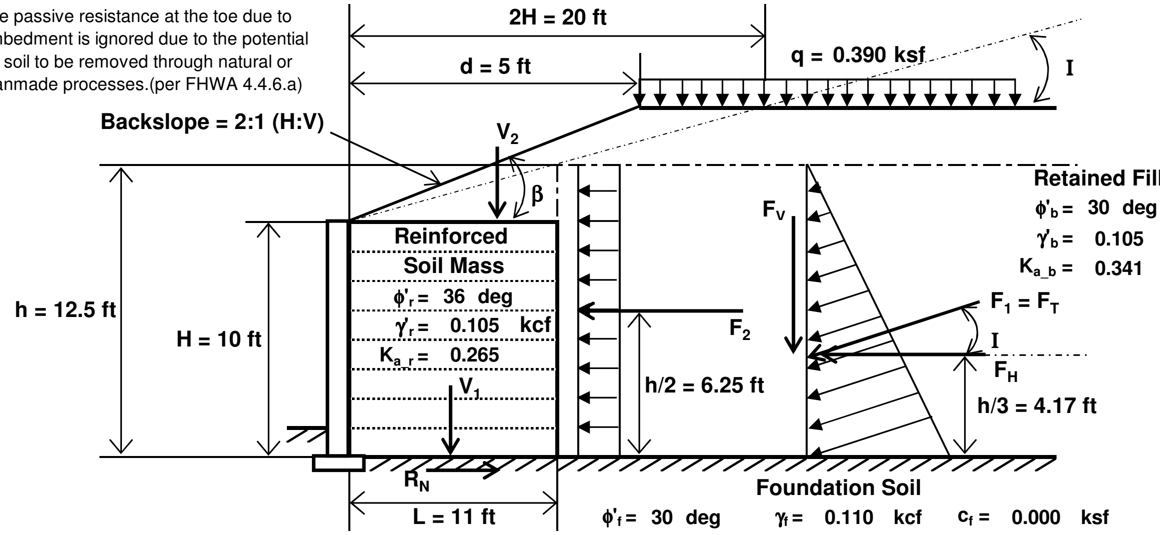
F_V = Vertical Force Generated from Lateral Earth Pressure = (F_1)(sin I)
= (2.797 kips)(sin 7.13 deg) = 0.347 kips

Horizontal Force from Traffic Surcharge

F_2 = Force Generated from Traffic Surcharge = (q)(h)(K_{ab}) *FHWA Eqn. 4-6*
= (0.390 ksf)(12.50 ft) (0.341) = 1.662 kips

Sliding Stability - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

The passive resistance at the toe due to embedment is ignored due to the potential for soil to be removed through natural or manmade processes.(per FHWA 4.4.6.a)



External Stability for MSE Walls: Sliding Stability - Broken Backslope Case
(Based on FHWA Figure 4-4 and AASHTO Figure 3.11.5.8.1-3)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Factored Sliding Resistance (R_R)

$R_R = \varphi R_N = \varphi_\tau R_\tau$ — *AASHTO Eqn. 10.6.3.4-1*

φ_τ = *Resistance Factor for Sliding =* 1.00 — *AASHTO Table 11.5.6-1*
R_τ = *Nominal Sliding Resistance between Reinforced Soil Mass and Foundation Soil*
$= \Psi_{EV}(V_1 + V_2 + \Psi_{EHA}F_V)\mu + (c_f)(L)$ — *FHWA Eqn. 4-13 and AASHTO 10.6.3.4*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 — *AASHTO Table 3.4.1-1*
(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 — *AASHTO Table 3.4.1-1*
V_1 = Total Vertical Force from the Reinforced Soil Mass = 11.550 kips
V_2 = Total Vertical Force from the Retained Fill above the Reinforced Soil Mass = 1.444 kips
F_V = Vertical Force Generated from Lateral Earth Pressure = 0.347 kips
μ = Coefficent of Friction between Reinforced Soil Mass and Foundation Soil = 0.58 — *AASHTO 11.10.5.3*
c_f = Cohesion for Foundation Soil = 0.000 ksf
L = Reinforcement Length = 11.00 ft

R_τ = (1.00)(11.550 kips + 1.444 kips + 1.50 x 0.347 kips)(0.58) + (0.000 ksf)(11.00) = 7.838 kips

R_R = (1.00)(7.838 kips) = 7.838 kips

Factored Horizontal Driving Force (P_d)

$P_d = (\Psi_{EHA})(F_H) + (\Psi_{LS})(F_2)$ — FHWA Eqn. 4-10

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 — *AASHTO Table 3.4.1-1*
F_H = Horizontal Force Generated from Lateral Earth Pressure = 2.776 kips — FHWA Eqn. 4-7
Ψ_{LS} = Load Factor for Horizontal (Active) Earth Pressure = 1.75 — *AASHTO Table 3.4.1-1*
F_2 = Force Generated from Traffic Surcharge = 1.662 kips — *FHWA Eqn. 4-6*

P_d = (1.50)(2.776 kips) + (1.75)(1.662 kips) = 7.073 kips

STATE OF NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION
GEOTECHNICAL ENGINEERING UNIT
1589 MAIL SERVICE CENTER
RALEIGH, NORTH CAROLINA 27699

WBS NO.: ______ TIP NO.: ______ COUNTY: ______
SUBJECT: LRFD External Stability Analysis for MSE Walls
Wall 31 B - Ramp 4 Sta 383+50
PREPARED BY: CLB DATE: 08/17/15 STATION: 383+50
CHECKED BY: ______ DATE: ______ STR. NO.: ______ SHEET: 4 OF 8

Sliding Stability Continued - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

