Bridge Railing & Deck Design Example

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Bridge Railing Design
Bridge Railing Design

• AASHTO 17th Edition and prior
  – 10k Load distributed over 5’
  – Applied perpendicular at top of rail

(To be used where there is no curb or curb projects 3” or less from traffic face of railing.)

TRAFFIC RAILING

FIGURE 2.7.48 Traffic Railing

Bridge Railing Design

NCHRP Report published in 1993

All Railing Systems must be crash tested.

NCHRP Report 350

Bridge Railing Design

Rail selection defined in IDM 404-4.01(05) Making Test-Level Determination

Based on:

- Construction year AADT
- Curvature
- Grade
- Deck Height
- % Trucks
- Design Speed
- Barrier Offset

Bridge Railing Design

AASHTO Manual for Assessing Safety Hardware (MASH)

Introduced in 2009


NCHRP 350 Railings do not have to be replaced.
Bridge Railing Design

Railing Design per AASHTO LRFD Bridge Design Specifications – Chapter 13

Intended for design of rails to be crash tested.

Table A13.2-1—Design Forces for Traffic Railings

<table>
<thead>
<tr>
<th>Design Forces and Designations</th>
<th>TL-1</th>
<th>TL-2</th>
<th>TL-3</th>
<th>TL-4</th>
<th>TL-5</th>
<th>TL-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_t$, Transverse (kips)</td>
<td>13.5</td>
<td>27.0</td>
<td>54.0</td>
<td>54.0</td>
<td>124.0</td>
<td>175.0</td>
</tr>
<tr>
<td>$F_L$, Longitudinal (kips)</td>
<td>4.5</td>
<td>9.0</td>
<td>18.0</td>
<td>18.0</td>
<td>41.0</td>
<td>58.0</td>
</tr>
<tr>
<td>$F_v$, Vertical (kips) Down</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>18.0</td>
<td>80.0</td>
<td>80.0</td>
</tr>
<tr>
<td>$L_r$ and $L_e$ (ft)</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>3.5</td>
<td>8.0</td>
<td>8.0</td>
</tr>
<tr>
<td>$L_h$ (min) (in.)</td>
<td>18.0</td>
<td>18.0</td>
<td>18.0</td>
<td>18.0</td>
<td>40.0</td>
<td>40.0</td>
</tr>
<tr>
<td>Minimum $H$, Height of Rail (in.)</td>
<td>27.0</td>
<td>27.0</td>
<td>27.0</td>
<td>32.0</td>
<td>42.0</td>
<td>56.0</td>
</tr>
</tbody>
</table>
Bridge Railing Design

AASHTO CA13.3.1
In this analysis it is assumed that the yield line failure pattern occurs within the parapet only and does not extend into the deck. This means that the deck must have sufficient resistance to force the yield line failure pattern to remain within the parapet.

Bridge Railing Design

IDM 404-3.02(02) Deck
Overhang
Based on observations of impacted bridge railings, an overhang designed according to previous AASHTO bridge-design specifications shows the desired behavior that the overhang does not fail if a railing failure occurs due to a collision. Accordingly, the overhang shall be designed for a collision force of 25% greater than the required capacity, which results in a design approximating present satisfactory practice.
Bridge Railing Design

IDM 404-4.01(05)
For a minor bridge rehabilitation project which does not include bridge-deck replacement or deck widening and the bridge currently has a crashworthy TL-4 bridge railing, the existing railing need not be upgraded to a TL-5 railing, though the warrants for the TL-5 railing are satisfied. If there is no significant history of truck accidents, the installation of the TL-5 bridge railing shall be deferred until the time of the deck replacement or deck widening.

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Interim Questions?

Thank You!

ASCE

INDIANA SECTION
Bridge Railing & Deck Design

The remainder of the presentation will discuss:

- INDOT LRFD bridge railing & deck design practice.
- Sidewalk railing applications.
- Barrier railing on bridge rehabilitation projects.

LRFD Bridge Deck Design

Deck design seems simple, but several LRFD design sections are involved:

- Section 3: Loads & Load Factors
- Section 4: Distribution
- Section 5: Reinforced Concrete Design
- Section 9: Deck & Deck Systems
- Section 13: Railings
LRFD Bridge Deck Design

Bridge deck design requirements are covered under IDM Chapter 404.

For longitudinal beam bridges, two conditions are checked in the transverse direction to design the deck reinforcing steel:

• The interior condition between beams.
• The exterior deck overhang condition.

LRFD Bridge Deck Design - Interior

• Interior design uses an equivalent strip method, where wheel loads are distributed over the strip width.

