Asymmetric Barriers

Pete White, PE
Systems Assessment Manager - Greenfield, INDOT
February 16, 2017

Overview

- What is an Asymmetric Barrier?
  - Median barrier with unbalanced roadway elevations
Overview

When Do We Need to Design?
- Unbalance < 2’, provide equivalent overturning resistance as standard unreinforced median barrier

- Unbalance > 2’, design as a reinforced retaining wall in accordance with AASHTO LRFD Bridge Design Specifications
Overview

- **What Shape is the Barrier?**
  - Based on standard 33” or 45” median barrier (E 602-CCMB-04)

  ![Diagram of barrier geometry]

- Geometry of faces should remain standard
  - Width may be increased

  ![Diagram showing standard face geometry and vertical face]
Overview

- **What Shape is the Barrier?**
  - Joint ‘B’ spacing doesn’t apply to reinforced (i.e. ≥ unbalance) barriers (E 602-CCMB-02)

Overview

- **How can Resistance be Increased?**
  - Increase width and/or embedment
    - Increased width will increase barrier weight; not efficient for higher loads
    - Increased embedment will increase passive resistance; has practical limits
Overview

- How can Resistance be Increased?
  - Add a spread footing

Spread footing increases overturning resistance by adding width and increases sliding resistance by adding weight, but increases construction complexity and excavation widths.

Overview

- How can Resistance be Increased?
  - Incorporate mechanically stabilized earth (MSE) (reduces resistance demand)

MSE reduces lateral earth pressures, but increases construction complexity and excavation width.

Wire Face Wall
Load Cases

- **Case 1 – During Construction**
  - Lower pavement not included in analysis, regardless of anticipated construction sequence

Omit lower pavement during construction to account for changes in MOT and future pavement replacement.

---

Load Cases

- **Case 1 – During Construction**
  - Vehicle collision force (CT) not required if temporary barriers utilized

Temporary barriers shall be shown in the plans.
**Load Cases**

- **Case 2 – Final In-Service Configuration**
  - Lower pavement in place and vehicle collision force applied

Vehicle collision force shall be applied to the top of the barrier, in addition to all other static loads.

**Lower pavement in place and providing passive resistance**

**Loading**

- **Driving Forces**
  - Active earth pressure ($E_{Ha}$), live load surcharge (LS), dead load surcharge ($E_{Sa}$), and vehicle collision force (CT); others as applicable

Water pressure may be omitted if adequate drainage is specified.
Loading

- **Driving Forces**
  - Vehicle collision force (CT) varies depending on the element being designed
    - CT = 10 kips, for stability analysis
    - CT = LRFD section 13, for barrier reinforcing

NCHRP Report 663 indicates that a vehicle collision force of 10 kips is appropriate for static equilibrium (overturning and sliding) analysis. Forces given in LRFD section 13 are impact loads appropriate for reinforced concrete design.

- **Driving Forces**
  - Load combinations and load factors shall be as given in LRFD Table 3.4.1.1
  - Load factors during construction may be reduced as appropriate, per section 3.4.2 of the LRFD Specifications

When investigating Strength Load Combinations I, III, and V during construction, load factors for the weight of the structure and appurtenances, \( DC \) and \( DW \), shall not be taken to be less than 1.25.

Unless otherwise specified by the Owner, the load factor for construction loads and for any associated dynamic effects shall not be less than 1.5 in Strength Load Combination I. The load factor for wind in Strength Load Combination III shall not be less than 1.25.
**Loading**

- **Resisting Forces**
  - Passive earth pressure ($R_{ep}$), dead load surcharge ($ES_p$), pavement passive resistance ($EH_{pp}$), barrier self-weight ($DL_b$), and sliding resistance ($R_s$)

  Sliding and passive may be used simultaneously, provided appropriate resistance factors are used (LRFD 10.5.5.2.2-1)

  Passive resistance of lower pavement shall not exceed allowable compressive strength

**Stability Analysis**

- **Sliding Check**
  - Sliding shall be checked per Section 10.6.3.4 of the LRFD Specifications
Stability Analysis

- **Overturning Check**
  - Overturning shall be checked per Section 11.6.3.3 of the LRFD Specifications

- **Bearing Resistance Check**
  - Bearing resistance shall be checked per Section 11.6.3.2 of the LRFD Specifications
Stability Analysis

Design Height and Length

- Design height of the barrier shall not be taken as less than the average height of barrier within a 100 foot length of barrier, or the length of barrier between non-load transferring joints in the barrier, whichever is less.

\[ H_{\text{design}} = (H_{\text{max}} - H_{\text{min}}) \times \frac{1}{2} \]

However,

\[ (H_{\text{max}} - H_{\text{design}}) \leq 1 \text{ foot} \]

Stability Analysis

Design Height and Length

- If at least 25 feet of the barrier within this length has an unbalanced height > 2 feet, the barrier should be designed for an unbalanced height > 2 feet.