Check Sliding

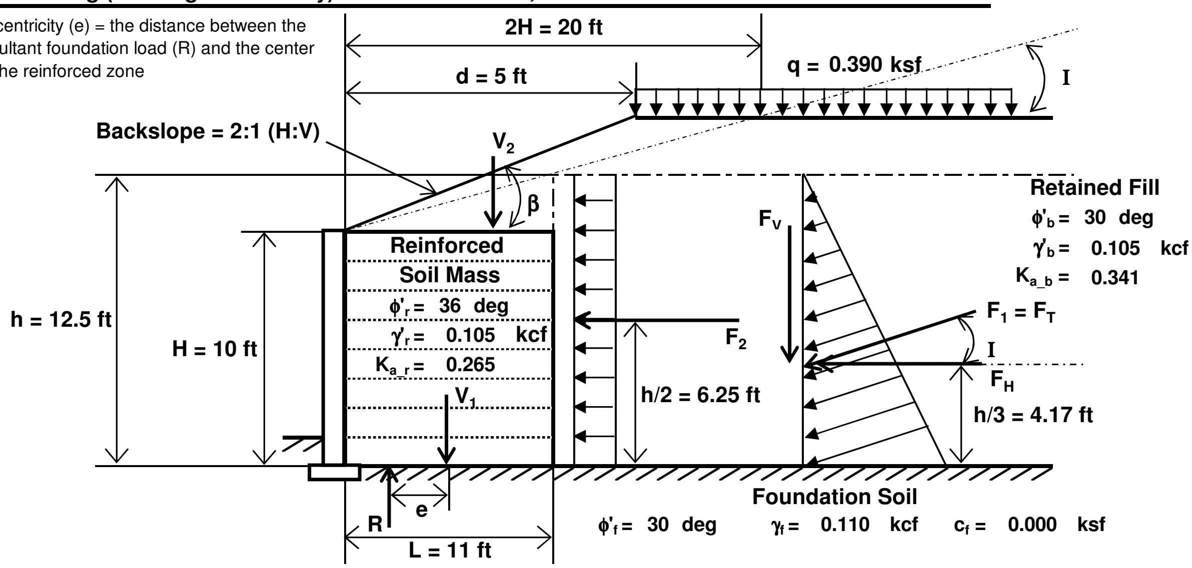
R_R must be greater than or equal to P_d **RF=** 0.90

7.838 kips ≥ 7.073 kips

OK

Overturning (Limiting Eccentricity) - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Eccentricity (e) = the distance between the resultant foundation load (R) and the center of the reinforced zone



External Stability for MSE Walls: Overturning - Broken Backslope Case
(Based on FHWA Figure 4-4 and AASHTO Figure 3.11.5.8.1-3)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity (e)

$$e = \frac{\Psi_{EHA}F_H(h/3) - \Psi_{EHA}F_V(L/2) + \Psi_{EV}V_2(L/6) + Y_{LS}F_2(h/2)}{\Psi_{EV}V_1 + \Psi_{EV}V_2 + Y_{EHA}F_V}$$ FHWA Eqn. 4-16

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 *AASHTO Table 3.4.1-1*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 *AASHTO Table 3.4.1-1*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.b, AASHTO C3.4.1, and AASHTO C11.5.5)

Ψ_{LS} = Load Factor for Surcharge = 1.75

F_H = Horizontal Force Generated from Lateral Earth Pressure = 2.776 kips FHWA Eqn. 4-7

F_V = Vertical Force Generated from Lateral Earth Pressure = 0.347 kips

F_2 = Force Generated from Traffic Surcharge = 1.662 kips

V_1 = Total Vertical Force from the Reinforced Soil Mass = 11.550 kips

V_2 = Total Vertical Force from the Retained Fill above the Reinforced Soil Mass = 1.444 kips

h = Height of Wall plus Backslope at the back of Reinforced Zone = 12.50 ft

L = Reinforcement Length = 11.00 ft

$$e = \frac{(\ 17.348\ \text{kip - ft}\ ) - (\ 2.86\ \text{kip - ft}\ ) + (\ 2.647\ \text{kip - ft}\ ) + (\ 18.18\ \text{kip - ft}\ )}{(\ 11.550\ \text{kips}\ ) + (\ 1.444\ \text{kips}\ ) + (\ 0.521\ \text{kips}\ )}$$

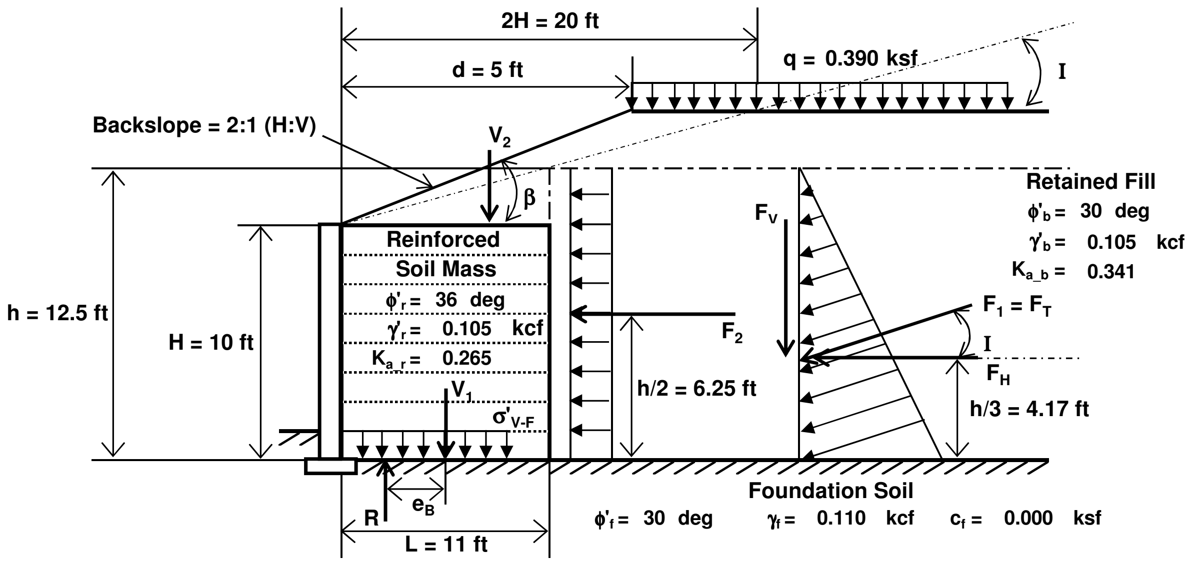
= 2.61 ft

Overturning (Limiting Eccentricity) Continued - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Check Eccentricity

e must be less than or equal to L/4 per AASHTO 11.6.3.3
2.61 ft ≤ 2.75 ft
OK

Bearing Resistance (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c



External Stability for MSE Walls: Bearing Resistance - Broken Backslope Case
(Based on FHWA Figure 4-4 and AASHTO Figure 3.11.5.8.1-3)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity (e_B)

$$e = \frac{\Psi_{EHA}F_H(h/3) - \Psi_{EHA}F_V(L/2) + \Psi_{EV}V_2(L/6) + Y_{LS}F_2(h/2)}{\Psi_{EV}V_1 + \Psi_{EV}V_2 + Y_{EHA}F_V}$$ FHWA Eqn. 4-16