Equivalent Strip Equations
LRFD Bridge Deck Design – Deck Overhang

The deck overhang design requires checking three cases (LRFD A13.4, in reverse order for the presentation):

- Design Case 3: The loads specified in Article 3.6.1 that occupy the overhang for the Load Combination Strength I limit state;
- Design Case 2: Vertical forces specified in Article A13.2 for the Extreme Event Load Combination II limit state;
- Design Case 1: Transverse and longitudinal forces specified in Article A13.2 for the Extreme Event Load Combination II limit state.

LRFD Bridge Deck Design – Deck Overhang

*Design Case 3: Strength I limit state*

• This is effectively the same design process as the interior strip using dead and live loads applied to the cantilever. (Only governs with large overhang)

\[
\text{Overhang Moment} = 45.0 + 10.0X
\]

*Equivalent Strip Equation*
LRFD Bridge Deck Design – Deck Overhang

Design Case 2: Extreme Event II limit state (Vertical Barrier Force)

• This case involves a vertical load applied to the top of the railing. For concrete barrier railing, this condition does not control.
• The barrier railing longitudinally distributes the force if it is constructed monolithically and continuous. (IDM 404-3.02 & 3.04)
• This case is applicable to post type railing.

LRFD Bridge Deck Design – Deck Overhang

Design Case 1: Extreme Event II limit state (Horizontal Barrier Force)

• Design procedures are in LRFD Section A13.4.

• This presentation will focus only on Section A13.4.2 – Decks Supporting Concrete Parapet Railings
Overhang Design Loading

Design Case 1: Extreme Event II limit state
(Horizontal Barrier Force)

- The deck reinforcing steel must be designed to accommodate the combined moment and tension force.

Overhang Design Loading

If certain conditions are met, AASHTO allows an easy solution to determine the live loading.

3.6.1.3.4—Deck Overhang Load

For the design of deck overhangs with a cantilever, not exceeding 6.0 ft from the centerline of the exterior girder to the face of a structurally continuous concrete railing, the outside row of wheel loads may be replaced with a uniformly distributed line load of 1.0 klf intensity, located 1.0 ft from the face of the railing.

Horizontal loads on the overhang resulting from vehicle collision with barriers shall be in accordance with the provisions of Section 13.
LRFD Bridge Deck Design – Deck Overhang

A13.4.2—Decks Supporting Concrete Parapet Railings

For Design Case 1, the deck overhang may be designed to provide a flexural resistance, $M$, in kip-ft which, acting coincident with the tensile force $T$ in kip/ft, specified herein, exceeds $M_e$ of the parapet at its base. The axial tensile force, $T$, may be taken as:

$$T = \frac{R_e}{L_e + 2H}$$  \hspace{1cm} (A13.4.2-1)

where:
- $R_e =$ parapet resistance specified in Article A13.3.1 (kips)
- $L_e =$ critical length of yield line failure pattern (ft)
- $H =$ height of wall (ft)
- $T =$ tensile force per unit of deck length (kip/ft)

LRFD Bridge Deck Design – Deck Overhang

A yield line analysis produces the nominal railing resistance.

A13.3.1—Concrete Railings

Yield line analysis and strength design for reinforced concrete and prestressed concrete barriers or parapets may be used.

The nominal railing resistance to transverse load, $R_{yx}$, may be determined using a yield line approach as:

- For impacts within a wall segment:

$$R_{yx} = \left( \frac{2}{2L_e - L_t} \right) \left( 8M_o + 8M_e + \frac{M_e L_t^2}{H} \right)$$  \hspace{1cm} (A13.3.1-1)
LRFD Bridge Deck Design – Deck Overhang

\[ H = \text{height of wall (ft)} \]

\[ L_o = \text{critical length of yield line failure pattern (ft)} \]

\[ L_r = \text{longitudinal length of distribution of impact force} \]

\[ F_r (ft) \]

\[ R_o = \text{total transverse resistance of the railing (kips)} \]

\[ M_o = \text{additional flexural resistance of beam in addition} \]

\[ \text{to } M_o, \text{ if any, at top of wall (kip-ft)} \]

\[ M_s = \text{flexural resistance of cantilevered walls about an} \]

\[ \text{axis parallel to the longitudinal axis of the bridge} \]

\[ \text{(kip-ft/ft)} \]

\[ M_w = \text{flexural resistance of the wall about its vertical} \]

\[ \text{axis (kip-ft)} \]

For use in the above equations, \( M_s \) and \( M_w \) should not vary significantly over the height of the wall. For other cases, a rigorous yield line analysis should be used.

