BDA 410-01 | JANUARY 10, 2017

ASYMMETRIC BARRIER STABILITY CHECK

Concrete roadway barriers also act as retaining walls when the surface elevation varies from one side of the barrier to the other. When the unbalance is less that two feet, the barrier may simply be designed to provide the same overturning resistance as a Standard Median Barrier (E 602-CCMB-04). This can be accomplished by increasing the weight or width of the barrier so that the additional overturning resistance is equal to or greater than the moment created by the unbalanced earth pressures.

When the unbalance is greater than two feet, the barrier needs to be designed as a reinforced concrete retaining wall in accordance with AASHTO LRFD Bridge Design Specifications. The following calculations are an example of the procedure to check the stability of barrier with unbalance greater than two feet. Reinforcing calculations are not given in the example, but would follow AASHTO LRFD section A13.3.

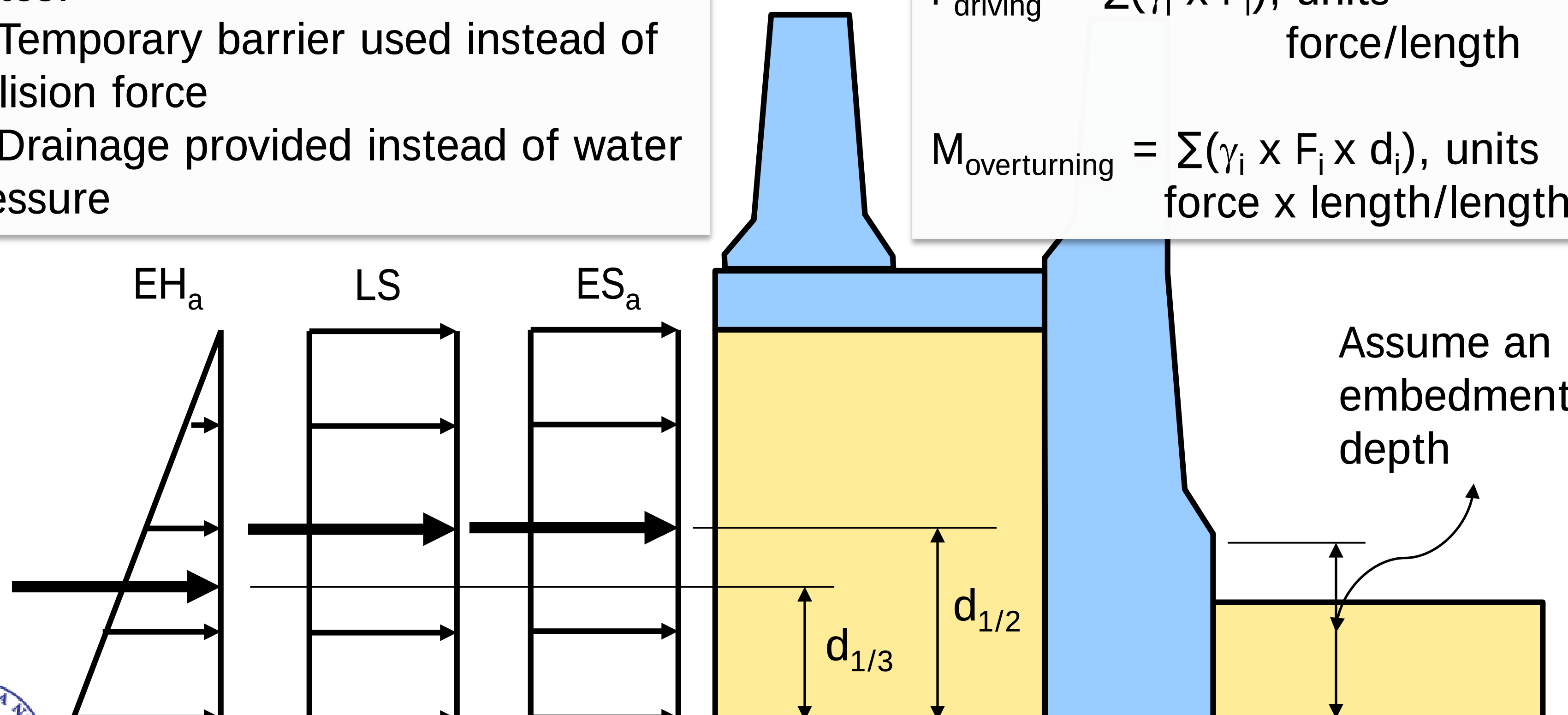
Example – Greater than 2’

- **Case 1 – During Construction**
  - Assume an embedment depth and calculate the driving lateral forces and overturning moment

Notes:
1. Temporary barrier used instead of collision force
2. Drainage provided instead of water pressure

$F_{driving} = \Sigma(\gamma_i \times F_i)$, units force/length

$M_{overturning} = \Sigma(\gamma_i \times F_i \times d_i)$, units force x length/length

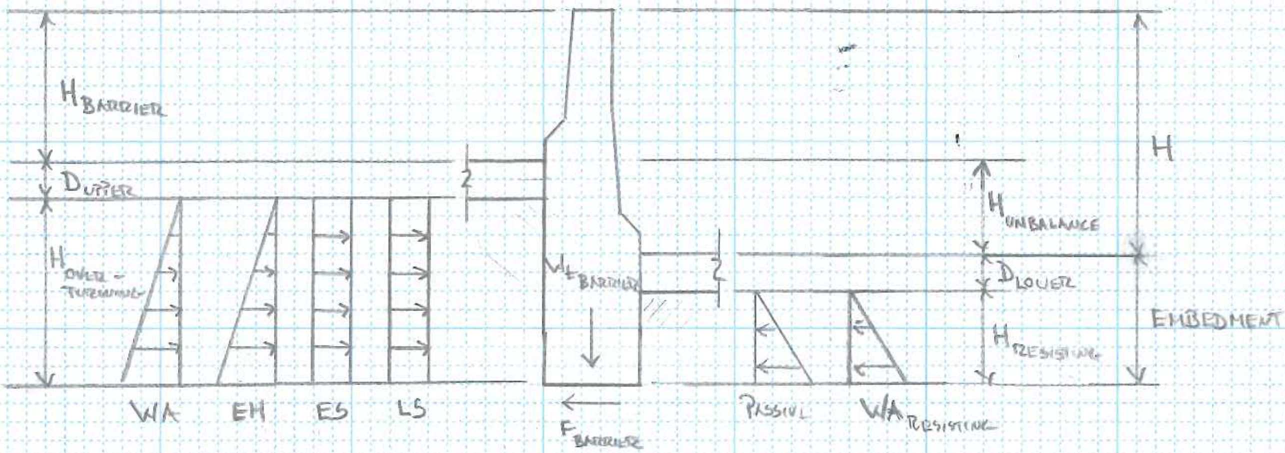


DESIGN COMPUTATIONS
State Form 4247 (R2 / 4-10)
INDIANA DEPARTMENT OF TRANSPORTATION

Structure/Project No. ASYMMETRIC BARRIERS

Design Computations for: LOAD CASE 1 - CONSTRUCTION

THIS LOAD CASE CHECKS THE STABILITY OF THE BARRIER DURING CONSTRUCTION WITHOUT THE LOWER PAVEMENT IN PLACE.



WA - WATER

EH - HORIZONTAL EARTH PRESSURE

ES - EARTH SURCHARGE LOAD

LS - LIVE LOAD SURCHARGE

Computed by

Checked by:

ASYMMETRIC BARRIER DESIGN

Overturning Design - Load Case 1

Check the stability of the barrier during construction with the upper pavement in place, but without the lower pavement section. Live load surcharge is applied to the upper pavement to account for construction loads, but barrier impact is not included in this load combination. Proper drainage is required to eliminate water pressure.

Barrier Dimensions:

$H := 7.75\ ft$ (Design height of barrier, measured from top of lower pavement to top of barrier)

$H_{barrier} := 3.75\ ft$ (Height of barrier, measured from top of upper pavement to top of barrier)

$H_{unbalance} := H - H_{barrier} = 4.00\ ft$ (Unbalanced height of barrier)

$D_{upper\_pavement} := 1.00\ ft$ (Thickness of upper pavement)

$D_{lower\_pavement} := 1.00\ ft$ (Thickness of lower pavement)

$Embedment := 5.25\ ft$ (Embedment depth of barrier, measured from top of lower pavement to bottom of buried barrier. This value is a variable that must be iterated until restoring forces are greater than or equal to overturning forces)

$H_{overturning} := \left(H + Embedment - H_{barrier} - D_{upper\_pavement}\right) = 8.25\ ft$ (Height of overturning soil, measured from the bottom of the upper pavement to the bottom of the buried barrier)

$H_{resisting} := \left(Embedment - D_{lower\_pavement}\right) = 4.25\ ft$ (Height of resisting soil, measured from the bottom of the lower pavement to the bottom of the bured barrier)

$B_{barrier} := 2.5\ ft$ (Width of the barrier)

$Wt_{barrier\_FT} := 860\ \frac{lb}{ft} + 150\ \frac{lb}{ft^3}\ \left(H_{unbalance} \cdot 22\ in + B_{barrier} \cdot Embedment\right) = 3928.75\ \frac{lb}{ft}$ (Weight of the barrier)

Overturning Force - Live Load Surcharge:

$h_{eq} := 2\ ft$ (Equivalent height of soil for vehicular loading, LRFD table 3.11.6.4-2)

$\gamma_{s\_retained\_dry} := 120\ \frac{lb}{ft^3}$ (Dry unit weight of retained soil. Value shall be obtained from Geotechnical Engineer based on actual site conditions.)

