PIER PROTECTION
(VEHICLE COLLISION)

September 13, 2018
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WHAT IS VEHICULAR COLLISION FORCE?

Introduction
Introduction

Dallas, Texas 2001
Introduction

- Two concepts that need to be investigated anytime we design a grade separation structure:
  - Protect the traffic from the bridge.
    - Roadway design using clear zone concepts.
  - Protect the bridge from traffic.
    - Vehicular collision design.
HOW DO WE DETERMINE IF WE NEED TO DESIGN FOR VEHICULAR COLLISION FORCE?

Investigation
Introduction

- Useful TxDOT publications:
  - Bridge Design Manual
    - Chapter 2, Section 2 Vehicular Collision Force
  - Bridge Design Guide
    - Guidance on design of bridges.
  - Bridge Railing Manual
    - Codifies TxDOT policy on the use of bridge Rails. Describes all bridge rails and their crash test ratings.
Investigation

- AASHTO LRFD Bridge Design Manual
- “Unless the Owner determines that site conditions indicate otherwise, abutments and piers located within a distance of 30.0 ft to the edge of roadway shall be investigated for collision.” (AASHTO LRFD 3.6.5.1)
Investigation

- Use the definition of clear zone from the Roadway Design Manual.
- “The clear zone includes shoulders, bike lanes, and auxiliary lanes, except those auxiliary lanes that function like through lanes.” (RDM 2.6 Clear Zone)
- Defer to the district; they may be planning on widening the lower roadway.
Investigation

- TxDOT Bridge Design Manual

  “Design for vehicular collision force for the final condition after all construction is completed, not during construction phases with temporary traffic conditions.”

  “A bridge deck adjacent to the column is considered an adjacent roadway.”

(BDM 2.2 Vehicular Collision Force)
Investigation
Investigation

Dallas, Texas 2001
Investigation

- TxDOT Bridge Design Manual

“Bents—Do not investigate bents and piers for collision if the annual frequency for a bridge bent or pier to be hit by a vehicle, $AF_{HBP}$, is less than 0.001 using Equation C3.6.5.1-1.” (BDM 2.2 Vehicular Collision Force)

$AF_{HBP} \geq 0.001$
Investigation

- AASHTO LRFD Bridge Design Manual

\[ A F_{HBP} = 2(ADTT) (P_{HBP})^{365} \]  
\[ (C3.6.5.1-1) \]

\[ ADTT = \]
the number of trucks per day in one direction

\[ P_{HBP} = \]
the annual probability for a bridge pier to be hit by a heavy vehicle
Investigation

\[ P_{HBP} = 3.457 \times 10^{-9} \text{ for undivided roadways in tangent and horizontally curved sections} \]

1.090 \times 10^{-9} \text{ for divided roadways in tangent sections}

2.184 \times 10^{-9} \text{ for divided roadways in horizontally curved sections}
## Table C3.6.5.1-1—Typical Values of $AF_{HBP}$

<table>
<thead>
<tr>
<th>ADT (Both Directions)</th>
<th>ADTT* (One Way)</th>
<th>Undivided</th>
<th>Divided Curved</th>
<th>Divided Tangent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000</td>
<td>50</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0000</td>
</tr>
<tr>
<td>2,000</td>
<td>100</td>
<td>0.0003</td>
<td>0.0002</td>
<td>0.0001</td>
</tr>
<tr>
<td>3,000</td>
<td>150</td>
<td>0.0004</td>
<td>0.0002</td>
<td>0.0001</td>
</tr>
<tr>
<td>4,000</td>
<td>200</td>
<td>0.0005</td>
<td>0.0003</td>
<td>0.0002</td>
</tr>
<tr>
<td>6,000</td>
<td>300</td>
<td>0.0008</td>
<td>0.0005</td>
<td>0.0002</td>
</tr>
<tr>
<td>8,000</td>
<td>400</td>
<td>0.0010</td>
<td>0.0006</td>
<td>0.0003</td>
</tr>
<tr>
<td>12,000</td>
<td>600</td>
<td>0.0015</td>
<td>0.0010</td>
<td>0.0005</td>
</tr>
<tr>
<td>14,000</td>
<td>700</td>
<td>0.0018</td>
<td>0.0011</td>
<td>0.0006</td>
</tr>
<tr>
<td>16,000</td>
<td>800</td>
<td>0.0020</td>
<td>0.0013</td>
<td>0.0006</td>
</tr>
<tr>
<td>18,000</td>
<td>900</td>
<td>0.0023</td>
<td>0.0014</td>
<td>0.0007</td>
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<td>20,000</td>
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<tr>
<td>22,000</td>
<td>1,100</td>
<td>0.0028</td>
<td>0.0018</td>
<td>0.0009</td>
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<tr>
<td>24,000</td>
<td>1,200</td>
<td>0.0030</td>
<td>0.0019</td>
<td>0.0010</td>
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<tr>
<td>26,000</td>
<td>1,300</td>
<td>0.0033</td>
<td>0.0021</td>
<td>0.0010</td>
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<tr>
<td>28,000</td>
<td>1,400</td>
<td>0.0035</td>
<td>0.0022</td>
<td>0.0011</td>
</tr>
</tbody>
</table>

