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Chapter 1
About this Guide

Purpose

The Texas Department of Transportation (TxDOT) Bridge Division has developed and implemented this guide to provide TxDOT and Consultant Engineers with guidelines for designing columns and vehicular deflection walls for vehicular impact and for providing vehicular redirection respectfully. For requirements for railroad overpasses refer to the AREMA Manual for Railway Engineering (AREMA) Ch. 8.2.1.5 and for vessel collision refer to AASHTO LRFD Bridge Design Specifications (AASHTO) Article 3.14.

Bent (pier) protection should be accomplished by using Redirection or Structural Resistance, and applies to all Roadway and Railroad Bridge structures that cross a lower roadway. The Bent (Pier) Protection Guide adheres to the design guidelines established by AASHTO and TxDOT Bridge Design Manual – LRFD (BDM).

Updates

<table>
<thead>
<tr>
<th>Version</th>
<th>Publication Date</th>
<th>Summary of Changes</th>
</tr>
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<tbody>
<tr>
<td>2021-1</td>
<td>June 2021</td>
<td>New guide published.</td>
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Organization

The information in this guide is organized as follows:

- Chapter 1, “About this Guide,” contains introductory information on the purpose and organization of this guide.
- Chapter 2, “Design Considerations,” contains information that needs to be considered when retrofitting or designing new bents, and determining when protection will be needed.
- Chapter 3, “Load Redirection Design,” focuses on semi-rigid or rigid barriers that are meant to be used in the redirection of the crash/load.
- Chapter 4, “Structural Resistance Design,” focuses on the design of columns with the intent of absorbing the impact without partial or total collapse.
- Chapter 5, “Widenings,” addresses considerations for bridge widening projects.
Appendix A, provides a flow chart to assist the engineering judgement. 
Appendix B, provides example sheets and details. 
Appendix C, provides example failure modes for yield line analysis.

Feedback

You may direct any questions or comments on the content of this guide to the Design Section Director of the Bridge Division, Texas Department of Transportation.
Several geometric and traffic aspects should be considered when evaluating a bent for protection. Investigate all bents that have columns within 30 feet of the travel lane. This dimension should not be confused with the roadway clear zone. Investigate bents adjacent to a lower roadway or a bridge.

For the example shown in Figure 1, the location of the column is between 10 to 20 feet. If the bridge was designed today, the column would need to be investigated for vehicular collision.

However, engineers should not be restricted to just lateral dimensions; engineering judgement is required to decide when vehicular collision should be investigated. See Appendix A for a flowchart to aid in this process. Consider if the geometry of the adjacent roadway creates a higher risk of a vehicle exiting the roadway and impacting the column.

As a first step to determine whether to investigate for vehicular collision, calculate the annual frequency for a bridge pier to be hit by a heavy vehicle ($AF_{HBP}$). BDM Chapter 2,
Section 2 – Vehicular Collision provides a formula that calculates $AF_{HBP}$. Alternately, Table 1 can be used to determine $AF_{HBP}$. To calculate $AF_{HBP}$ the engineer should determine the average daily truck traffic in one direction (ADTT) for the roadway adjacent to the bent. The TxDOT Transportation Planning Maps can be used to determine annual average daily traffic (AADT) of the facility crossed. If no project specific information is available, the percentage of traffic in one direction and the percentage of trucks can be approximated based on AASTHO C3.6.1.4.2. Values of $P_{HBP}$ are provided in Figure 2.

$$AF_{HBP} = 2 \times ADTT \times 365 \times P_{HBP}$$

<table>
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<th>ADT (Both Directions)</th>
<th>ADTT* (One Way)</th>
<th>Undivided</th>
<th>Divided</th>
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</table>

*Assumes 55% in one direction and twenty percent of ADT is truck traffic.

**Table 1 – Typical Values of $AF_{HBP}$**
The 9th edition of AASHTO LRFD added the calculation of the annual frequency for a bridge collapse ($AF_{BC}$). At the designer’s discretion, the $AF_{BC}$ can be calculated. If the $AF_{BC}$ is less than 0.001, the bridge does not need to be designed for vehicular collision force, regardless of the value of $AF_{HBP}$. The calculation of $AF_{BC}$ is only suggested in cases where the $AF_{HBP}$ is just above the 0.001 threshold and where providing a vehicular collision design conflicts with other site restrictions.