$k_a := 0.3$ (Lateral active earth pressure coefficient of retained soil. Value shall be obtained from Geotechnical Engineer based on actual site conditions.)

$p_{LS\_service} := h_{eq} \cdot \gamma_{s\_retained\_dry} \cdot k_a = 72.00\ \frac{lb}{ft^2}$ (Live load surcharge uniform unfactored pressure)

$F_{LS\_service} := p_{LS\_service} \cdot \left(H_{overturning}\right) = 594.00\ \frac{lb}{ft}$ (Live load surcharge unfactored force)

$M_{LS\_service} := F_{LS\_service} \cdot \frac{H_{overturning}}{2} = 2450\ lb \cdot \frac{ft}{ft}$ (Live load surcharge unfactored overturning moment)

$\gamma_{LS} := 1.75$ (Strength load factor for live load surcharge, LRFD table 3.4.1-1)

$F_{LS\_strength} := F_{LS\_service} \cdot \gamma_{LS} = 1039.50\ \frac{lb}{ft}$ (Live load surcharge factored force)

$M_{LS\_strength} := F_{LS\_strength} \cdot \frac{H_{overturning}}{2} = 4288\ lb \cdot \frac{ft}{ft}$ (Live load surcharge factored overturning moment)

Overturning Force - Active Earth Pressure:

$k_a = 0.30$ (Active earth pressure coefficient. Value shall be obtained from Geotechnical Engineer based on actual site conditions.)

$\gamma_{s\_retained\_dry} = 120.00\ \frac{lb}{ft^3}$

$\gamma_{soil} := \gamma_{s\_retained\_dry} = 120.00\ \frac{lb}{ft^3}$ (Design unit weight of soil)

$p_{EH} := \gamma_{soil} \cdot H_{overturning} \cdot k_a = 297.00\ \frac{lb}{ft^2}$ (Active earth pressure at bottom of wall)

$F_{EH\_service} := p_{EH} \cdot \frac{H_{overturning}}{2} = 1225.13\ \frac{lb}{ft}$ (Horizontal earth load unfactored force)

$M_{EH\_service} := F_{EH\_service} \cdot \frac{H_{overturning}}{3} = 3369.09\ lb \cdot \frac{ft}{ft}$ (Horizontal earth load unfactored overturning moment)

$\gamma_{EH} := 1.5$ (Strength load factor for active horizontal earth pressure, LRFD table 3.4.1-1)

$F_{EH\_strength} := F_{EH\_service} \cdot \gamma_{EH} = 1837.69\ \frac{lb}{ft}$ (Horizontal earth load factored force)

$M_{EH\_strength} := F_{EH\_strength} \cdot \frac{H_{overturning}}{3} = 5053.64\ lb \cdot \frac{ft}{ft}$ (Horizontal earth load factored overturning moment)

Overturning Force - Upper Pavement Surcharge:

$k_a = 0.30$ (Active earth pressure coefficient. Value shall be obtained from Geotechnical Engineer based on actual site conditions.)

$\gamma_{pavement} := 145 \ \frac{lb}{ft^3}$ (Unit weight of upper pavement)

$D_{upper\_pavement} = 1.00 \ ft$ (Thickness of upper pavement)

$p_{ES} := \gamma_{pavement} \cdot D_{upper\_pavement} \cdot k_a = 43.50 \ \frac{lb}{ft^2}$ (Uniform surcharge pressure along the height of the wall)

$F_{ES\_service} := p_{ES} \cdot H_{overturning} = 358.88 \ \frac{lb}{ft}$ (Horizontal surcharge unfactored force)

$M_{ES\_service} := F_{ES\_service} \cdot \frac{H_{overturning}}{2} = 1480.36 \ lb \cdot \frac{ft}{ft}$ (Horizontal surcharge load unfactored overturning moment)

$\gamma_{ES} := 1.5$ (Strength load factor for earth surcharge, LRFD table 3.4.1-1)

$F_{ES\_strength} := F_{ES\_service} \cdot \gamma_{ES} = 538.31 \ \frac{lb}{ft}$ (Horizontal surcharge load factored force)

$M_{ES\_strength} := F_{ES\_strength} \cdot \frac{H_{overturning}}{2} = 2220.54 \ lb \cdot \frac{ft}{ft}$ (Horizontal surcharge load factored overturning moment)

Overturning Forces - Total:

$$F_{LS\_service} = 594.00\ \frac{lb}{ft}$$

$$F_{EH\_service} = 1225.13\ \frac{lb}{ft}$$

$$F_{ES\_service} = 358.88\ \frac{lb}{ft}$$

$$F_{overturning\_service} := F_{LS\_service} + F_{EH\_service} + F_{ES\_service} = 2178.00\ \frac{lb}{ft}$$

$$F_{LS\_strength} = 1039.50\ \frac{lb}{ft}$$

$$F_{EH\_strength} = 1837.69\ \frac{lb}{ft}$$

$$F_{ES\_strength} = 538.31\ \frac{lb}{ft}$$

$$F_{overturning\_strength} := F_{LS\_strength} + F_{EH\_strength} + F_{ES\_strength} = 3415.50\ \frac{lb}{ft}$$

$$M_{LS\_service} = 2450.25\ lb \cdot \frac{ft}{ft}$$

$$M_{EH\_service} = 3369.09\ lb \cdot \frac{ft}{ft}$$

$$M_{ES\_service} = 1480.36\ lb \cdot \frac{ft}{ft}$$

$$M_{overturning\_service} := M_{LS\_service} + M_{EH\_service} + M_{ES\_service} = 7299.7\ lb \cdot \frac{ft}{ft}$$

$$M_{LS\_strength} = 4287.94\ lb \cdot \frac{ft}{ft}$$

$$M_{EH\_strength} = 5053.64\ lb \cdot \frac{ft}{ft}$$

$$M_{ES\_strength} = 2220.54\ lb \cdot \frac{ft}{ft}$$

$$M_{overturning\_strength} := M_{LS\_strength} + M_{EH\_strength} + M_{ES\_strength} = 11562.1\ lb \cdot \frac{ft}{ft}$$

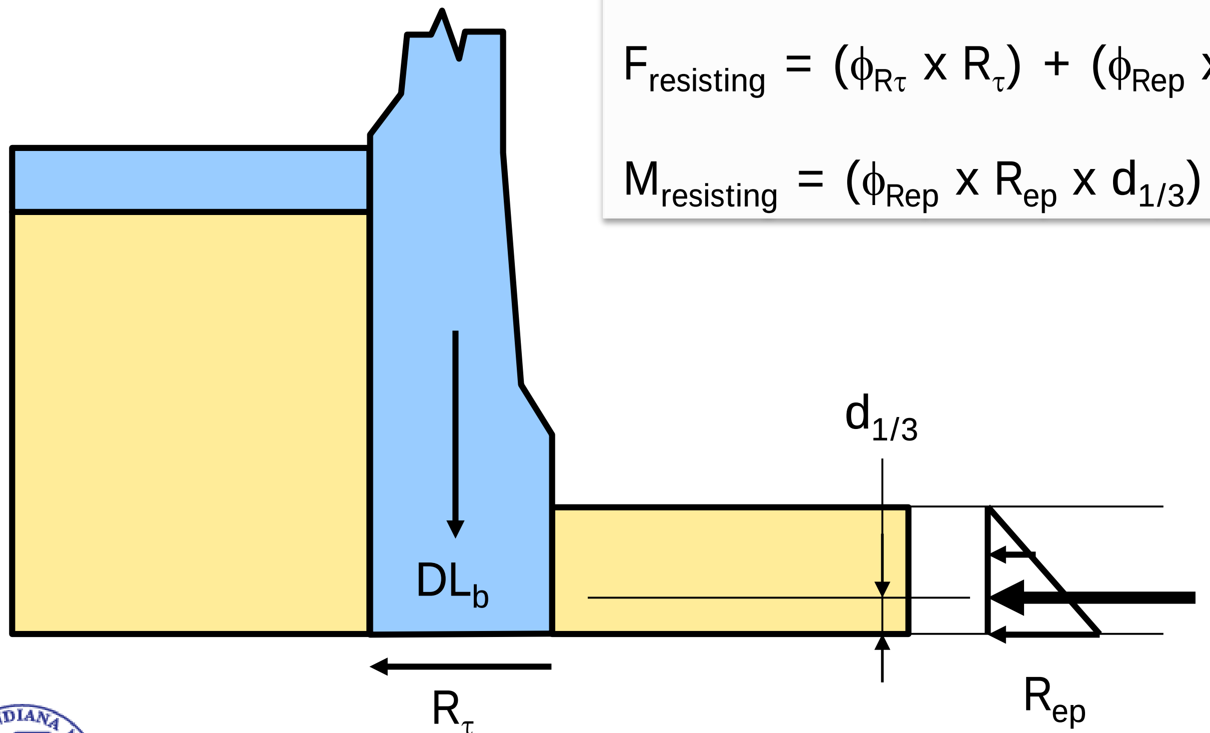
Example – Greater than 2'

- **Case 1 – During Construction**
  - Calculate the resisting forces and moments

$$R_\tau = DL_b \text{ x } \tan(\delta)$$

$$F_{resisting} = (\phi_{R\tau} \text{ x } R_\tau) + (\phi_{Rep} \text{ x } R_{ep})$$

$$M_{resisting} = (\phi_{Rep} \text{ x } R_{ep} \text{ x } d_{1/3})$$



Resisting Force - Passive Earth Pressure:

$k_p := 6$ (Coulomb's Passive earth pressure coefficient. Value shall be obtained from Geotechnical Engineer based on actual site conditions.)