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 *AASHTO Table 3.4.1-1*
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 *AASHTO Table 3.4.1-1*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.b, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75
F_H = Horizontal Force Generated from Lateral Earth Pressure = 2.776 kips FHWA Eqn. 4-7
F_V = Vertical Force Generated from Lateral Earth Pressure = 0.347 kips
F_2 = Force Generated from Traffic Surcharge = 1.662 kips
V_1 = Total Vertical Force from the Reinforced Soil Mass = 11.550 kips
V_2 = Total Vertical Force from the Retained Fill above the Reinforced Soil Mass = 1.444 kips
h = Height of Wall plus Backslope at the back of Reinforced Zone = 12.50 ft
L = Reinforcement Length = 11.00 ft

$$e = \frac{(\ 17.348\ \text{kip - ft}) - (\ 2.86\ \text{kip - ft}) + (\ 3.57\ \text{kip - ft}) + (\ 18.18\ \text{kip - ft})}{(\ 15.59\ \text{kips}) + (\ 1.949\ \text{kips}) + (\ 0.521\ \text{kips})}$$

= 2.01 ft

Bearing Resistance (General Shear) Continued - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c

Calculate Nominal Bearing Resistance, (q_n) — *AASHTO Eqn. 10.6.3.1.2a-1*

$q_n = c_f N_c + 0.5\gamma B' N_\gamma C_{w\gamma}$ — *AASHTO Eqn. 10.6.3.1.2a-1*

c_f = Cohesion for Foundation Soil = 0.000 kips
N_c = Bearing Capacity Factor (based on ϕ'_f) = 30.10 — *AASHTO Table 10.6.3.1.2a-1*
γ = Total Unit Weight for Foundation Soil = 0.110 kcf
B' = Effective Foundation Width = $L - 2e_B$ — *AASHTO C11.10.5.4*
= 11.0 ft - 2(2.01 ft) = 6.98 ft
N_γ = Bearing Capacity Factor (based on ϕ'_f) = 22.40 — *AASHTO Table 10.6.3.1.2a-1*
$C_{w\gamma}$ = Correction Factor to Account for Location of Groundwater Table = 1.0 — *AASHTO Table 10.6.3.1.2a-2*

q_n = (0.000 ksf)(30.10) + (0.5)(0.110 kcf)(6.98 ft)(22.40)(1.00) = 8.599 ksf

Calculate Factored Bearing Resistance, (q_r)

$q_r = \varphi_b q_n$ — *AASHTO Eqn. 10.6.3.1.1-1*

φ_b = Resistance Factor for Bearing = 0.65 — *AASHTO Table 11.5.6-1*
q_n = Nominal Bearing Resistance = 8.599 ksf — *AASHTO Eqn. 10.6.3.1.2a-1*

q_r = (0.65)(8.599 ksf) = 5.589 ksf

Calculate Factored Vertical Bearing Pressure at the base, (q_{V-F})

$$\sigma_{V-F} = \frac{\Psi_{EV}V_1 + \Psi_{EV}V_2 + \Psi_{EHA}F_V}{L - 2e_B}$$ FHWA Eqn. 4-23

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 — *AASHTO Table 3.4.1-1*
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 — *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.c, AASHTO C3.4.1, and AASHTO C11.5.5)
V_1 = Total Vertical Force from the Reinforced Soil Mass = 11.550 kips
V_2 = Total Vertical Force from the Retained Fill above the Reinforced Soil Mass = 1.444 kips
F_V = Vertical Force Generated from Lateral Earth Pressure = 0.347 kips
L = Reinforcement Length = 11.00 ft
e_B = Eccentricity for Bearing = 2.01 ft — FHWA Eqn. 4-19

$$\sigma_{V-F} = \frac{(1.35)(11.550 \text{ kips ft}) + (1.35)(1.444 \text{ kips}) + (1.50)(0.347 \text{ kips})}{11.00 \text{ ft} - 2(2.01 \text{ ft})}$$

= 2.588 ksf

Check Bearing

q_R must be greater than or equal to q_{V-F}
5.589 ksf ≥ 2.588 ksf
OK

Bearing Resistance (Local/Punching Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1.2b, and FHWA 4.4.6.c

Local and Punching shear failure occurs in loose or compressible soils and in weak soils under slow (drained) loading. This mode of failure will only be considered for foundation material that is cohesive.

The Foundation Material for this Project is not Cohesive.

Seismic Stablity - SCDOT GDM Section 14.12

Calculate Wave Scattering Effects

Wave Scattering Coefficient, α_w =1+0.01H((0.5β)-1<1.0 — SCDOT Equation 13-103

α_w = 0.92

Ground Motion Index, f=k_{max}/S_{d1} = 0.70 — SCDOT Equation 13-104

Average seismic horizontal coefficient due to wave scattering

$k_h = \alpha_w * k_{max}$ = 0.20 — SCDOT Equation 13-102

Calculate Seismic Active Earth Pressure Coefficinet (Mononobe -Kobe Method) SCDOT GDM Section 14.4.1

Seismic Active Earth Pressure Coefficient Reinforced Soils, K_{AEr} = N/A

Seismic Active Earth Pressure Coefficient Retained, K_{AEb} = N/A

$$K_{ae} = \frac{\cos^2(\phi - \Psi - \theta)}{\cos(\Psi)\cos^2(\theta)\cos(\delta+\theta+\Psi)\left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\Psi-\beta)}{\cos(\delta+\theta+\Psi)\cos(\beta-\theta)}}\right]^2} \quad \text{Equation 14-2}$$

Where,

γ	=	unit weight of soil
H	=	height of wall or effective height of wall (h_{eff})
ϕ	=	angle of internal friction of soil
Ψ	=	$\tan^{-1}[k_h/(1-k_v)]$
δ	=	angle of friction between soil and wall
k_h	=	horizontal acceleration coefficient
k_v	=	vertical acceleration coefficient, typically set to zero.
β	=	backfill slope angle
θ	=	angle of backface of the wall with the vertical

	Reinforced Soil		Retained Soil
φ =	36.0 deg	φ =	30.0 deg
Ψ =	11.3 deg	Ψ =	11.3 deg
θ =	0 deg	θ =	0 deg
δ =	7.13 deg	δ =	7.1 deg
β =	26.57 deg	β =	26.57 deg

Calculate Inertial Wall Width, $B_{inertial} = \omega H$ 9

coefficient, ω = 0.70

Calculate Active Earth Thrust Force, $P_{AE} = \gamma_p * 0.5 K_{AEr} * \gamma_p * H^2$ = 1.8 kips — GDM Eq. 14-40