To calculate $AF_{BC}$, the Critical Pier Component Nominal Lateral Resistance, $R_{CPC}$, must be calculated. $R_{CPC}$ is the lateral force, in kips, applied at the locations and angles described in AASHTO LRFD 3.6.5.1 that causes the total or partial collapse of the bridge. Typically, we will consider the column collapse sufficient to cause partial collapse. A column collapse will occur when the column reaches its shear capacity or develops a failure mechanism from plastic hinging. The connection details to the cap and footings should be considered in the structural analysis and the capacity of the plastic hinges.

<table>
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<tr>
<th>$P_{HBP}$</th>
<th>Description</th>
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<tr>
<td>$3.457 \times 10^{-9}$</td>
<td>for undivided roadways in tangent and horizontally curved sections</td>
</tr>
<tr>
<td>$1.090 \times 10^{-9}$</td>
<td>for divided roadways in tangent sections</td>
</tr>
<tr>
<td>$2.184 \times 10^{-9}$</td>
<td>for divided roadways in curved sections</td>
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**Figure 2 – $P_{HBP}$ Values**
Chapter 3
Load Redirection Design

When Load Redirection design is used to protect the bent, a structurally independent barrier or embankment is placed between the traffic and the bridge bent. The barrier intercepts errant vehicles and redirects them prior to the vehicle impacting the bridge bent.

As per BDM Chapter 2, Section 2 – Vehicular Collision, the protection shall consist of one of the following:

- An embankment, such as a soil slope sloping away from the column. See Figure 3;
- A test level (TL-5) structurally independent, crashworthy ground mounted 54.0-in. high barrier, located within 3.25 ft. from the component being protected. See Figure 4;
- A test level (TL-5) structurally independent, crashworthy ground mounted 42.0-in. high barrier, located between 3.25 ft. to 10 ft. from the component being protected. See Figure 4; or
- A TL-5 42.0-in. high barrier located at more than 10.0 ft. from the component being protected. See Figure 5.

Figure 3 - Embankments
The barrier should be designed to resist the TL-5 loads provided in AASTHO Section 13, Railings, and geometrically be a nationally approved shape, such as vertical wall, single slope, or F shape.

See T80PP-RF standard and TL-5 independent foundation standard for more information.

Alternatively, a 54” or 42” tall vertical wall may be used if designed to resist TL-5 loading.

*TL-5 Rails
C412
T224
T80HT
T80SS
T80PP

Figure 4 – Barriers at less than 10’

An SSCB rail may be modified for reinforcement similar to the T80SS. Barriers shown in Figure 4 may also be used.

Figure 5 – Barriers between 10’ and 30’
In highway corridors, the bent may be located between 2 roadways, such as in the median; in this case a split rail may be the solution. The height requirements for the split rail at the bent locations will be the same as the less than 3.25-ft. option (Figure 4). The minimum length of the split rail is 50 feet with a minimum offset of 3 inches from the columns. Additionally, consider how the barrier will be ended, such as transitioning to MBGF, a crash-cushion, or a median barrier.

Figure 6– Split Rail Guidance (See Two Side T80PP Traffic Rail (T80PP-TS) standard.)
New Construction

One of the methods to design for structural resistance is to design the columns to absorb the vehicular collision force. Constraints consistent with the structural detailing and the soil characteristics should be modelled when analysing the force distribution in the column. Shear, flexure, and connections should be designed to resist the 600 kip vehicular collision force.

Additional design considerations can be found in BDM Chapter 4, Section 6 and in Figure 7 below.

![Figure 7 – Design Guidelines](image)
The shear capacity can be calculated using the Modified Compression Field Theory (MCFT). Generally, when using MCFT, increased axial compression increases the shear capacity of the member. For shear capacity, the below factors supersede the factors in the table in AASHTO for the axial compression and limits an unwarranted capacity increase. This can be simplified by assuming no axial compression.

- Axial Compression: $\gamma_{DC} = 0.9$, $\gamma_{LL+IM} = 0$
- Shear: $\gamma_{CT} = 1.0$

As an alternate to designing the columns for impact, a Vehicular Deflection Wall (VDW) may be designed and used. VDWs should not be confused with Crash Walls (CW), a CW is meant to redirect train collisions. CWs are not discussed in this document, please refer to AREMA for more information. VDWs are discussed under Existing Facilities.

**Existing Facilities**

For existing facilities, bent protection usually comes as a pre-emptive measure or a reactive measure.