$\gamma_{s\_retained\_dry} = 120.00 \; \frac{lb}{ft^3}$

$\gamma_{soil} := \gamma_{s\_retained\_dry} = 120.00 \; \frac{lb}{ft^3}$ (Design unit weight of soil)

$p_{passive} := \gamma_{soil} \cdot H_{resisting} \cdot k_p = 3060.00 \; \frac{lb}{ft^2}$ (Passive earth pressure at bottom of wall)

$F_{passive\_service} := p_{passive} \cdot \frac{H_{resisting}}{2} = 6502.50 \; \frac{lb}{ft}$ (Passive earth load unfactored force)

$M_{passive\_service} := F_{passive\_service} \cdot \frac{H_{resisting}}{3} = 9211.88 \; lb \cdot \frac{ft}{ft}$ (Passive earth load unfactored overturning moment)

$\varphi_{passive} := 0.5$ (Strength resistance factor for passive earth pressure, when used in conjuction with sliding resistance, LRFD table 10.5.5.2.2-1)

$F_{passive\_strength} := F_{passive\_service} \cdot \varphi_{passive} = 3251.25 \; \frac{lb}{ft}$ (Passive earth load factored force)

$M_{passive\_strength} := \frac{F_{passive\_strength}}{\varphi_{passive}} \cdot \frac{H_{resisting}}{3} = 9211.88 \; lb \cdot \frac{ft}{ft}$ (Passive earth load factored overturning moment. Sliding resistance factor removed for overturning resistance)

Resisting Force - Barrier Self-Weight:

$$Wt_{barrier\_FT} = 3928.75\ \frac{lb}{ft}$$

$\phi_f := 30\ deg$ (Internal friction angle of soil below barrier. Value shall be obtained from Geotechnical Engineer based on actual site conditions.)

$$F_{barrier\_resist\_service} := Wt_{barrier\_FT} \cdot \tan\left(\phi_f\right) = 2268.26\ \frac{lb}{ft}$$

(Unfactored sliding resistance between the barrier and soil)

$$M_{barrier\_resist\_service} := Wt_{barrier\_FT} \cdot \frac{B_{barrier}}{2} = 4910.94\ lb \cdot \frac{ft}{ft}$$

(Unfactored overturning resistance of the barrier due to selfweight, taken about the toe of the barrier)

$\varphi_{sliding} := 0.8$ (Strength resistance factor for sliding of cast-in-place concrete on sandy soils, LRFD table 10.5.5.2.2-1)

$$F_{barrier\_resist\_strength} := F_{barrier\_resist\_service} \cdot \varphi_{sliding} = 1814.61\ \frac{lb}{ft}$$

(Factored sliding resistance between the barrier and soil)

Lateral Resisting Force - Total:

$$F_{passive\_service}=6502.50\ \frac{lb}{ft}$$

$$F_{barrier\_resist\_service}=2268.26\ \frac{lb}{ft}$$

$$F_{resisting\_service}:=F_{passive\_service}+F_{barrier\_resist\_service}=8770.76\ \frac{lb}{ft}$$

$$F_{passive\_strength}=3251.25\ \frac{lb}{ft}$$

$$F_{barrier\_resist\_strength}=1814.61\ \frac{lb}{ft}$$

$$F_{resisting\_strength}:=F_{passive\_strength}+F_{barrier\_resist\_strength}=5065.86\ \frac{lb}{ft}$$

$$M_{passive\_service}=9211.88\ lb\cdot\frac{ft}{ft}$$

$$M_{barrier\_resist\_service}=4910.94\ lb\cdot\frac{ft}{ft}$$

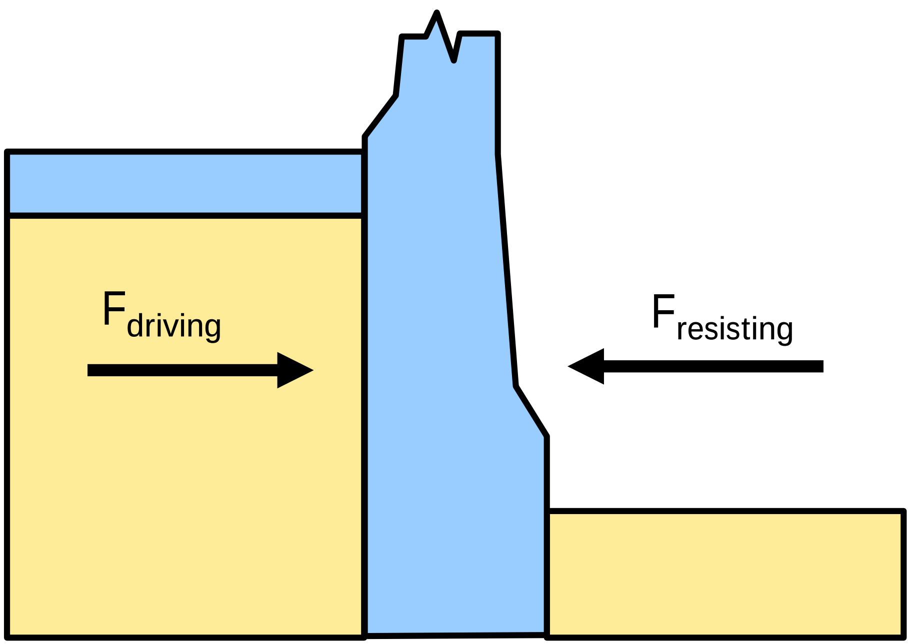
$$M_{resisting\_service}:=M_{passive\_service}+M_{barrier\_resist\_service}=14122.8\ lb\cdot\frac{ft}{ft}$$

Example – Greater than 2’

- **Case 1 – During Construction**
  - Check sliding resistance

If, $F_{resisting} > F_{driving}$, Sliding resistance is adequate

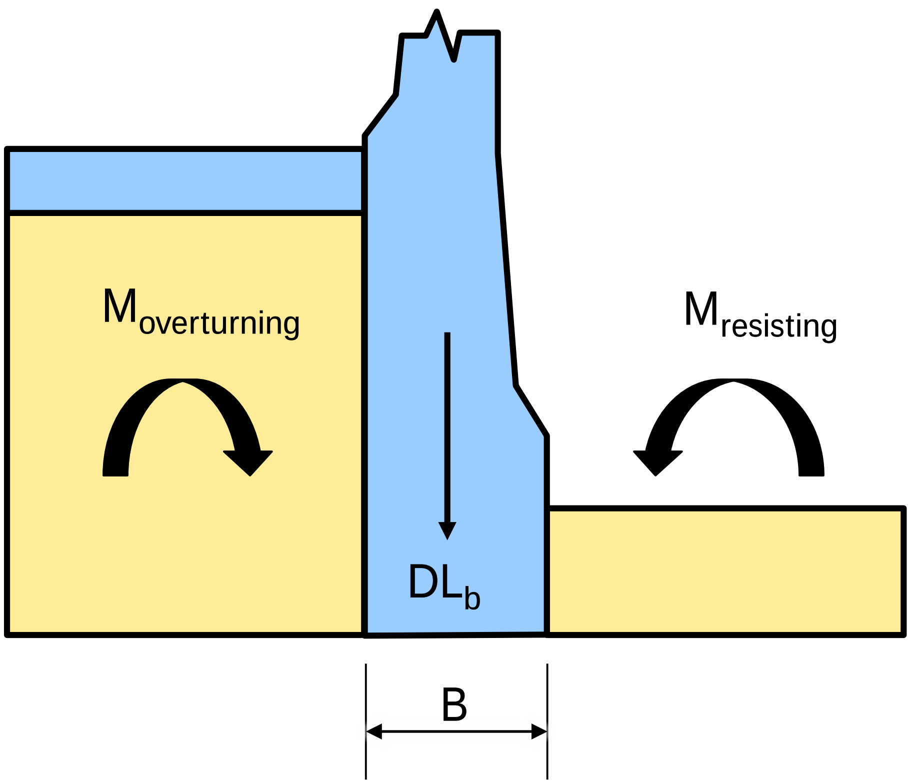
If, $F_{resisting} < F_{driving}$, Sliding resistance is deficient. Increase resistance by increasing barrier weight (width), embedment depth, or decrease driving force (MSE, etc.)