Calculate Intertial Reinforced Soil Mass Force, $P_{IR} = \gamma_p * k_{avg} * B_{inertial}$ = 0.01 kips — GDM Eq. 14-41

Dead Load Surcharge Force, P_{DC} = = N/A kips — GDM Eq. 14-45

Live Load Surcharge Force, P_{LL} = = 0.312 kips — GDM Eq. 14-46

Total Seismic Driving Force, F_H = 2.2 kip Calculated Resistance Factor, $\varphi = F_H/R_t$ = **0.3**

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EQ\text{-}P}F_{1s}(H/2) + \Psi_{EQ\text{-}LL}F_{2s}(H/2}{\Psi_{EV}V_1 + \Psi_{EQ\text{-}LL}qL}$$ *FHWA Eqn. 4-19*

$\Psi_{EHAeq} = \Psi_{EQ\text{-}p} =$ Load Factor for Horizontal (Active) Earth Pressure = 1.00 *AASHTO Table 3.4.1-1*

$\Psi_{EV} =$ Load Factor for Dead Load of Earth Fill = 1.00 *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

$\Psi_{LSeq} = \Psi_{EQ\text{-}p} =$ Load Factor for Surcharge = 1.00 *AASHTO Table 3.4.1-1*

$F_{1s} =$ Force Generated from Lateral Earth Pressure = 1.833 kips *FHWA Eqn. 4-5*

$F_{2s} =$ Force Generated from Traffic Surcharge = 0.000 kips *FHWA Eqn. 4-6*

$V_1 =$ Total Vertical Force from the Reinforced Soil Mass = 11.550 kips

$q =$ Live Load Traffic Surcharge = 0.000 ksf *FHWA Eqn. 4-19*

$H =$ MSE Wall Height = 10.00 ft

$L =$ Reinforcement Length = 11.00 ft

$$e_B = \frac{(\ 1.00\ )(\ 1.833\ \text{kips})(\ 5.00\ \text{ft}) + (\ 1.00\ )(\ 0.000\ \text{kips})(\ 5.00\ \text{ft})}{(\ 1.00\ )(\ 11.6\ \text{kips}) + (\ 1.00\ )(\ 0.000\ \text{ksf})(\ 11.00\ \text{ft})}$$

$= 0.79$ ft

Calculate Factored Vertical Bearing Pressure at the base, ($q_{V\text{-}F}$)

$$\sigma_{V\text{-}F} = \frac{\Psi_{EQ\text{-}P}V_1 + \Psi_{EQ\text{-}LS}qL}{L - 2e_B}$$ *FHWA Eqn. 4-20*

$\Psi_{EQ\text{-}p} =$ Load Factor for Dead Load of Earth Fill = 1.00

$V_1 =$ Total Vertical Force from the Reinforced Soil Mass = 11.550 kips

$\Psi_{LSeq} = \Psi_{EQ\text{-}II} =$ Load Factor for Surcharge = 1.00

$q =$ Live Load Traffic Surcharge = 0.250 ksf

$L =$ Reinforcement Length = 11.00 ft

$e_B =$ Eccentricity for Bearing = 0.79 ft

$$\sigma_{V\text{-}F} = \frac{(\ 1.00\ )(\ 11.55\ \text{kips ft}) + (\ 1.00\ )(\ 0.250\ \text{ksf})(\ 11.00\ \text{ft})}{11.0\ \text{ft} - 2(\ 0.79\ \text{ft})}$$

$= 1.682$ ksf

Calculated Resistance Factor

$\sigma_{V\text{-}F}/q_n =$ **0.30**

STATE OF NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION
GEOTECHNICAL ENGINEERING UNIT
1589 MAIL SERVICE CENTER

WBS NO.: ___ TIP NO.: ___ COUNTY: ___
SUBJECT: LRFD External Stability Analysis for MSE Walls
Wall 33 - Ramp 2B
PREPARED BY: CLB DATE: 09/11/15 STATION: 40+75
CHECKED BY: ___ DATE: ___ STR. NO.: ___ SHEET: 1 OF 8

Input Traffic Surcharge, Backslope, Wall Geometry, and Soil Parameters

Traffic and Overlay Surcharge Surcharge

q = 390 psf *Live Load Traffic Surcharge and Pavement Overlay*
35.9 % Surcharge due to overlay
q_{ol} = 140 psf *Pavement overlay surcharge*

Backslope

Horizontal Backslope

(d = horizontal distance from back of wall face to top of backslope)

Wall Geometry

H = 68.00 ft *Wall Height*
L/H = 0.85 *Ratio of Reinforcement Length to Wall Height*
($L/H \geq 0.7$ per NCDOT MSE Wall Standard Provision)
L = 58.00 ft *Reinforcement Length*
($L \geq 6$ ft per NCDOT MSE Wall Standard Provision)
h = 68.00 ft *Height of Wall & Slope at the back of Reinforced Zone*

D_w = 12.00 ft *Distance of Water Table below the Bottom of the Wall*

Soil Parameters for Reinforced Zone

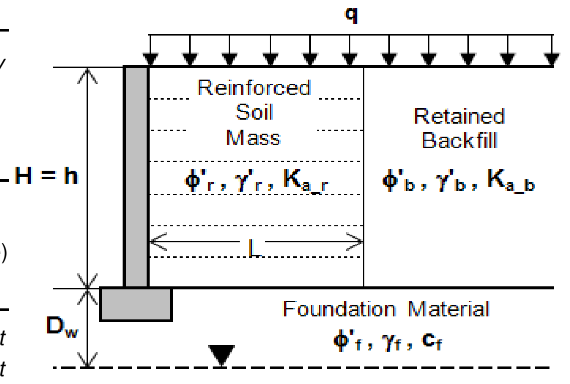
ϕ'_r = 36 deg *Effective Friction Angle*
γ'_r = 120 pcf *Effective Unit Weight*
K_{a_r} = 0.260 *Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

Soil Parameters for Retained Backfill

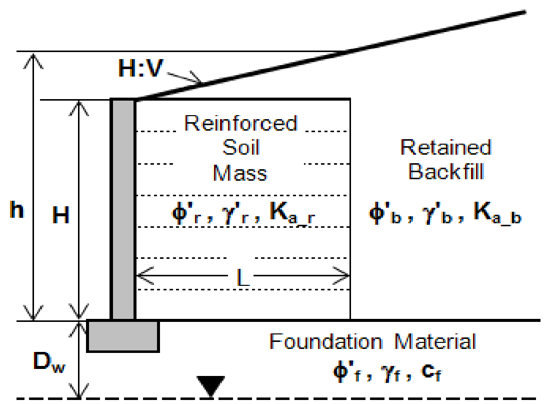
ϕ'_b = 28 deg *Effective Friction Angle*
γ'_b = 117 pcf *Effective Unit Weight*
K_{a_b} = 0.361 *Active Earth Pressure Coefficent (AASHTO Eqn 3.11.5.3-2)*