Design as a reinforced retaining wall in accordance with AASHTO LRFD Bridge Design Specifications.
Reinforcing Design

- Barrier reinforcing shall be designed in accordance with section A13.3 of the LRFD Specifications

(LRFD Table A13.2.1, TL-4 = 54 kips, TL-5 = 124 kips)

Lateral earth pressures not required in conjunction with vehicle collision force

Example – Less than 2’

- Calculate the overturning resistance of standard median barrier

\[ P_{\text{std}} = \frac{D_{Lb} \times B/2}{H} \]
Example – Less than 2’

- Calculate the overturning moments due to earth pressures and convert that to an equivalent force at the top of the barrier

\[
M_{ul} = (E_h \times H_{ul}/3) + (LS \times H_{ul}/2)
\]

\[
P_{eq} = M_{ul}/H
\]

Notes:
1. Lateral earth pressure forces should be factored
2. Upper pavement has been conservatively assumed as soil in this example

Example – Less than 2’

- Calculate the total required lateral moment resistance and determine the required barrier weight

\[
P_{req} = P_{std} + P_{eq}
\]

\[
M_{req} = P_{req} \times H
\]

\[
WT_{req} = M_{req}/(B/2)
\]

Note:
- Moment resistance can also be increased by widening the barrier instead of, or in conjunction with, increasing the barrier depth
Example – Greater than 2’

Case 1 – During Construction

Assume an embedment depth and calculate the driving lateral forces and overturning moment.

- Calculate the resisting forces and moments

\[ \tau = D_Lb \times \tan(\delta) \]
\[ F_{\text{resisting}} = (\phi_{R_i} \times R_i) + (\phi_{\text{rep}} \times R_{\text{rep}}) \]
\[ M_{\text{resisting}} = (\phi_{\text{rep}} \times R_{\text{rep}} \times d_{1/3}) \]
Example – Greater than 2’

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

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

  If $F_{\text{resisting}} < F_{\text{driving}}$, 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

$$M_{\text{net}} = M_{\text{overturning}} - M_{\text{resisting}}$$ (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

\[ e_{\text{max}} = \frac{B}{3} \text{ (per LRFD section 11.6.3.3)} \]

\[ e = \frac{M_{\text{net}}}{D_L b} \]

If \( e_{\text{max}} > e \), overturning resistance is acceptable

If \( e_{\text{max}} < e \), overturning 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 bearing pressure
    - Calculate the effective barrier width due to the eccentricity of the applied loads and determine the applied bearing pressure

\[ B' = B - 2e \]

\[ q_{\text{applied}} = \frac{D_L b}{B'} \]

\[ q_{\text{max allowable}} = \text{Per geotechnical recommendations} \]

If \( q_{\text{max allowable}} > q_{\text{applied}} \), bearing pressure is acceptable

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

\[ F_{\text{driving}} = \sum (\gamma_i \times F_i), \text{ units force} \]
\[ M_{\text{overturing}} = \sum (\gamma_i \times F_i \times d_i), \text{ units force x length} \]

![Diagram showing driving forces and overturning moment](image)

\[ \text{CT (10 kips)} \]
\[ \text{Embedment depth from Case 1} \]

---

**Example – Greater than 2’**

**Case 2 – Final Condition**

- Calculate the resisting forces and moments.

\[ R_c = D L_b \times \tan(\delta) \]
\[ F_{\text{resisting}} = \sum (\phi_i \times F_i) \]
\[ M_{\text{resisting}} = \sum (\phi_i \times F_i \times d_i) \]

![Diagram showing resisting forces and moments](image)

**Note:**

The passive resistance of the lower pavement shall not exceed the allowable compressive strength.
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.)

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
    
      \[
      e_{\text{max}} = \frac{B}{3} \quad \text{(per LRFD section 11.6.3.3)}
      \]
    
    \[
    e = \frac{M_{\text{net}}}{D_{Lb}}
    \]
    
    If \( e_{\text{max}} > e \), overturning resistance is acceptable
    
    If \( e_{\text{max}} < e \), overturning 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 bearing pressure
    - Calculate the effective barrier width due to the eccentricity of the applied loads and determine the applied bearing pressure
    
      \[
      B' = B - 2e
      \]
    
    \[
    q_{\text{applied}} = \frac{D_{Lb}}{B'}
    \]
    
    \[
    q_{\text{max allowable}} = \text{Per geotechnical recommendations}
    \]
    
    If \( q_{\text{max allowable}} > q_{\text{applied}} \), bearing pressure is acceptable
    
    If \( q_{\text{max allowable}} < q_{\text{applied}} \), bearing pressure is deficient.
    
    Increase resistance by increasing barrier weight (width), embedment depth, design length or decrease driving force (MSE, etc.)