Example – Greater than 2'

- **Case 1 – During Construction**
  - Check overturning
    - Determine the net factored lateral load moments

$M_{net} = M_{overturning} - M_{resisting}$ (moments taken about center of barrier, B/2)



Example – Greater than 2'

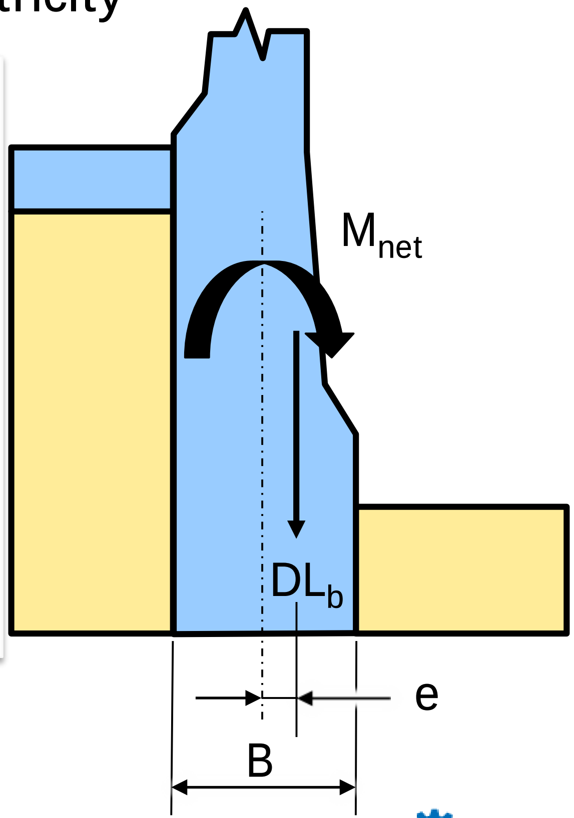
- **Case 1 – During Construction**
  - Check overturning
    - Calculate the eccentricity of the applied loads and check against the maximum allowable eccentricity

e_{max} = B/3 (per LRFD section 11.6.3.3)

$e = M_{net}/DL_b$

If $e_{max} > e$, overturning resistance is acceptable

If $e_{max} < e$, overturning resistance is deficient, increase resistance by increasing barrier weight (width), embedment depth, or decrease driving force (MSE, etc.)



Sliding and Overturning Check - Strength Load Method:

Sliding Check:

$$F_{resisting\_strength} := F_{passive\_strength} + F_{barrier\_resist\_strength} = 5065.86\ \frac{lb}{ft}$$

$$F_{overturning\_strength} := F_{LS\_strength} + F_{EH\_strength} + F_{ES\_strength} = 3415.50\ \frac{lb}{ft}$$

$$Demand\_Capacity_{sliding} := \frac{F_{overturning\_strength}}{F_{resisting\_strength}} = 0.67$$

(Must be less than or equal to 1.0, per AASHTO LRFD , section 10.6.3.4)

$$Check_{sliding\_strength} := \text{if}\left(Demand\_Capacity_{sliding} \le 1.0, \text{“OK”}, \text{“No Good”}\right) = \text{“OK”}$$

Overturning Check:

$$e_{max} := \frac{B_{barrier}}{3} = 0.83\ ft$$

(Maximum allowable eccentricity, per AASHTO LRFD, section 11.6.3.3)

$$M_{resisting\_strength\_centroid} := M_{passive\_strength} = 9212\ lb \cdot \frac{ft}{ft}$$

(Resisting moment taken about the centroid of the barrier)

$$M_{overturning\_strength} = 11562\ lb \cdot \frac{ft}{ft}$$

$$e_{barrier} := \frac{\left(M_{overturning\_strength} - M_{resisting\_strength\_centroid}\right)}{Wt_{barrier\_FT}} = 0.60\ ft$$

$$Check_{overturning\_strength} := \text{if}\left(e_{barrier} \le e_{max}, \text{“OK”}, \text{“No Good”}\right) = \text{“OK”}$$

Example – Greater than 2'

- **Case 1 – During Construction**
  - Check bearing pressure
    - Calculate the effective barrier width due to the eccentricity of the applied loads and determine the applied bearing pressure

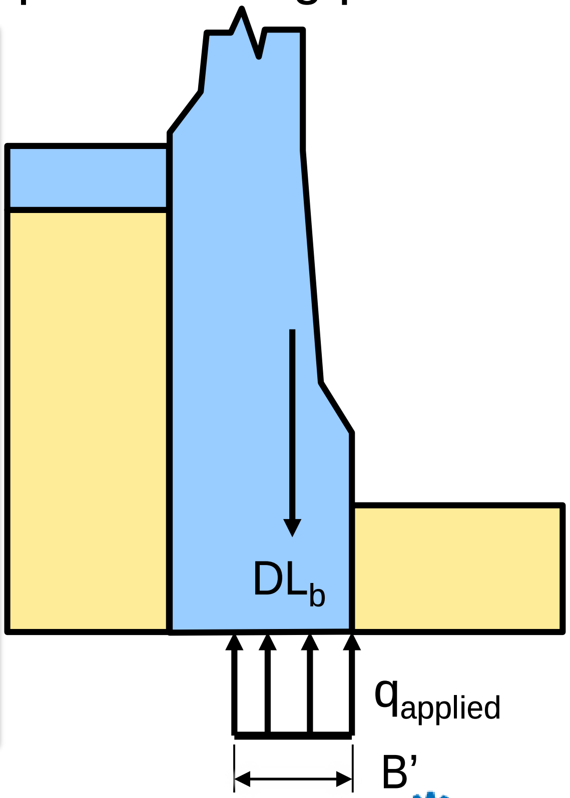
$B' = B - 2e$

$q_{applied} = DL_b / B'$

$q_{max\ allowable}$ = Per geotechnical recommendations

If $q_{max\ allowable} > q_{applied}$, bearing pressure is acceptable

If $q_{max\ allowable} < q_{applied}$, bearing pressure is deficient. Increase resistance by increasing barrier weight (width), embedment depth, or decrease driving force (MSE, etc.)



Bearing Capacity Check:

$$\sigma_{allowable\_factored\_resistance} := 4000 \ \frac{lb}{ft^2}$$

(Factored bearing resistance. Value shall be obtained from Geotechnical Engineer based on actual site conditions.)

$$B' := B_{barrier} - 2 \cdot e_{barrier} = 1.30 \ ft$$

$$\sigma_{overturning\_strength} := \frac{Wt_{barrier\_FT}}{B'} = 3013.84 \ \frac{lb}{ft^2}$$

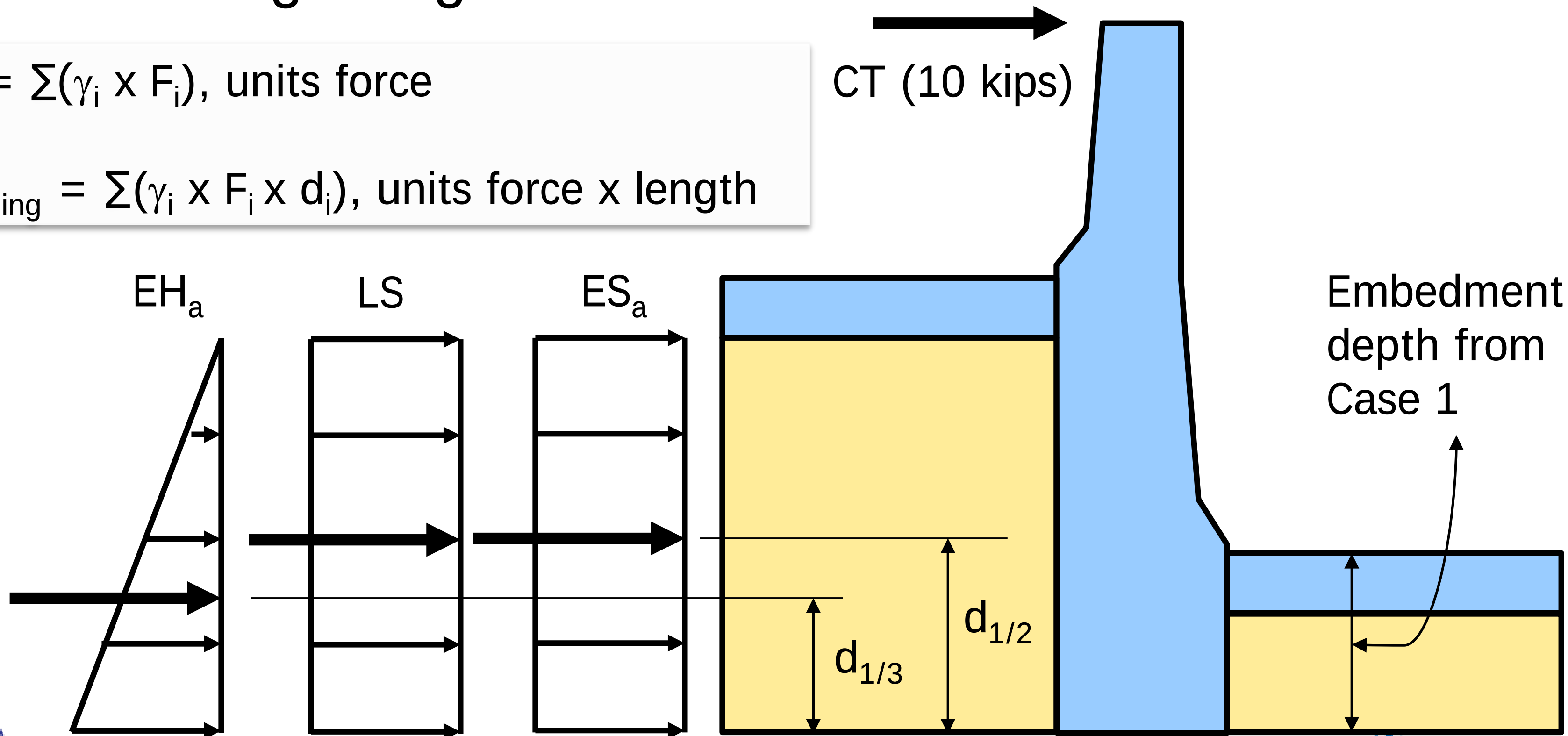
$$Check_{bearing\_capacity} := \mathbf{if} \left(\sigma_{allowable\_factored\_resistance} \ge \sigma_{overturning\_strength}, \text{“OK”}, \text{“No Good”}\right) = \text{“OK”}$$