Pre-emptive measures are usually a VDW that reinforces the structural capacity of the columns. See Figure 8.

![Figure 8 – Vehicular Deflection Wall](image)

When using a VDW as a structural resistance solution, the same concept is used as for designing the column for new construction, except that the columns are not being replaced with new columns, the VDW will aid the columns in distributing the load to the other
columns. For sample details of a deflection wall please refer to Appendix B in this document.

When designing the VDW, use the 600-kip point load like the column design. For the VDW multiply the 600-kip force by the sum of the differential skew of the lower roadway to the bent and the 15-degree departure angle. See Figure 9. For the most common case, when the bent is parallel to the lower roadway, this point load is 155 kips.

![Diagram of Vehicular Deflection Wall - Point Load](image)

** 600 kips × sin(15° + differential angle of the lower rdwy to the bent)

**Figure 9 – Vehicular Deflection Wall – Point Load**

If the end column of the bent is exposed to a head on collision, the bent system should be evaluated for the full 600-kip force. The VDW will distribute the force to all the columns of the bent, so each column will see only a portion of the load.

The wall will need to be designed to resist the point load applied. One method for determining the capacity of the wall is to use a yield line analysis. Caution, a yield line analysis is an upper-bound analysis approach, which means the capacity derived from a single yield line analysis may be higher than the actual capacity. The lowest capacity from all possible yield line is the capacity of the structure. See Appendix C for example failure modes for yield line analysis.
Every VDW must be analysed based on the geometry of the bent, its relative angle to the lower roadway, and the design details provided in the plans such as the thickness of the wall, the reinforcing of the wall, and the connection to the column. One-Sided VDWs are used on bents where only one side of the bent faces the traffic. Two-Sided VDWs are used in bents that lay in the median part of a divided highway to protect both sides of the bent. VDW drawings must be tailored to each specific project, just as the sample details in Appendix B were tailored to that project. Since VDW are dependent on site specific conditions, sample details cannot be replicated without analysing the wall for strength.

Additional consideration needs to be made for the end conditions of the VDW. Some end conditions to consider are transitioning to MBGF, a crash-cushion, or a median barrier. Details will be needed for these transitions. Transitioning to median barrier could involve shape and/or height transitions. Another end treatment option involves placing sand barrels next the bent. The selection of how to terminate the VDW are roadway roadside safety decisions, so coordination is needed between the VDW designer and the roadway engineer.

Aesthetics can be used on the VDW, but there are limitations. The aesthetics cannot protrude from the surface, they must be inset. The bottom 3 ft. of the wall should be smooth. This is to prevent snagging of the pickup and car. Above that, a ¾-in. relief on a vertical wall is allowed. If there is a 36-in. or taller rail in front of the VDW, the maximum amplitude of the relief above the rail is 2 in. The concrete cover of the reinforcing will need to be increased so that the minimum cover is still provided. The reduction in wall thickness for the aesthetics will affect the capacity of the wall. If the current design (without aesthetics) is barely meeting the required resistance, adding inset aesthetics may require a wider wall. Analyse the wall assuming the width for analysis is the width of the wall minus the maximum amplitude of the reliefs.

Reactive measures are usually done after the bent has already suffered damage and concrete repair is required. Repairs may require one of the following:

- Concrete repair + jacketing of column (Figure 10) (See Appendix B for example details.)
- Concrete repair + adding a vehicular deflection wall
- Partial removal + replacement with a bigger column
Figure 10 – Column with Jacket
Chapter 5
Widenings

In bridge widenings, the bent protection is intended for the existing columns, and the type of connection between bents, if any, should be considered during the analysis. For the new column(s) in a widening project, the design is similar to new structures. When modelling the distribution of the collision load, use constraints that are consistent with the details used to connect to the existing structure. If there is a gap between the existing bent, then the two caps are structurally independent. If the connection does not fully engage the reinforcing of the existing cap, the connection of the two caps is a simple pin. A full moment connection between the existing bent and the new bent should only be modelled if the widening is detailed to transfer the force from the reinforcing in the existing cap to the widening. See Figure 11 for typical connection details.

Figure 11 – Cap Elevation Views Showing Pin and Moment Connections
For the existing structure, analyse the column capacity for the vehicular collision force.