Soil Parameters for Foundation Soil

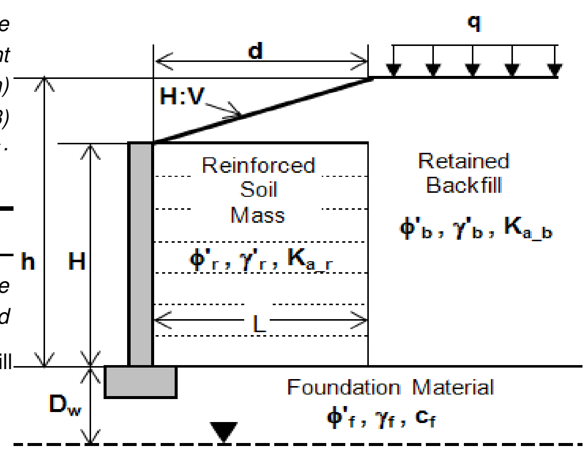
ϕ'_f = 32 deg *Effective Friction Angle*
γ_f = 110 pcf *Total Unit Weight*
c_f = 0 psf *Undrained Shear Strength (Cohesion)*
μ = 0.62 *Coefficient of Friction (AASHTO 11.10.5.3)*
The coefficient of friction shall be based on the lesser of ϕ'_r and ϕ'_f.



Typical MSE Wall with Level Backslope and Traffic Surcharge



Typical MSE Wall with Infinite Backslope



Typical MSE Wall with Broken Backslope and Traffic Surcharge

Input Load and Resistance Factors

Load Factors (See AASHTO Table 3.4.1-1 and 2)

Ψ_{LS} = 1.75 *Lilve Load Surcharge*
$\Psi_{EH(A)}$ = 1.50 *Horizontal (Active) Earth Pressure Load*
Ψ_{EV} = 1.00 min / 1.35 max Vertical Dead Load Generated from Earth Fill
$\Psi_{EQ\text{-}p}$ = 1.00
$\Psi_{EQ\text{-}LL}$ = 0.50

Resistance Factors (See AASHTO Table 11.5.6-1)

φ_b = 0.65 *Bearing Resistance for MSE Walls*
φ_τ = 1.00 *Sliding Resistance for MSE Walls*

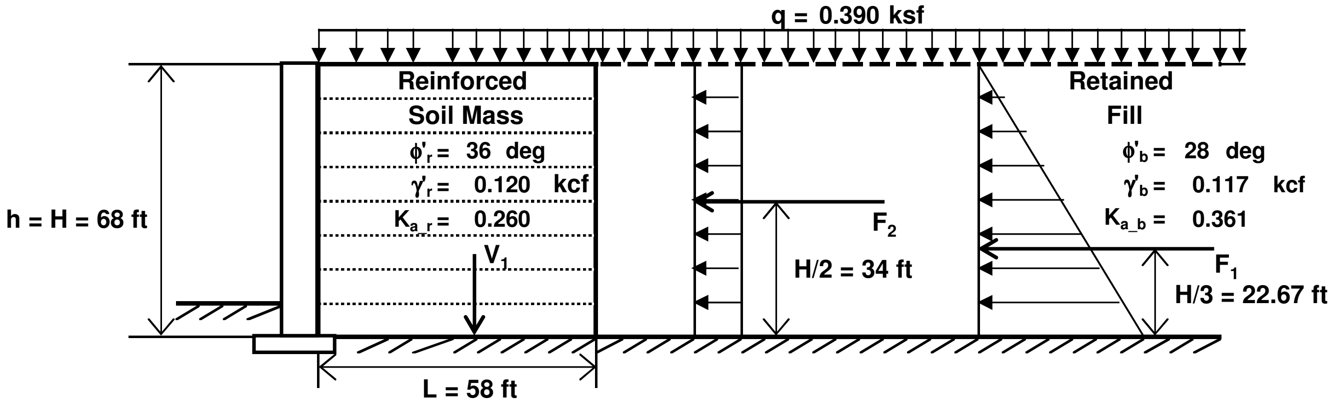
Seismic Design Acceleration Parameters

k_{max} = 0.20 *Maximum Horizontal Ground Acceration (PGA)*
S_{d1} = 0.14 *Peak spectral acceleration at 1 second*

References:

1. *AASHTO LRFD Bridge Design Specifications, 5th Edition, 2010*
2. *FHWA-NHI-10-024 Design and Construction of MSE Walls and Reinforced Soil Slopes - Vol I, 2009*
3. *SCDOT Geotechnical Design Manual version 1.1, 2010*

Calculate Forces acting on Wall



External Stability for MSE Walls: Earth Pressure - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Forces from Vertical Earth Loads

V_1 = Total Vertical Force from the Reinforced Soil Mass = $(\gamma'_r)(H)(L)$
= (0.120 kcf)(68.00 ft)(58.00 ft) = 473.280 kips

Forces from Lateral Earth Pressure

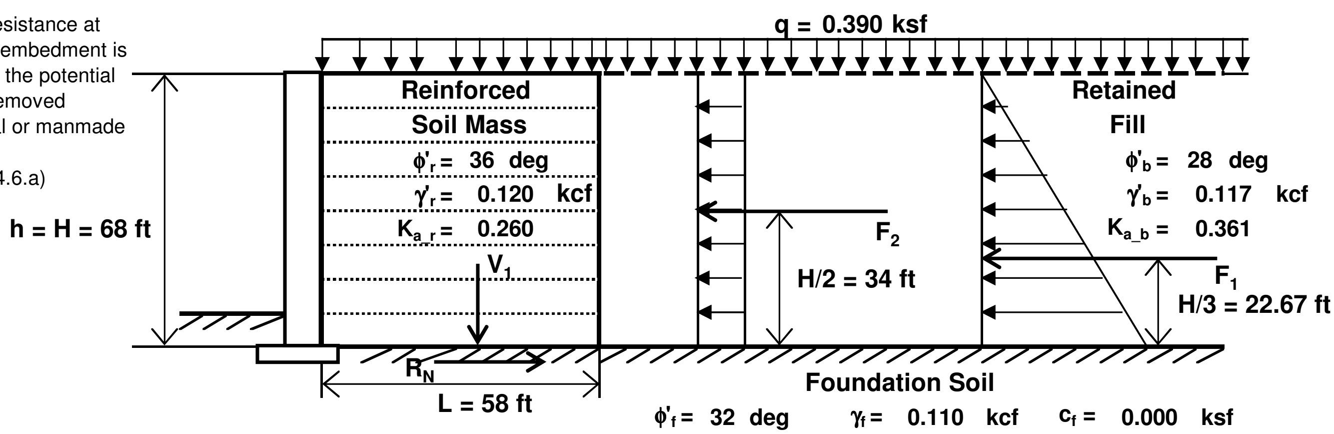
F_1 = Total Force Generated from Lateral Earth Pressure = $0.5(\gamma'_b)(H^2)(K_{ab})$ FHWA Eqn. 4-5
= (0.5)(0.117 kcf)(68.00 ft)^2(0.361) = 97.652 kips