Example – Greater than 2’

- **Case 2 – Final Condition**
  - Using the Case 1 section geometry, calculate the driving forces and overturning moment applied over the design length of the barrier

$F_{driving} = \Sigma(\gamma_i \times F_i)$, units force

$M_{overturning} = \Sigma(\gamma_i \times F_i \times d_i)$, units force x length



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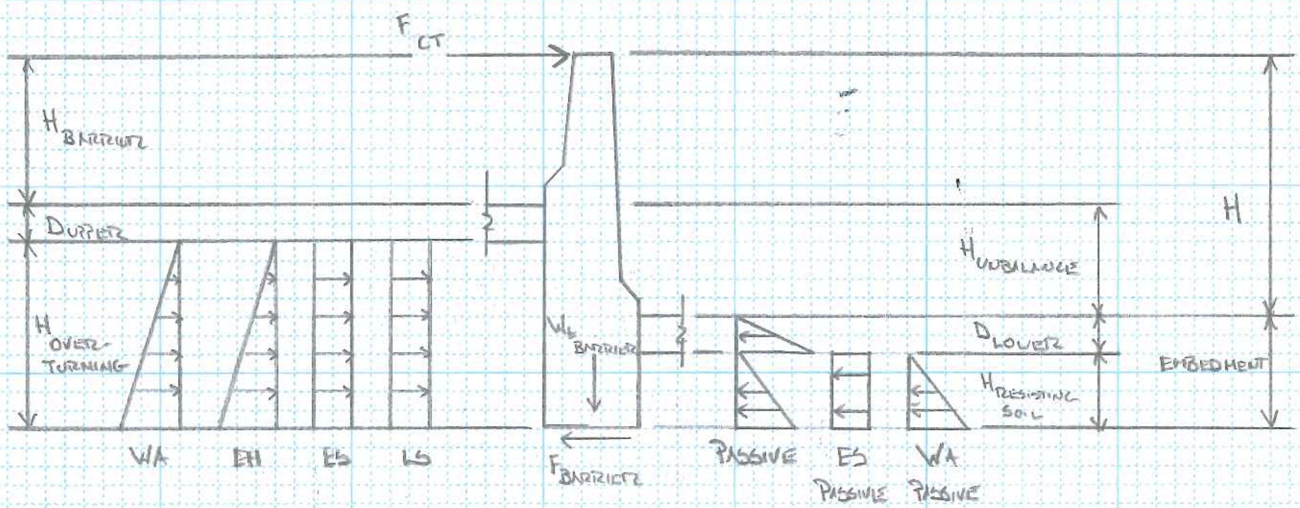
Structure/Project No. ASYMMETRIC BARRIERS

Design Computations for: LOAD CASE 2 - FINAL CONDITION

THIS LOAD CASE CHECKS THE STABILITY OF THE BARRIER IN THE FINAL CONDITION WITH THE LOWER PAVEMENT IN PLACE.



WA - WATER

EH - HORIZONTAL EARTH PRESSURE

ES - EARTH SURCHARGE LOAD

LS - LIVE LOAD SURCHARGE

CT - VEHICLE COLLISION LOAD

Computed by

Checked by:

ASYMMETRIC BARRIER DESIGN

Overturning Design - Load Case 2

Check the stability of the barrier in the final configuration, assuming asphalt pavement. The embedment depth must be equal to or greater than that required for the construction load case. Calculate the length of wall required to resist the earth pressure and impact loads. Proper drainage is required to eliminate water pressure.

Barrier Dimensions:

$H := 7.75\ ft$ (Design height of barrier, measured from top of lower pavement to top of barrier)

$H_{barrier} := 3.75\ ft$ (Height of barrier, measured from top of upper pavement to top of barrier)

$H_{unbalance} := H - H_{barrier} = 4.00\ ft$ (Unbalanced height of barrier)

$D_{upper\_pavement} := 1.00\ ft$ (Thickness of upper pavement)

$D_{lower\_pavement} := 1.00\ ft$ (Thickness of lower pavement)

$Embedment := 5.25\ ft$ (Embedment depth of barrier, measured from top of lower pavement to bottom of buried barrier. This value must be equal to or greater than the embedment required for the construction load case.)

$L_{Barrier} := 4\ ft$ (Continuous length of barrier required to resist collision force. This value must be iterated.)

$H_{overturning} := \left(H + Embedment - H_{barrier} - D_{upper\_pavement}\right) = 8.25\ ft$ (Height of overturning soil, measured from the bottom of the upper pavement to the bottom of the buried barrier)

$H_{resisting\_soil} := \left(Embedment - D_{lower\_pavement}\right) = 4.25\ ft$ (Height of resisting soil, measured from the bottom of the lower pavement to the bottom of the buried barrier)

$B_{barrier} := 2.5\ ft$ (Width of the barrier)

$Wt_{barrier\_FT} := 860\ \frac{lb}{ft} + 150\ \frac{lb}{ft^3}\left(H_{unbalance} \cdot 22\ in + B_{barrier} \cdot Embedment\right) = 3928.75\ \frac{lb}{ft}$ (Weight of the barrier)

Overturning Force - Live Load Surcharge:

$h_{eq} := 2\ ft$ (Equivalent height of soil for vehicular loading, LRFD table 3.11.6.4-2)

$\gamma_{s\_retained\_dry} := 120\ \dfrac{lb}{ft^3}$ (Dry unit weight of retained soil)

$k_a := 0.3$ (Lateral active earth pressure coefficient of retained soil. Value shall be obtained from Geotechnical Engineer for actual site conditions.)

$p_{LS\_service} := h_{eq} \cdot \gamma_{s\_retained\_dry} \cdot k_a = 72.00\ \dfrac{lb}{ft^2}$ (Live load surcharge uniform unfactored pressure)

$F_{LS\_service} := p_{LS\_service} \cdot \left(H_{overturning}\right) \cdot L_{Barrier} = 2376.00\ lb$ (Live load surcharge unfactored force)

$M_{LS\_service} := F_{LS\_service} \cdot \dfrac{H_{overturning}}{2} = 9801\ lb \cdot ft$ (Live load surcharge unfactored overturning moment)

$\gamma_{LS} := 1.75$ (Strength load factor for live load surcharge, LRFD table 3.4.1-1)

$F_{LS\_strength} := F_{LS\_service} \cdot \gamma_{LS} = 4158.00\ lb$ (Live load surcharge factored force)

$M_{LS\_strength} := F_{LS\_strength} \cdot \dfrac{H_{overturning}}{2} = 17152\ lb \cdot ft$ (Live load surcharge factored overturning moment)

Overturning Force - Active Earth Pressure:

$k_a = 0.30$ (Active earth pressure coefficient. Value shall be obtained from Geotechnical Engineer for actual site conditions.)

$\gamma_{s\_retained\_dry} = 120.00 \ \frac{lb}{ft^3}$

$\gamma_{soil} := \gamma_{s\_retained\_dry} = 120.00 \ \frac{lb}{ft^3}$ (Design unit weight of soil)

$p_{EH} := \gamma_{soil} \cdot H_{overturning} \cdot k_a = 297.00 \ \frac{lb}{ft^2}$ (Active earth pressure at bottom of wall)

$F_{EH\_service} := p_{EH} \cdot \frac{H_{overturning}}{2} \cdot L_{Barrier} = 4900.50 \ lb$ (Horizontal earth load unfactored force)

$M_{EH\_service} := F_{EH\_service} \cdot \frac{H_{overturning}}{3} = 13476.38 \ lb \cdot ft$ (Horizontal earth load unfactored overturning moment)

$\gamma_{EH} := 1.5$ (Strength load factor for active horizontal earth pressure, LRFD table 3.4.1-1)

$F_{EH\_strength} := F_{EH\_service} \cdot \gamma_{EH} = 7350.75 \ lb$ (Horizontal earth load factored force)

$M_{EH\_strength} := F_{EH\_strength} \cdot \frac{H_{overturning}}{3} = 20214.56 \ lb \cdot ft$ (Horizontal earth load factored overturning moment)

Overturning Force - Upper Pavement Surcharge:

$k_a = 0.30$ (Active earth pressure coefficient. Value shall be obtained from Geotechnical Engineer for actual site conditions.)