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

*Assumes ten percent of ADT is truck traffic.
Investigation

“Consultation with traffic engineers regarding any directionality of truck traffic may lead to the conclusion that one direction carries more than one-half of the bidirectional ADTT. If such data is not available from traffic engineers, designing for 55 percent of the bidirectional ADTT is suggested…

The ADTT can be determined by multiplying the ADT by the fraction of trucks in the traffic. In lieu of site-specific fraction of truck traffic data, the values of Table C3.6.1.4.2-1 may be applied for routine bridges.” (AASHTO LRFD C3.6.1.4.2)

<table>
<thead>
<tr>
<th>Class of Highway</th>
<th>Fraction of Trucks in Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural Interstate</td>
<td>0.20</td>
</tr>
<tr>
<td>Urban Interstate</td>
<td>0.15</td>
</tr>
<tr>
<td>Other Rural</td>
<td>0.15</td>
</tr>
<tr>
<td>Other Urban</td>
<td>0.10</td>
</tr>
</tbody>
</table>
HOW DO WE DESIGN FOR VEHICULAR COLLISION FORCE?

Redirect vs. Structural Resistance
### Redirect the Load

**Concept:**
- A structurally independent barrier is placed between the traffic and the bridge pier intercepting any errant vehicles preventing the bridge pier from being hit.

**Pros:**
- Prevents the structure from being hit.

**Cons:**
- Requires space for a barrier between the travel lanes and the structure.
- Reduced available clear zone of lower roadway.

### Provide Structural Resistance

**Concept:**
- The bridge pier is designed to withstand the impact of a tractor trailer without collapsing.

**Pros:**
- May not require an increase in pier width, or only a moderate increase.

**Cons:**
- Structure is designed to get hit.
- Structure often needs repair after a collision.
- Can cause closures to upper and lower roadways.

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**Bottom-line:**
- The most desirable way to design for the vehicle collision force will depend on site conditions and the preference of the district.
HOW DO WE REDIRECT VEHICULAR COLLISION FORCE?
• AASHTO LRFD Bridge Design Manual

  “Where the design choice is to redirect or absorb the collision load, protection shall consist of one of the following:
  
  – An embankment;
  
  – A structurally independent, crashworthy ground mounted 54.0-in. high barrier, located within 10.0 ft from the component being protected; or
  
  – A 42.0-in. high barrier located at more than 10.0 ft from the component being protected.

• Such barrier shall be structurally and geometrically capable of surviving the crash test for Test Level 5, as specified in Section 13.” (AASHTO LRFD 3.6.5.1)
The distance is measured from the effective face of the barrier to the surface of the column.
Redirect

- Barrier 10’ to 30’ from pier
  - TL-5
  - 42” high

Dallas, Texas 2007
- Barrier 10’ to 30’ from pier
  - Mounted on a bridge deck or concrete pavement.
  - Augment reinforcing in concrete pavement to match typical bridge deck reinforcing.
- Barrier 10’ to 30’ from pier
  - We have no current TL-5 ground mounting standard.
  - Designer will have to design either a footing or drilled shafts to resist the TL-5 loading as described in AASHTO LRFD Ch. 13.
  - Can use the 42”, 48”, or 54” SSCB.
Redirect

- Barrier within 10 ft of pier
  - TL-5
  - 54” high
  - Structurally Independent

Tyler, Texas 2004
- Barrier within 10 ft of pier
  - Mounted on a bridge deck or concrete pavement.
  - Augment reinforcing in concrete pavement to match typical bridge deck reinforcing.

54” Vertical Wall  T80SS(MOD)
- Barrier within 10 ft of pier
  - 54” Vertical Wall – this shape is geometrically TL-5 approved.
  - The rail reinforcing and slab anchorage need to be designed to resist the TL-5 loading as described in AASHTO LRFD Ch. 13.
- Barrier within 10 ft of pier
  - T80SS(MOD) – modified to increase the rail height to 54”
  - Must keep the top of the rail 9” and keep the slope of the face the same. This will result in a wider toe.
  - The reinforcing cage must increase in size with the rail, and the horizontal bars must maintain the same in²/ft.
- Barrier within 10 ft of pier
  - We have no current TL-5 ground mounting standard.
  - Designer will have to design either a footing or drilled shafts to resist the TL-5 loading as described in AASHTO LRFD Ch. 13.
  - Can use the 54” SSCB.
- Barrier within 10 ft of pier

  - Must be structurally independent.