Horizontal Force from Traffic Surcharge

F_2 = Force Generated from Traffic Surcharge = $(q)(H)(K_{ab})$ *FHWA Eqn. 4-6*
= (0.390 ksf)(68.00 ft) (0.361) = 9.574 kips

Sliding Stability - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

The passive resistance at the toe due to embedment is ignored due to the potential for soil to be removed through natural or manmade processes. (per FHWA 4.4.6.a)



External Stability for MSE Walls: Sliding Stability - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-2 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Factored Sliding Resistance (R_R)

$R_R = \varphi R_N = \varphi_\tau R_\tau$ *AASHTO Eqn. 10.6.3.4-1*

Sliding Stability Continued - AASHTO 11.10.5.3, AASHTO 10.6.3.4, and FHWA 4.4.6.a

φ_τ = *Resistance Factor for Sliding* = 1.00 — *AASHTO Table 11.5.6-1*

R_τ = *Nominal Sliding Resistance between Reinforced Soil Mass and Foundation Soil*

$= \Psi_{EV}(V_1)\mu + (c_f)(L)$ — *FHWA Eqn. 4-12 and AASHTO 10.6.3.4*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 — *AASHTO Table 3.4.1-1*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

V_1 = Total Vertical Force from the Reinforced Soil Mass = 473.280 kips

μ = Coefficent of Friction between Reinforced Soil Mass and Foundation Soil = 0.62 — *AASHTO 11.10.5.3*

c_f = Cohesion for Foundation Soil = 0.000 ksf

L = Reinforcement Length = 58.00 ft

R_τ = (1.00)(473.28 kips)(0.62) + (0.000 ksf)(58.00 ft) = 293.43 kips

R_R = (1.00)(293.43 kips) = 293.43 kips

Calculate Factored Horizontal Driving Force (P_d)

$P_d = (\Psi_{EHA})(F_1) + (\Psi_{LS})(F_2)$ — *FHWA Eqn. 4-9*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 — *AASHTO Table 3.4.1-1*

F_1 = Force Generated from Lateral Earth Pressure = 97.652 kips — *FHWA Eqn. 4-5*

Ψ_{LS} = Load Factor for Horizontal (Active) Earth Pressure = 1.75 — *AASHTO Table 3.4.1-1*

F_2 = Force Generated from Traffic Surcharge = 9.574 kips — *FHWA Eqn. 4-6*

P_d = (1.50)(97.652 kips) + (1.75)(9.574 kips) = 163.232 kips

Check Sliding

R_R must be greater than or equal to P_d

293.434 kips ≥ 163.232 kips

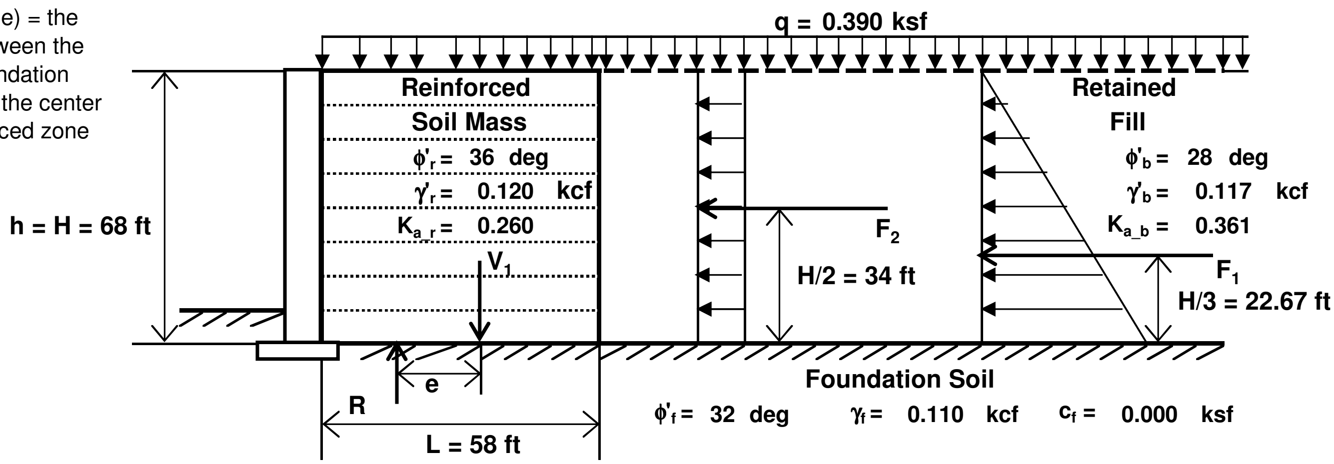
OK

Calculated Resistance Factor

$P_d/(Rr/\varphi_t)$ = **0.56**

Overturning (Limiting Eccentricity) - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Eccentricity (e) = the distance between the resultant foundation load (R) and the center of the reinforced zone



External Stability for MSE Walls: Overturning - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
Figure Not Drawn to Scale - All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity (e)

$$e = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1}$$ — *FHWA Eqn. 4-15*

Overturning (Limiting Eccentricity) Continued - AASHTO 11.6.3.3, AASHTO 11.10.5.5 and FHWA 4.4.6.b

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00
(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75
F_1 = Force Generated from Lateral Earth Pressure = 97.652 kips
F_2 = Force Generated from Traffic Surcharge = 9.574 kips
V_1 = Total Vertical Force from the Reinforced Soil Mass = 473.280 kips
H = MSE Wall Height = 68.00 ft