$\gamma_{pavement} := 145 \, \frac{lb}{ft^3}$ (Unit weight of upper pavement)

$D_{upper\_pavement} = 1.00 \, ft$ (Thickness of upper pavement)

$p_{ES} := \gamma_{pavement} \cdot D_{upper\_pavement} \cdot k_a = 43.50 \, \frac{lb}{ft^2}$ (Uniform surcharge pressure along the height of the wall)

$F_{ES\_service} := p_{ES} \cdot H_{overturning} \cdot L_{Barrier} = 1435.50 \, lb$ (Horizontal surcharge unfactored force)

$M_{ES\_service} := F_{ES\_service} \cdot \frac{H_{overturning}}{2} = 5921.44 \, lb \cdot ft$ (Horizontal surcharge load unfactored overturning moment)

$\gamma_{ES} := 1.5$ (Strength load factor for earth surcharge, LRFD table 3.4.1-1)

$F_{ES\_strength} := F_{ES\_service} \cdot \gamma_{ES} = 2153.25 \, lb$ (Horizontal surcharge load factored force)

$M_{ES\_strength} := F_{ES\_strength} \cdot \frac{H_{overturning}}{2} = 8882.16 \, lb \cdot ft$ (Horizontal surcharge load factored overturning moment)

Overturning Force - Barrier Collision:

$F_{CT\_service} := 10000\ lb$ (Vehicle impact load used for stability calculations)

$M_{CT\_service} := F_{CT\_service} \cdot (H + Embedment) = 130000.00\ lb \cdot ft$ (Vehicle impact load unfactored overturning moment)

$\gamma_{CT} := 1.0$ (Strength load factor for horizontal vehicle collision force)

$F_{CT\_strength} := F_{CT\_service} \cdot \gamma_{CT} = 10000.00\ lb$ (Vehicle impact load factored force)

$M_{CT\_strength} := F_{CT\_strength} \cdot (H + Embedment) = 130000.00\ lb \cdot ft$ (Vehicle impact load factored overturning moment)

Overturning Forces - Total:

$F_{LS\_service} = 2376.00\ lb$

$F_{CT\_service} = 10000.00\ lb$

$F_{EH\_service} = 4900.50\ lb$

$F_{ES\_service} = 1435.50\ lb$

$F_{overturning\_service} := F_{LS\_service} + F_{EH\_service} + F_{ES\_service} + F_{CT\_service} = 18712.00\ lb$

$F_{LS\_strength} = 4158.00\ lb$

$F_{CT\_strength} = 10000.00\ lb$

$F_{EH\_strength} = 7350.75\ lb$

$F_{ES\_strength} = 2153.25\ lb$

$F_{overturning\_strength} := F_{LS\_strength} + F_{EH\_strength} + F_{ES\_strength} + F_{CT\_strength} = 23662.00\ lb$

$M_{LS\_service} = 9801.00\ lb \cdot ft$

$M_{CT\_service} = 130000.00\ lb \cdot ft$

$M_{EH\_service} = 13476.38\ lb \cdot ft$

$M_{ES\_service} = 5921.44\ lb \cdot ft$

$M_{overturning\_service} := M_{LS\_service} + M_{EH\_service} + M_{ES\_service} + M_{CT\_service} = 159198.8\ lb \cdot ft$

$M_{LS\_strength} = 17151.75\ lb \cdot ft$

$M_{CT\_strength} = 130000.00\ lb \cdot ft$

$M_{EH\_strength} = 20214.56\ lb \cdot ft$

$M_{ES\_strength} = 8882.16\ lb \cdot ft$

$M_{overturning\_strength} := M_{LS\_strength} + M_{EH\_strength} + M_{ES\_strength} + M_{CT\_strength} = 176248.5\ lb \cdot ft$

Example – Greater than 2’

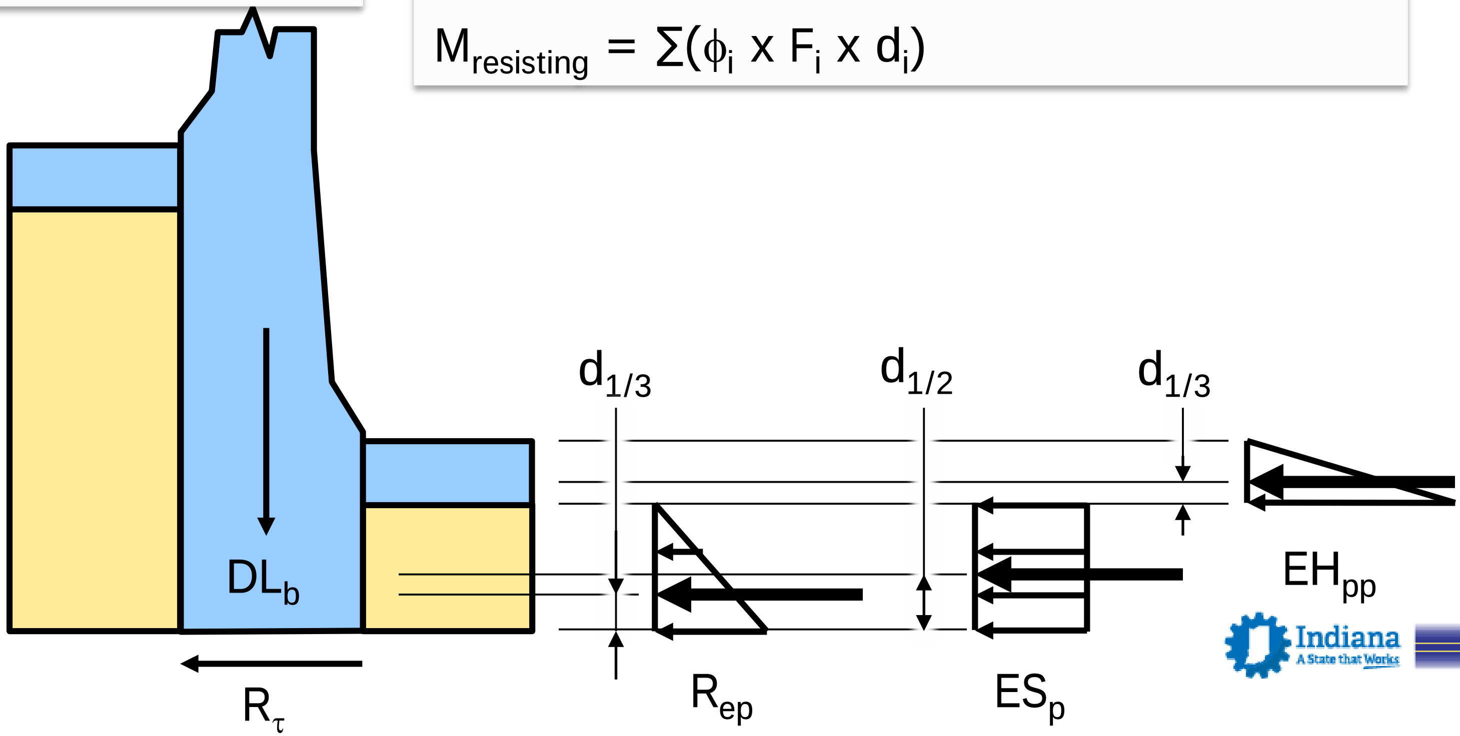
- **Case 2 – Final Condition**
  - Calculate the resisting forces and moments

Note:
The passive resistance of the lower pavement shall not exceed the allowable compressive strength

$R_\tau = DL_b \text{ x } \tan(\delta)$

$F_{resisting} = \Sigma(\phi_i \text{ x } F_i)$

$M_{resisting} = \Sigma(\phi_i \text{ x } F_i \text{ x } d_i)$



Resisting Force - Passive Earth Pressure of Lower Pavement:

$\sigma_{max\_asphalt} := 225\ \dfrac{lb}{in^2}$ (Maximum compressive strength of asphalt. Value shall be obtained for actual materials used.)

$\sigma_{allowable\_asphalt} := 33\% \cdot \sigma_{max\_asphalt} = 74.25\ \dfrac{lb}{in^2}$ (Allowable compressive strength of asphalt)

$\gamma_{asphalt} := 145\ \dfrac{lb}{ft^3}$ (unit weight of asphalt)

$k_{p\_asphalt} := \dfrac{\sigma_{allowable\_asphalt}}{D_{lower\_pavement} \cdot \gamma_{asphalt}} = 73.74$ (Passive pressure coefficient of asphalt to maintain allowable compression in asphalt)

$p_{passive\_pave} := \gamma_{asphalt} \cdot D_{lower\_pavement} \cdot k_{p\_asphalt} = 10692.00\ \dfrac{lb}{ft^2}$ (Passive pavement pressure at bottom of pavement)

$F_{passive\_pave\_service} := p_{passive\_pave} \cdot \dfrac{D_{lower\_pavement}}{2} \cdot L_{Barrier} = 21384.00\ lb$ (Passive pavement load unfactored force)

$M_{passive\_pave\_service} := F_{passive\_pave\_service} \cdot \left(\dfrac{D_{lower\_pavement}}{3} + H_{resisting\_soil}\right) = 98010.00\ lb \cdot ft$

(Passive earth load unfactored overturning moment)

$\varphi_{passive} := 0.5$ (Strength resistance factor for passive earth pressure, when used in conjuction with sliding resistance, LRFD table 10.5.5.2.2-1)

$F_{passive\_pave\_strength} := F_{passive\_pave\_service} \cdot \varphi_{passive} = 10692.00\ lb$ (Passive pavement load factored force)

$M_{passive\_pave\_strength} := \dfrac{F_{passive\_pave\_strength}}{\varphi_{passive}} \cdot \left(\dfrac{D_{lower\_pavement}}{3} + H_{resisting\_soil}\right) = 98010.00\ lb \cdot ft$

(Passive earth load factored overturning moment. Sliding resistance factor removed for overturning resistance)

Resisting Force - Passive Earth Pressure of Soil:

$k_p := 6$ (Coulomb's passive earth pressure coefficient. Value shall be obtained from Geotechnical Engineer for actual site conditions.)