- Can the bent resist the load as is?
- Does a VDW need to be added to increase the capacity of the bent/columns?
- Consider the roadside safety concerns.
  - Will adding a VDW adversely affect sight distances at an intersection?
  - Is adding the VDW going to increase the ponding of the design storm to where it encroaches on the travel lane?

If all the design criteria cannot be met, this includes structural design criteria as well as roadway design criteria, discuss with the District’s project lead and decide which criteria takes precedence. All conflicts and decisions need to be identified and addressed on a case-by-case basis. The sooner these conflicts are brought to the attention of the District’s project lead the better.

Once the design decisions have been made, follow the procedures outlined in Chapters 3 or 4 depending on the design solution selected for the widening.

If a deflection wall will be added between the columns of the existing bent, consider adding it to the widening as well for uniformity.
Appendix A

Figure 12 – Design Consideration Flow Chart

This flow chart is mainly used when Bents are being evaluated routinely, however, a more direct approach can be taken by reviewing crash data and decide to add Pier Protection based on crash data alone.
Appendix B

Figure 13: Example Details for Vehicular Deflection Wall

1. \( w(#5) \) bars are to be placed with bars \( w(#5) \) and bars \( w(#5) \). Bars \( w(#5) \) are to be spaced no more than 2'-0" in plan and at a distance of no more than 1'-0" from the edge of the column. Bars \( w(#5) \) are to be spaced no more than 2'-0" in elevation and placed with the upper and lowermost \( w(#5) \) bars.

2. Place a Deflection Wall between all columns in each bent where a Vehicle Deflection Wall is used.

3. The Deflection Wall as shown on the SINGLE-SIDE PIER PROTECTION details can only be used between columns that have a clear distance not more than ten feet. In locations where the clear distance between the columns exceeds ten feet use the Deflection Wall as shown on the DOUBLE-SIDE PIER PROTECTION details.
Figure 13: Example Details for Vehicular Deflection Wall (continued)
Figure 13: Example Details for Vehicular Deflection Wall (continued)
BARS wD (#6)

COLUMN INSTALLATION

Reinforcing Bars wD shall be embeded 15" deep into the column in accordance with Item 420.4.7.10, "Concrete Substructures, Installation of Dowels and Anchor Bolts".

<table>
<thead>
<tr>
<th>Column Size</th>
<th>Angle &quot;A&quot;</th>
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</thead>
<tbody>
<tr>
<td>30&quot; Diam</td>
<td>148°</td>
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</tr>
<tr>
<td>36&quot; Diam</td>
<td>142°</td>
<td>1'-4 1/2&quot;</td>
</tr>
<tr>
<td>42&quot; Diam</td>
<td>138°</td>
<td>1'-6&quot;</td>
</tr>
<tr>
<td>48&quot; Diam</td>
<td>135°</td>
<td>1'-7&quot;</td>
</tr>
</tbody>
</table>

BARS wD DETAILS & INSTALLATION

AT COLUMNS WITH DRILLED SHAFTS AND OUTSIDE FOOTINGS

AT COLUMNS WITH FOOTINGS

SECTIONS THRU MBGF TERMINAL WITH SINGLE-SIDE PIER PROTECTION

Figure 13: Example Details for Vehicular Deflection Wall (continued)
Figure 13: Example Details for Vehicular Deflection Wall (continued)

5. 3" I.D. Drain Pipe or Hole located and sloped as directed by the Engineer to prevent water retention next to the wall.

6. If cast against soil, adjust reinforcing to ensure that 3" minimum cover is maintained.

7. If Deflection Wall is adjacent to a Concrete Pavement (including road way and/or sidewalk), a "Type A" Joint shall be placed between Wall and pavement so as to prevent the transferance of side loads between the members. Place 1/" Bituminous Fiber Material in the vertical joint and the top 1" thereof shall be filled with a Class 4, 5, or 7 Silicone Sealant. Omit "Type A" Joint if concrete pavement is not present.
METAL BEAM GUARD FENCE TERMINAL CONNECTOR DETAILS

MBGF TERMINAL CONNECTION SPECIAL NOTES:

METAL BEAM GUARD FENCE TRANSITION and METAL BEAM GUARD FENCE detail sheets must be referred to for additional details and information not shown herein. Omit if Metal Beam Guard Fence is not used.

Metal Beam Guard Fence shall be attached to the Deflection Wall and extend along the embankment using the Thrie-Beam Terminal Connection unless shown otherwise on the plans. The Thrie-Beam Terminal Connection shall be attached to the Wall using 5 - 1/2" diameter A125 Hex Head Bolts, each with 2 - 1 1/2" O.D. washers. Place washer under each head and nut.