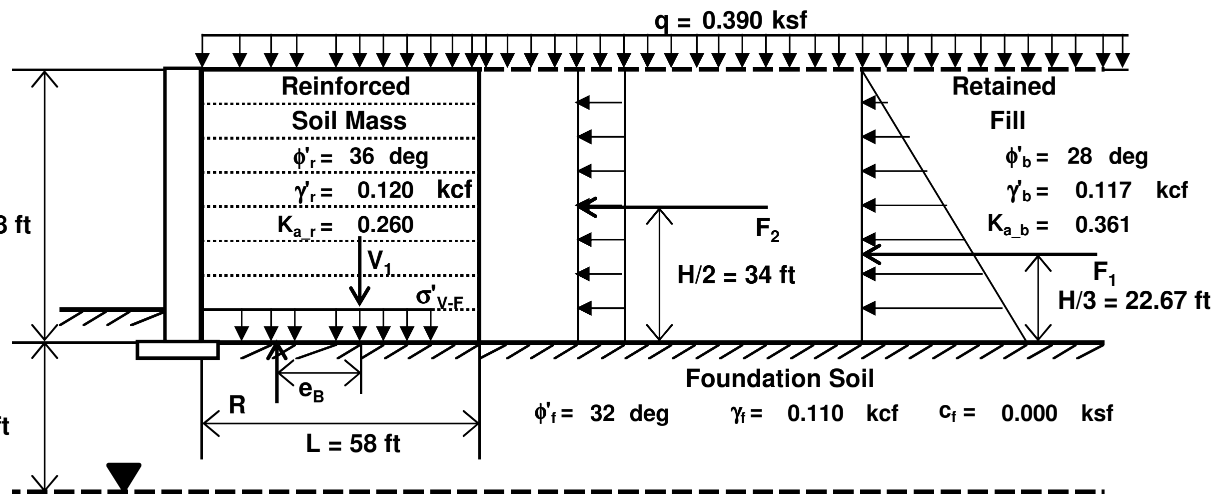
$$e = \frac{(1.50)(97.652\text{ kips})(22.67\text{ ft}) + (1.75)(9.574\text{ kips})(34.00\text{ ft})}{(1.00)(473.280\text{ kips})}$$

$= 8.22$ ft

Check Eccentricity

e must be less than or equal to L/4 per AASHTO 11.6.3.3
8.22 ft ≤ 14.5 ft
OK

Bearing Resistance (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c



External Stability for MSE Walls: Bearing Resistance - Level Backslope with Surcharge Case
(Based on FHWA Figure 4-7 and AASHTO Figure 11.10.5.2-1)
All Forces are Calculated per Unit Length of Wall
Figure Not Drawn to Scale

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EHA}F_1(H/3) + \Psi_{LS}F_2(H/2)}{\Psi_{EV}V_1 + \Psi_{LS}qL}$$ *FHWA Eqn. 4-19*

Ψ_{EHA} = Load Factor for Horizontal (Active) Earth Pressure = 1.50 — *AASHTO Table 3.4.1-1*
Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 — *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)
Ψ_{LS} = Load Factor for Surcharge = 1.75 — *AASHTO Table 3.4.1-1*
F_1 = Force Generated from Lateral Earth Pressure = 97.652 kips — *FHWA Eqn. 4-5*
F_2 = Force Generated from Traffic Surcharge = 9.574 kips — *FHWA Eqn. 4-6*
V_1 = Total Vertical Force from the Reinforced Soil Mass = 473.280 kips

Bearing Resistance Continued (General Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1, and FHWA 4.4.6.c

q = Live Load Traffic Surcharge = 0.390 ksf
H = MSE Wall Height = 68.00 ft
L = Reinforcement Length = 58.00 ft

$$e_B = \frac{(1.50)(97.652\ \text{kips})(22.67\ \text{ft}) + (1.75)(9.574\ \text{kips})(34.00\ \text{ft})}{(1.35)(473.3\ \text{kips}) + (1.75)(0.390\ \text{ksf})(58.00\ \text{ft})}$$

= 5.73 ft

Calculate Nominal Bearing Resistance, (q_n) — *AASHTO Eqn. 10.6.3.1.2a-1*

$q_n = c_f N_c + 0.5\gamma B' N_\gamma C_{w\gamma}$ — *AASHTO Eqn. 10.6.3.1.2a-1*

c_f = Cohesion for Foundation Soil = 0.000 ksf
N_c = Bearing Capacity Factor (based on ϕ'_f) = 0.00 — *AASHTO Table 10.6.3.1.2a-1*
γ_f = Total Unit Weight for Foundation Soil = 0.110 kcf
B' = Effective Foundation Width = L - $2e_B$ — *AASHTO C11.10.5.4*
= 58.0 ft - 2(5.73 ft) = 46.54 ft
N_γ = Bearing Capacity Factor (based on ϕ'_f) = 15.00 — *AASHTO Table 10.6.3.1.2a-1*
$C_{w\gamma}$ = Correction Factor to Account for Location of Groundwater Table = 0.6 — *AASHTO Table 10.6.3.1.2a-2*

q_n = (0.000 ksf)(0.00) + (0.5)(0.110 kcf)(46.54 ft)(15.00)(0.60)

= 23.037 ksf

Calculate Factored Bearing Resistance, (q_r)

$q_r = \varphi_b q_n$ — *AASHTO Eqn. 10.6.3.1.1-1*

φ_b = Resistance Factor for Bearing = 0.65 — *AASHTO Table 11.5.6-1*
q_n = Nominal Bearing Resistance = 23.037 ksf — *AASHTO Eqn. 10.6.3.1.2a-1*

q_r = (0.65)(23.037 ksf) = 14.974 ksf

Calculate Factored Vertical Bearing Pressure at the base, (q_{V-F})

$$\sigma_{V-F} = \frac{\Psi_{EV} V_1 + \Psi_{LS} qL}{L - 2e_B}$$ — *FHWA Eqn. 4-20*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.35 — *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*
(Use the Max Value of Ψ_{EV} per FHWA 4.4.6.c, AASHTO C3.4.1, and AASHTO C11.5.5)
V_1 = Total Vertical Force from the Reinforced Soil Mass = 473.280 kips
Ψ_{LS} = Load Factor for Surcharge = 1.75 — *AASHTO Table 3.4.1-1*
q = Live Load Traffic Surcharge = 0.390 ksf
L = Reinforcement Length = 58.00 ft
e_B = Eccentricity for Bearing = 5.73 ft — *FHWA Eqn. 4-19*

$$\sigma_{V-F} = \frac{(1.35)(473.28\ \text{kips ft}) + (1.75)(0.390\ \text{ksf})(58.00\ \text{ft})}{58.00\ \text{ft} - 2(5.73\ \text{ft})}$$

= 14.579 ksf

Check Bearing

q_R must be greater than or equal to q_{V-F}
14.974 ksf ≥ 14.579 ksf
OK

Calculated Resistance Factor

σ_{V-F}/q_n = **0.63**

Bearing Resistance (Local/Punching Shear) - AASHTO 11.10.5.4, AASHTO 10.6.3.1.2b, and FHWA 4.4.6.c

Local and Punching shear failure occurs in loose or compressible soils and in weak soils under slow (drained) loading. This mode of failure will only be considered for foundation material that is cohesive.