$\gamma_{s\_retained\_dry} = 120.00\ \frac{lb}{ft^3}$

$\gamma_{soil} := \gamma_{s\_retained\_dry} = 120.00\ \frac{lb}{ft^3}$ (Design unit weight of soil)

$p_{passive} := \gamma_{soil} \cdot H_{resisting\_soil} \cdot k_p = 3060.00\ \frac{lb}{ft^2}$ (Passive earth pressure at bottom of wall)

$F_{passive\_service} := p_{passive} \cdot \frac{H_{resisting\_soil}}{2} \cdot L_{Barrier} = 26010.00\ lb$ (Passive earth load unfactored force)

$M_{passive\_service} := F_{passive\_service} \cdot \frac{H_{resisting\_soil}}{3} = 36847.50\ lb \cdot ft$ (Passive earth load unfactored overturning moment)

$\varphi_{passive} := 0.5$ (Strength resistance factor for passive earth pressure, when used in conjuction with sliding resistance, LRFD table 10.5.5.2.2-1)

$F_{passive\_strength} := F_{passive\_service} \cdot \varphi_{passive} = 13005.00\ lb$ (Passive earth load factored force)

$M_{passive\_strength} := \frac{F_{passive\_strength}}{\varphi_{passive}} \cdot \frac{H_{resisting\_soil}}{3} = 36847.50\ lb \cdot ft$ (Passive earth load factored overturning moment. Sliding resistance factor removed for overturning resistance)

Resisting Force - Pavement Surcharge Passive Earth Pressure of Soil:

$k_p = 6.00$ (Coulomb's passive earth pressure coefficient. Value shall be obtained from Geotechnical Engineer for actual site conditions.)

$\gamma_{asphalt} = 145.00 \ \frac{lb}{ft^3}$

$p_{ES\_passive} := \gamma_{asphalt} \cdot D_{lower\_pavement} \cdot k_p = 870.00 \ \frac{lb}{ft^2}$ (Surcharge passive earth pressure)

$F_{ES\_passive\_service} := p_{ES\_passive} \cdot H_{resisting\_soil} \cdot L_{Barrier} = 14790.00 \ lb$ (Surcharge passive load unfactored force)

$M_{ES\_passive\_service} := F_{ES\_passive\_service} \cdot \frac{H_{resisting\_soil}}{2} = 31428.75 \ lb \cdot ft$ (Surcharge passive load unfactored overturning moment)

$\varphi_{passive} := 0.5$ (Strength resistance factor for passive earth pressure, when used in conjuction with sliding resistance, LRFD table 10.5.5.2.2-1)

$F_{ES\_passive\_strength} := F_{ES\_passive\_service} \cdot \varphi_{passive} = 7395.00 \ lb$ (Passive earth load factored force)

$M_{ES\_passive\_strength} := \frac{F_{ES\_passive\_strength}}{\varphi_{passive}} \cdot \frac{H_{resisting\_soil}}{2} = 31428.75 \ lb \cdot ft$ (Passive earth load factored overturning moment. Sliding resistance factor removed for overturning resistance)

Resisting Force - Barrier Self-Weight:

$$Wt_{barrier\_FT} = 3928.75\ \frac{lb}{ft}$$

$\phi_f := 30\ deg$ (Internal friction angle of soil below barrier. Value shall be obtained from Geotechnical Engineer for actual site conditions.)

$F_{barrier\_resist\_service} := Wt_{barrier\_FT} \cdot \tan\left(\phi_f\right) \cdot L_{Barrier} = 9073.06\ lb$ (Unfactored sliding resistance between the barrier and soil)

$M_{barrier\_resist\_service} := Wt_{barrier\_FT} \cdot \dfrac{B_{barrier}}{2} \cdot L_{Barrier} = 19643.75\ lb \cdot ft$ (Unfactored overturning resistance of the barrier due to selfweight, taken about the toe of the barrier)

$\varphi_{sliding} := 0.8$ (Strength resistance factor for sliding of cast-in-place concrete on sandy soils, LRFD table 10.5.5.2.2-1)

$F_{barrier\_resist\_strength} := F_{barrier\_resist\_service} \cdot \varphi_{sliding} = 7258.45\ lb$ (Factored sliding resistance between the barrier and soil)

$M_{barrier\_resist\_strength} := M_{barrier\_resist\_service} \cdot \varphi_{sliding} = 15715.00\ lb \cdot ft$ (Factored overturning resistance of the barrier due to selfweight, taken about the toe of the barrier)

Lateral Resisting Force - Total:

$F_{passive\_service} = 26010.00\ lb$ $\quad F_{ES\_passive\_service} = 14790.00\ lb$

$F_{barrier\_resist\_service} = 9073.06\ lb$ $\quad F_{passive\_pave\_service} = 21384.00\ lb$

$$F_{resisting\_service} := F_{passive\_service} + F_{barrier\_resist\_service} + F_{passive\_pave\_service} + F_{ES\_passive\_service}$$

$$F_{resisting\_service} = 71257.06\ lb$$

$F_{passive\_strength} = 13005.00\ lb$ $\quad F_{ES\_passive\_strength} = 7395.00\ lb$

$F_{barrier\_resist\_strength} = 7258.45\ lb$ $\quad F_{passive\_pave\_strength} = 10692.00\ lb$

$$F_{resisting\_strength} := F_{passive\_strength} + F_{barrier\_resist\_strength} + F_{passive\_pave\_strength} + F_{ES\_passive\_strength}$$

$$F_{resisting\_strength} = 38350.45\ lb$$

$M_{passive\_service} = 36847.50\ lb \cdot ft$ $\quad M_{ES\_passive\_service} = 31428.75\ lb \cdot ft$

$M_{barrier\_resist\_service} = 19643.75\ lb \cdot ft$ $\quad M_{passive\_pave\_service} = 98010.00\ lb \cdot ft$

$$M_{resisting\_service} := M_{passive\_service} + M_{barrier\_resist\_service} + M_{passive\_pave\_service} + M_{ES\_passive\_service}$$

$$M_{resisting\_service} = 185930.00\ lb \cdot ft$$

$M_{passive\_strength} = 36847.50\ lb \cdot ft$ $\quad M_{ES\_passive\_strength} = 31428.75\ lb \cdot ft$

$M_{barrier\_resist\_strength} = 15715.00\ lb \cdot ft$ $\quad M_{passive\_pave\_strength} = 98010.00\ lb \cdot ft$

$$M_{resisting\_strength} := M_{passive\_strength} + M_{barrier\_resist\_strength} + M_{passive\_pave\_strength} + M_{ES\_passive\_strength}$$

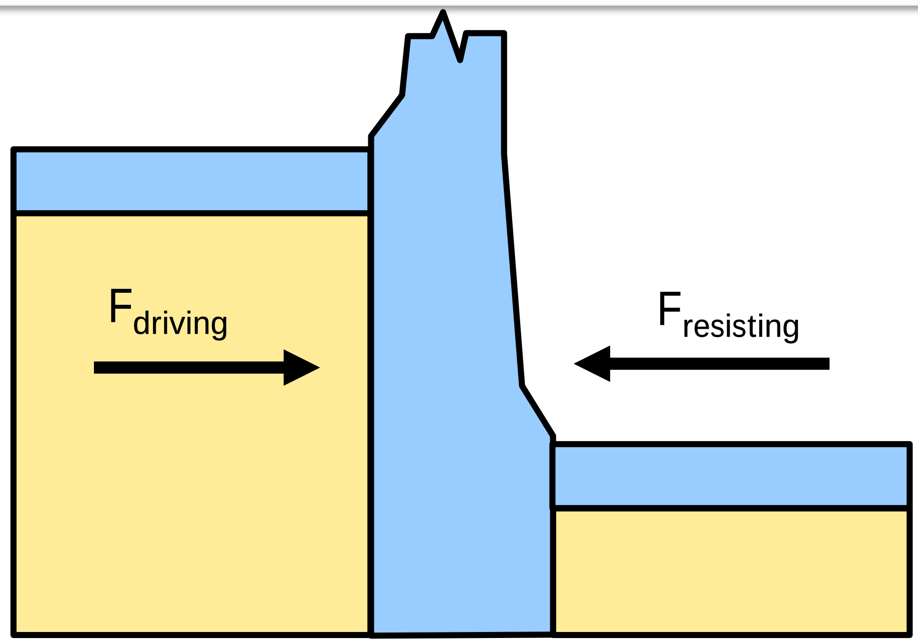
$$M_{resisting\_strength} = 182001.25\ lb \cdot ft$$