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LRFD Bridge Deck Design – Deck Overhang

The critical wall length over which the yield line mechanism occurs, \( L_o \), shall be taken as:

\[ L_o = \frac{L_o}{2} + \left( \frac{L_o}{2} \right)^2 + \frac{8H(M_o + M_w)}{M_o} \]  \hspace{1cm} (A13.3.1-2)

- For impacts at end of wall or at joint:

\[ R_o = \left[ \frac{2}{2L_o - L_i} \right] \left( M_s + M_w + \frac{M_1 L_r^2}{H} \right) \]  \hspace{1cm} (A13.3.1-3)

\[ L_o = \frac{L_o}{2} + \left( \frac{L_o}{2} \right)^2 + H \left( \frac{M_w + M_o}{M_s} \right) \]  \hspace{1cm} (A13.3.1-4)

Figure CA13.3.1-3: Yield Line Analysis of Concrete Parapet Walls for Impact with Wall Segment
**LRFD Bridge Deck Design – Deck Overhang**

LRFD CA13.4.2 states,

*The crash testing program is oriented toward survival and not necessarily the identification of the ultimate strength of the railing system. This could produce a railing system that is significantly over-designed leading to the possibility that the deck overhang is also over-designed.*

---

**How Much Force???</p>

Using the railing capacity to design the deck overhang reinforcing can be overly conservative.
The IDM now allows the use of 1.25 x F_t as a maximum.
**LRFD Railing Design Forces**

The $F_t$ value comes from LRFD Table A13.2-1 using the appropriate railing test level.

<table>
<thead>
<tr>
<th>Design Forces and Designations</th>
<th>Railing Test Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TL-1</td>
</tr>
<tr>
<td>$F_t$, Transverse (kips)</td>
<td>13.5</td>
</tr>
<tr>
<td>$F_l$, Longitudinal (kips)</td>
<td>4.5</td>
</tr>
<tr>
<td>$F_r$, Vertical (kips) Down</td>
<td>4.5</td>
</tr>
<tr>
<td>$L_d$ and $L_x$ (ft)</td>
<td>4.0</td>
</tr>
<tr>
<td>$H_r$ (min) (in.)</td>
<td>18.0</td>
</tr>
<tr>
<td>Minimum $H$ Height of Rail (in.)</td>
<td>27.0</td>
</tr>
</tbody>
</table>

**Load Application & Distribution**

The collision forces are distributed over a distance $L_c$ for moment and $L_c + 2H$ for axial force. The distribution length increases at a 30 - 45 degree angle from the barrier face to the design section.
Rail Load Design for Test Level

- Calculate $R_w$ & $L_c$ from a yield line analysis. Use the lower force value between $R_w$ or $1.25 \times F_t$.
- Calculate $T$ & $M$ at the Design Section.
- A linear interaction equation is typically used to design the reinforcing steel for the combined loading.

\[
\frac{P_n}{P} + \frac{M_n}{M} = 1.0
\]

Solving for $M_n$:

\[
M_n = M \left(1.0 - \frac{P}{P_n}\right)
\]

Cutoff Location & Bar Development

- After the reinforcing steel is designed, any required cut-off locations must be determined, and the development length must be verified.
- There are numerous design guides available.
- FHWA is a good resource.
Federal Highway has many design guides available for download at:

http://www.fhwa.dot.gov/bridge/steel/pubs/if12052/


### Minnesota Design Tables

Since the design values are specific to a rail type and test level, Minnesota tabulated them:

<table>
<thead>
<tr>
<th>Description</th>
<th>End Panel</th>
<th>Interior Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Barrier (Type F, R-4)</td>
<td>6.6</td>
<td>6.9</td>
</tr>
<tr>
<td>S-297-116, Integrated End Post w/ M.C.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-297-114, Standard End Post w/ M.C.</td>
<td>6.6</td>
<td>103.3</td>
</tr>
<tr>
<td>Concrete Barrier (Type F, R-4)</td>
<td>9.3</td>
<td>103.5</td>
</tr>
<tr>
<td>S-297-120, Standard End Post w/ M.C.</td>
<td>9.3</td>
<td>125.5</td>
</tr>
<tr>
<td>Concrete Barrier (Type F, R-5)</td>
<td>9.2</td>
<td>90.3</td>
</tr>
<tr>
<td>S-297-120, Standard End Post w/ M.C.</td>
<td>9.2</td>
<td>125.5</td>
</tr>
<tr>
<td>Concrete Barrier (Type F, R-5)</td>
<td>9.3</td>
<td>125.5</td>
</tr>
<tr>
<td>S-297-120, Standard End Post w/ M.C.</td>
<td>9.2</td>
<td>135.4</td>
</tr>
<tr>
<td>Concrete Barrier and Glass Screen (Type F, R-5)</td>
<td>9.3</td>
<td>108.5</td>
</tr>
<tr>
<td>S-297-120, Standard End Post w/ M.C.</td>
<td>9.2</td>
<td>135.4</td>
</tr>
<tr>
<td>Side Median Barrier (Type F, R-4)</td>
<td>6.5</td>
<td>135.1</td>
</tr>
<tr>
<td>S-297-120, w/ M.C.</td>
<td>9.2</td>
<td>135.1</td>
</tr>
<tr>
<td>Side Median Barrier and Glass Screen (Type F, R-4)</td>
<td>6.5</td>
<td>135.1</td>
</tr>
<tr>
<td>S-297-120, w/ M.C.</td>
<td>9.2</td>
<td>135.1</td>
</tr>
</tbody>
</table>
Caltrans Overhang Design