The 5 Terminal Connection Bolt Holes shall be 1" diameter holes perpendicular to the back face of the railing. Each Bolt Hole shall have a 2 1/2" diameter x 2" deep recess, as shown, when pedestrian sidewalks are adjacent to back of rail. Adjust placement of reinforcing steel as necessary to avoid bolt holes. Holes and recesses must be formed or cored. Percussion drilling is not permitted.

Bolts must be of sufficient length to extend 1/2" to 3/4" beyond nut. End of cut-off bolts shall be painted with Zinc-rich paint.

The splice between the Approach Guard Rail and the Terminal Connection shall be with the normal 12 Connection Bolts. The Terminal Connector shall receive the same protective coating as the attached Metal Beam Guard Fence.

GENERAL NOTES:

Payment for this wall will be by CY of Class "C" Concrete (Vehicle Deflection Wall). All other materials and installation, including excavation, shall be subsidiary to the Bid Item. Note that the Terminal Connector and associated hardware are to be paid for under the item "Metal Beam Guard Fence".

See the LAYOUT sheets for locations, type, and lengths for payment. Shop drawings will not be required for this wall.

MATERIAL NOTES:

Galvanize all steel components unless otherwise noted.

Provide Class "C" concrete.

Provide Grade 60 reinforcing steel.

Figure 13: Example Details for Vehicular Deflection Wall (continued)
COLUMN REPAIR PROCEDURES:
1. Remove all unsound concrete.
2. Abrasive blast clean concrete and expose steel surfaces.
3. Install additional reinforcing and column forms. Moisten surface of existing concrete by thoroughly water blasting with minimum 5,000 psi pressure at Max 12" stand off distance.
4. Place forms for encasement.
5. Rewet surfaces accessible prior to placing concrete.
6. Place concrete and cure for four days.
7. Disassemble and remove shoring from site. This work will be considered subsidiary to other bid items.

SUPERSTRUCTURE SOFFIT:
1. Anchor and secure existing deburred reinforcing steel into sound substrate.
2. Anchor WWF securely to deck soffit prior to performing concrete repairs. Use either 2 x 2 - W1.2 x W1.2 or 3 x 3 - W1.5 x W1.5.
3. Support reinforcing wire fabric using mushroom headed anchors, expansion hook bolts, or grooved rebar capable of resisting a pull-out force of 2,500 lb. Space anchors 12" C-C.
4. Vertical and overhead concrete repairs may be pneumatically placed in accordance with Item 431.

GENERAL NOTES:
Perform all repairs in accordance with Item 420, 429 of the TxDOT Concrete Repair Manual.
Identify and mark all repairs locations prior to beginning work. Verify areas and quantities with the Engineer.
Clean all corroded or burned reinforcing steel prior to placing patching material.
Pressure wash all surfaces not repaired that have carbon staining. Water blast to remove black fish scale. This work will be paid for in accordance with Item 422 Blast Cleaning. No surface finish will be required.
Provide CL K Concrete for column encasement Fc (3 days) = 3,600 psi.
Remove and replace concrete riprap at base of columns to allow for full encasement to ground line. This work will be considered subsidiary to Item 420-6157 CL C CONC (COLUMN ENCASMENT).

Figure 14: Example Details Column Jacket
Appendix C

The following are example failure modes for yield line analysis for a typical VDW. Site specific designs may require more or alternate modes.

- In the first failure mode, the load is applied at 5 feet above the ground at the mid-point of the wall and the failure mode is plastic hinges at the columns and at the vertical line coincident with the load.

![Figure 15 – Failure Mode 1](image1)

- Failure mode 2 is much like failure mode 1 except the load and the plastic hinge line up with the cut-out for a footing, if there is a footing.

![Figure 16 – Failure Mode 2](image2)
• Failure mode 3 has the load at 5 feet above the ground at the mid-point of the wall and the failure mode assumes the wall forms plastic hinges at the columns, the ground line, from the intersection of the ground to the column and the point load, and up.

Figure 17 – Failure Mode 3

• Failure mode 4 assumes the plastic hinges are at the columns, from the cut-out for the footings to the point of load, and up.

Figure 18 – Failure Mode 4
• Failure modes 5 through 8 combine local punch-out due to the point load with plastic hinges at the columns.