Example – Greater than 2’

- **Case 2 – Final Condition**
  - Check sliding resistance

If, $F_{resisting} > F_{driving}$, Sliding resistance is adequate

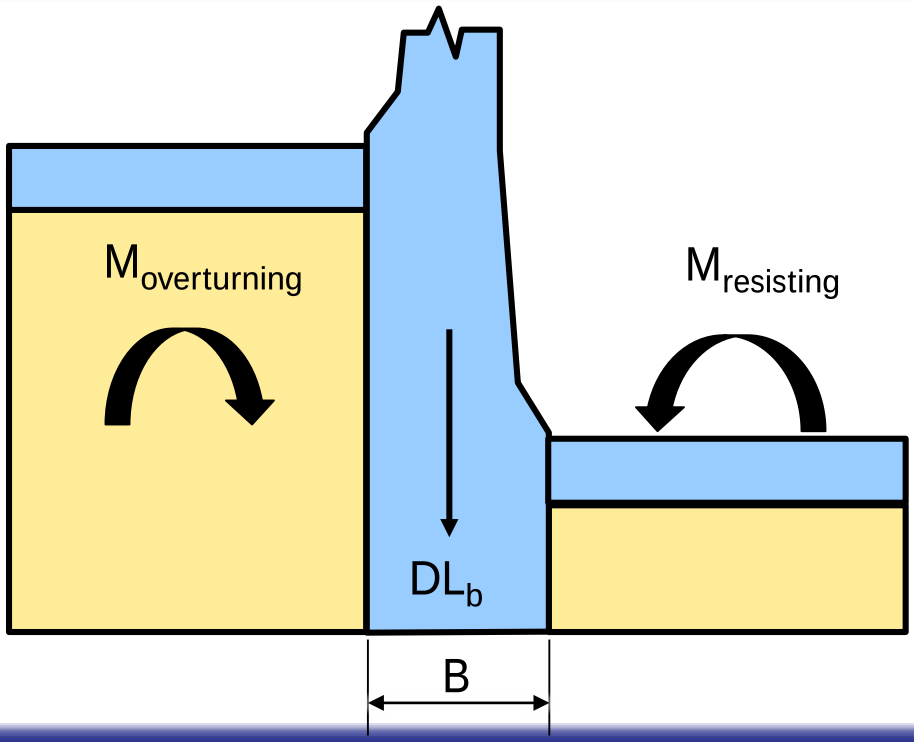
If, $F_{resisting} < F_{driving}$, Sliding resistance is deficient. Increase resistance by increasing barrier weight (width), embedment depth, barrier design length or decrease driving force (MSE, etc.)



Example – Greater than 2'

- **Case 2 – Final Condition**
  - Check overturning
    - Determine the net factored lateral load moments

$M_{net} = M_{overturning} - M_{resisting}$ (moments taken about center of barrier, B/2)



Example – Greater than 2'

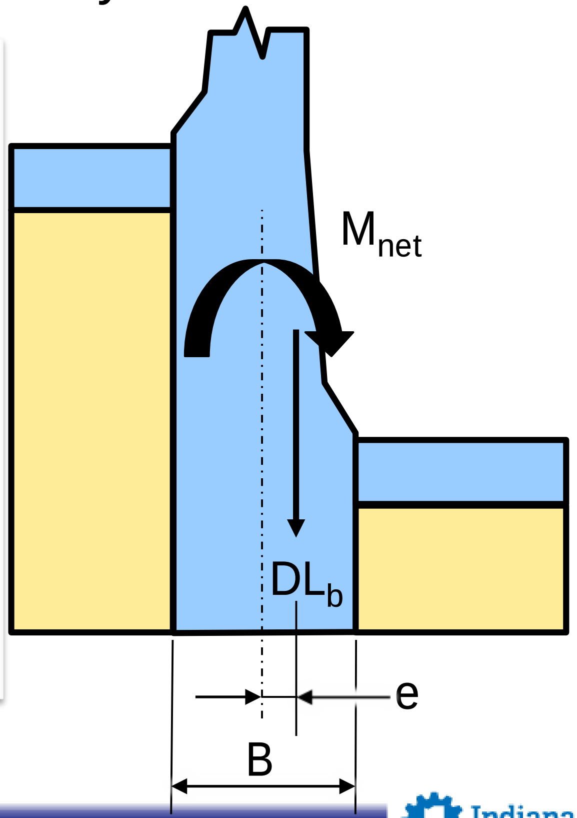
- **Case 2 – Final Condition**
  - Check overturning
    - Calculate the eccentricity of the applied loads and check against the maximum allowable eccentricity

e_{max} = B/3 (per LRFD section 11.6.3.3)

$e = M_{net}/DL_b$

If $e_{max} > e$, overturning resistance is acceptable

If $e_{max} < e$, overturning resistance is deficient. Increase resistance by increasing barrier weight (width), embedment depth, barrier design length or decrease driving force (MSE, etc.)



Sliding and Overturning Check - Strength Load Method:

Sliding Check:

$F_{resisting\_strength} = 38350.45\ lb$

$F_{overturning\_strength} = 23662.00\ lb$

$Demand\_Capacity_{sliding} := \dfrac{F_{overturning\_strength}}{F_{resisting\_strength}} = 0.62$ (Must be less than or equal to 1.0, per AASHTO LRFD , section 10.6.3.4)

$Check_{sliding\_strength} := \text{if}\left(Demand\_Capacity_{sliding} \le 1.0, \text{"OK"}, \text{"No Good"}\right) = \text{"OK"}$

Overturning Check:

$e_{max} := \dfrac{B_{barrier}}{3} = 0.83\ ft$ (Maximum allowable eccentricity, per AASHTO LRFD, section 11.6.3.3)

$M_{resisting\_strength\_centroid} := M_{passive\_strength} + M_{passive\_pave\_strength} + M_{ES\_passive\_strength}$

$M_{resisting\_strength\_centroid} = 166286\ lb \cdot ft$ (Resisting moment taken about the centroid of the barrier)

$M_{overturning\_strength} = 176248\ lb \cdot ft$

$e_{barrier} := \dfrac{\left(M_{overturning\_strength} - M_{resisting\_strength\_centroid}\right)}{Wt_{barrier\_FT} \cdot L_{Barrier}} = 0.63\ ft$

$Check_{overturning\_strength} := \text{if}\left(e_{barrier} \le e_{max}, \text{"OK"}, \text{"No Good"}\right) = \text{"OK"}$

Example – Greater than 2’

- **Case 2 – Final Condition**
  - Check bearing pressure
    - Calculate the effective barrier width due to the eccentricity of the applied loads and determine the applied bearing pressure

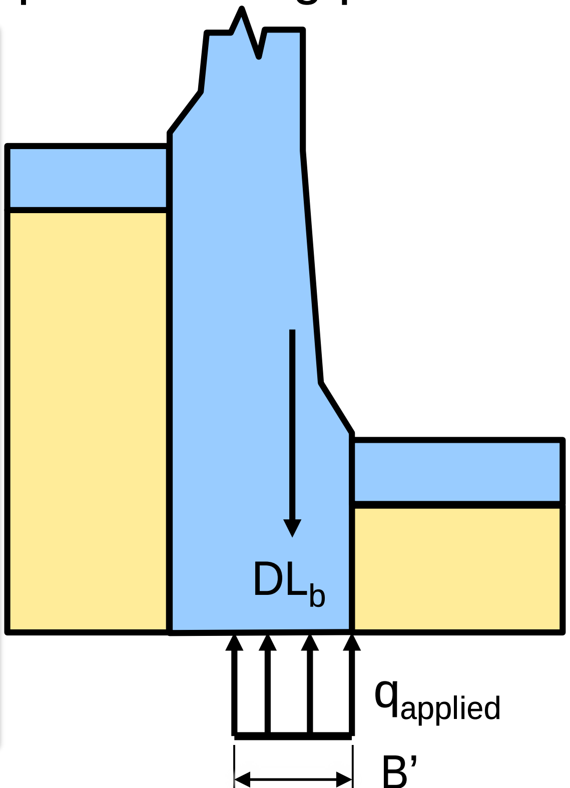
$B' = B - 2e$

$q_{applied} = DL_b / B'$

$q_{max\ allowable}$ = Per geotechnical recommendations

If $q_{max\ allowable} > q_{applied}$, bearing pressure is acceptable

If $q_{max\ allowable} < q_{applied}$, bearing pressure is deficient. Increase resistance by increasing barrier weight (width), embedment depth, design length or decrease driving force (MSE, etc.)



Bearing Capacity Check:

$$\sigma_{allowable\_factored\_resistance} := 4000 \ \frac{lb}{ft^2}$$

$$B' := B_{barrier} - 2 \cdot e_{barrier} = 1.23 \ ft$$

$$\sigma_{overturning\_strength} := \frac{Wt_{barrier\_FT}}{B'} = 3188.56 \ \frac{lb}{ft^2}$$

$$Check_{bearing\_capacity} := \mathbf{if} \left(\sigma_{allowable\_factored\_resistance} \ge \sigma_{overturning\_strength}, \text{“OK”}, \text{“No Good”} \right) = \text{“OK”}$$