Caltrans amended LRFD A13.4.2 as follows:

A13.4.2 Decks Supporting Concrete Parapet Railings

Revise as follows:

For Design Case 1, the deck overhang shall may be designed to resist provide a flexural resistance $M_c$ in kip-ft. which acting coincident with the combined effect of tensile force $T$ in kip-ft. and moment $M_e$ as specified herein, exceeds $M_c$ of the parapet at its base. The axial tensile force, $T$, may be taken as:

\[
x = \frac{R_e}{L_e + 2H}
\]

\[
T = 1.3 \left( \frac{R_e}{L_e} \right)
\]

\[
M_e = 1.3 \left( \frac{FH}{L} \right)
\]

where:

- $R_e$ — parapet resistance specified in Article A13.3.3-1 (kips)
- $L_c$ — critical length of yield line failure pattern (ft.)
- $H$ — height of wall (ft.)
- $T$ — tensile force per unit of deck length (kip/ft.)
- $M_e$ — moment in the deck overhang due to $T$ (kip-ft.)

Overhang Design Recommendations

There are discussion within the Structures Committee regarding the possibility of developing design aids for railing loading on overhangs in one of the following formats:

- Tabulated design forces and critical wall lengths for INDOT Railing for each available test levels, or
- A modified design process similar to Caltrans.
Sidewalk Railing Applications

- LRFD Section 13.4 provides two options for pedestrian walkways railing depending on speed.
- IDM 404-4.02(03) discusses considerations if sidewalks are present, and like LRFD identifies low speed as 45mph or less.

Sidewalk Railing Applications

- If this type is used, a shyline is preferred.
- During a collision, a vehicle can still potentially mount the curb.
- This does not protect pedestrians from falling into traffic.
Sidewalk Railing Applications

- Many municipalities and trail groups are now in favor of providing railing to separate pedestrians from vehicular traffic regardless of the speed.
- There appears to be a trend towards this “High Speed” railing system.
- This system has the benefit of producing a lower structure dead load.

Johnny Appleseed Memorial Bridge

SR 930 over the St. Joseph River, in Fort Wayne

- Widened existing INDOT bridge to extend the river greenway trail
- PF-1 Railing w/ pipe added
- Pedestrian rail at coping
- Great visibility
Johnny Appleseed Memorial Bridge

- The structure could only support an 8 foot trail width
- Provided curved railing to give the illusion of added width and for bicycle pedal protection.
Johnny Appleseed Memorial Bridge

- The system produces a very straight top rail appearance.

- Pedestrians are separated from vehicular traffic and both are protected by appropriate railing systems.

Johnny Appleseed Memorial Bridge

Because there is structure behind the railing to carry the shear force, the tension component can be reduced or eliminated from the design.
Bridge Rehabilitation Railing

• For an existing bridge having an older safety shape railing with reinforcing that doesn’t meet current standards, the first step should be to determine if it can remain.

• Communication with Anne’s Rearick’s Department should occur early in the process to determine if a level one design exception is appropriate.

• A short form and submittal process to streamline the initial review is under development.

• Utilizing the existing railing will reduce costs, but every situation is unique.

Bridge Rehabilitation Railing

For an existing bridge with unacceptable railing, replacement will be required.
Bridge Rehabilitation Railing

Remove enough of the existing railing & curb to accommodate installation of the new railing.

Bridge Rehabilitation Railing

Older decks may only be 6 1/2’’ thick. This makes it difficult to install the anchor system without drilling through the deck.

On past projects, we have installed a bar at an angle to use the beam flange as a drill stop.
Bridge Rehabilitation Railing

This method can also be used on a reinforced concrete girder section.

Bridge Rehabilitation Railing

Open railing on old slab bridges allowed salt to corrode the bottom reinforcing steel.
Bridge Rehabilitation Railing

To repair the corroded reinforcing steel and allow for the addition of new barrier railing, a section of the slab must be removed.

Bridge Rehabilitation Railing

A standard railing concrete form can be blocked 1 1/2” to allow the railing to act as an overlay form and screed rail during construction.
Retrofit Barrier Drainage Detail

- With the new solid barrier railing, water can no longer drain off the slab edge.
- A bentonite waterstop can be installed to ensure water flows through the new drain and not along the edge where salt can migrate into the slab.

Bentonite Waterstop

- Bentonite waterstop is readily available from multiple suppliers and is self adhering.
Railing Aesthetic Treatments & Safety

This report contains guidelines for aesthetic treatment of concrete safety shape barriers.


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Questions?

Thank You!