The Foundation Material for this Project is not Cohesive.

Seismic Stablity - SCDOT GDM Section 14.12

Calculate Wave Scattering Effects

Wave Scattering Coefficient, α_w =1+0.01H((0.5β)-1<1.0 — SCDOT Equation 13-103

α_w = 0.558

Ground Motion Index, $\beta = k_{max}/S_{d1}$ = 0.70 — SCDOT Equation 13-104

Average seismic horizontal coefficient due to wave scattering

$k_h = \alpha_w * k_{max}$ = 0.112 — SCDOT Equation 13-102

Calculate Seismic Active Earth Pressure Coefficinet (Mononobe -Kobe Method) SCDOT GDM Section 14.4.1

Seismic Active Earth Pressure Coefficient Reinforced Soils, K_{AEr} = 0.5

Seismic Active Earth Pressure Coefficient Retained, K_{AEb} = 0.621

$$K_{ae} = \frac{\cos^2(\phi - \Psi - \theta)}{\cos(\Psi)\cos^2(\theta)\cos(\delta+\theta+\Psi)\left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\Psi-\beta)}{\cos(\delta+\theta+\Psi)\cos(\beta-\theta)}}\right]^2} \quad \text{Equation 14-2}$$

Where,

γ	=	unit weight of soil
H	=	height of wall or effective height of wall (h_{eff})
ϕ	=	angle of internal friction of soil
Ψ	=	$\tan^{-1}[k_h/(1-k_v)]$
δ	=	angle of friction between soil and wall
k_h	=	horizontal acceleration coefficient
k_v	=	vertical acceleration coefficient, typically set to zero.
β	=	backfill slope angle
θ	=	angle of backface of the wall with the vertical

	Reinforced Soil	Retained Soil
φ	36.0 deg	28.0 deg
Ψ	6.4 deg	6.4 deg
θ	0 deg	0 deg
δ	0 deg	0.00 deg
β	0 deg	0 deg

Calculate Inertial Wall Width, $B_{inertial} = \omega H$ 48

coefficient, ω = 0.70

Calculate Active Earth Thrust Force, $P_{AE} = \gamma_p * 0.5 K_{AEr} * \gamma_p * H^2$ = 168.0 kips — GDM Eq. 14-40

Calculate Intertial Reinforced Soil Mass Force, $P_{IR} = \gamma_p * k_{avg} * B_{inertial} * H_{wall} *$ = 0.64 kips — GDM Eq. 14-41

Dead Load Surcharge Force, P_{DC} = = 5.913 kips — GDM Eq. 14-45

Live Load Surcharge Force, P_{LL} = = 5.279 kips — GDM Eq. 14-46

Total Seismic Driving Force, F_H = #### kip

Calculated Resistance Factor, $\varphi = F_H/R_t$ = **0.61**

Calculate Eccentricity for Bearing, (e_B)

$$e_B = \frac{\Psi_{EQ\text{-}P}F_{1s}(H/2) + \Psi_{EQ\text{-}LL}F_{2s}(H/2)}{\Psi_{EV}V_1 + \Psi_{EQ\text{-}LL}qL}$$ *FHWA Eqn. 4-19*

Ψ_{EHAeq} = $\Psi_{EQ\text{-}p}$ = Load Factor for Horizontal (Active) Earth Pressure = 1.00 *AASHTO Table 3.4.1-1*

Ψ_{EV} = Load Factor for Dead Load of Earth Fill = 1.00 *AASHTO Table 3.4.1-1 and FHWA 4.4.6.a*

(Use the Min Value of Ψ_{EV} per FHWA 4.4.6.a, AASHTO C3.4.1, and AASHTO C11.5.5)

Ψ_{LSeq} = $\Psi_{EQ\text{-}p}$ = Load Factor for Surcharge = 1.00 *AASHTO Table 3.4.1-1*

F_{1s} = Force Generated from Lateral Earth Pressure = 174.562 kips *FHWA Eqn. 4-5*

F_{2s} = Force Generated from Traffic Surcharge = 5.279 kips *FHWA Eqn. 4-6*

V_1 = Total Vertical Force from the Reinforced Soil Mass = 473.280 kips

q = Live Load Traffic Surcharge = 0.250 ksf *FHWA Eqn. 4-19*

H = MSE Wall Height = 68.00 ft

L = Reinforcement Length = 58.00 ft

$$e_B = \frac{(1.00)(174.562\text{ kips})(34.00\text{ ft}) + (1.00)(5.279\text{ kips})(34.00\text{ ft})}{(1.00)(473.3\text{ kips}) + (1.00)(0.250\text{ ksf})(58.00\text{ ft})}$$

= 12.54 ft

Calculate Factored Vertical Bearing Pressure at the base, ($q_{V\text{-}F}$)

$$\sigma_{V\text{-}F} = \frac{\Psi_{EQ\text{-}P}V_1 + \Psi_{EQ\text{-}LS}qL}{L - 2e_B}$$ *FHWA Eqn. 4-20*

$\Psi_{EQ\text{-}p}$ = Load Factor for Dead Load of Earth Fill = 1.00

V_1 = Total Vertical Force from the Reinforced Soil Mass = 473.280 kips

Ψ_{LSeq} = $\Psi_{EQ\text{-}ll}$ = Load Factor for Surcharge = 1.00

q = Live Load Traffic Surcharge = 0.250 ksf

L = Reinforcement Length = 58.00 ft

e_B = Eccentricity for Bearing = 12.54 ft

$$\sigma_{V\text{-}F} = \frac{(1.00)(473.28\text{ kips})(\text{ ft}) + (1.00)(0.250\text{ ksf})(58.00\text{ ft})}{58.0\text{ ft} - 2(12.54\text{ ft})}$$

= 15.064 ksf

Calculated Resistance Factor

$\sigma_{V\text{-}F}/q_n$ = **0.65**