  - Minimum 6” gap between the rail or barrier and the pier. This allows the rail or barrier to deflect when hit without transferring load into the pier.

Unpinned SSCB
TL-4

Pinned SSCB
TL-4
HOW DO WE PROVIDE STRUCTURAL RESISTANCE?

Structural Resistance
Structural Resistance

- TxDOT Bridge Design Manual
- “See Article 3.6.5…”
- “When the design choice is to provide structural resistance, design for the 600-kip equivalent static load as described in Article 3.6.5. See Chapter 4 - Substructure Design, Sections 6 - Columns for Multi-Column Bents and Section 7 - Columns for Single Column Bents or Piers for design information.”

(BDM 2.2 Vehicular Collision Force)
Structural Resistance

- AASHTO LRFD Bridge Design Manual

“Where the design choice is to provide structural resistance, the pier or abutment shall be designed for an equivalent static force of 600 kip, which is assumed to act in a direction of zero to 15 degrees with the edge of the pavement in a horizontal plane, at a distance of 5.0 ft above ground.” (AASHTO LRFD 3.6.5.1)
Structural Resistance

- 600 kip force
- 5 feet above ground
- 0 to 15 degrees from the direction of traffic
Structural Resistance

- TxDOT Bridge Design Manual
- “Provisions under Extreme Event II must be considered only when vehicular collision or vessel collision evaluation is required. “

(BDM 2.1 Extreme Event Limit State)
### Structural Resistance

- **Extreme Event II Load Combination**

#### Table 3.4.1-1—Load Combinations and Load Factors

<table>
<thead>
<tr>
<th>Load Combination Limit State</th>
<th>Load Type</th>
<th>WA</th>
<th>WS</th>
<th>WL</th>
<th>FR</th>
<th>TU</th>
<th>TG</th>
<th>SE</th>
<th>EQ</th>
<th>BL</th>
<th>IC</th>
<th>CT</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme Event II</td>
<td>DC</td>
<td>1.00</td>
<td>0.50</td>
<td>1.00</td>
<td>—</td>
<td>—</td>
<td>1.00</td>
<td>—</td>
<td>—</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>
HOW DO WE PROVIDE STRUCTURAL RESISTANCE?

New Construction
New Construction

- TxDOT Bridge Design Manual
- “Design the column to withstand the collision force in shear only, not flexure, and do not consider the transfer of this force to the other elements such as bent caps, footings, piles, or drilled shafts.”

(BDM 4.6 Column Collision)
New Construction

- 600 kip force
- 5 feet above ground
- 0 to 15 degrees from the direction of traffic
- Shear Capacity only
New Construction

- TxDOT Bridge Design Manual

- “Use a 0.9 load factor for all dead loads and no live load for the axial compression used for shear design.” (BDM 4.6 Column Collision)
New Construction

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

<table>
<thead>
<tr>
<th>Load Combination Limit State</th>
<th>DC</th>
<th>DD</th>
<th>DW</th>
<th>EH</th>
<th>EV</th>
<th>ES</th>
<th>EL</th>
<th>PS</th>
<th>CR</th>
<th>SH</th>
<th>LL</th>
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</thead>
<tbody>
<tr>
<td>Extreme Event II</td>
<td>1.00</td>
<td>0.50</td>
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<td>—</td>
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<td>—</td>
<td>1.00</td>
<td>—</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>Use One of These at a Time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>
New Construction

- TxDOT Bridge Design Manual

  “Bents with three or more columns that provide sufficient redundancy may use two shear planes to distribute the collision force...”

  “Bents with a lack of redundancy, such as two or fewer columns or large column spacing, such as straddle bents, require special consideration. For these, consider only one shear plane for the resistance of the collision force.”

(BDM 4.6 Column Collision)
New Construction

- Redundant columns: Design for a shear of 300 kips
- Non-redundant columns: Design for a shear of 600 kips
New Construction

- What is redundant?
  - Three or more columns.
  - Stay within the column spacing limits of the detailing guide.
  - Use your engineering judgement: will losing one column result in partial or total collapse?
New Construction

- TxDOT Bridge Design Manual

- “Generally single-column bents have sufficient mass and will meet the requirements of Article 3.6.5. No further analysis is required for columns with a gross cross-sectional area no less than 40 sq. ft., a least dimension of no less than 5 ft. and column transverse reinforcement is composed of at least No. 4 ties at 12-in maximum spacing or a No. 4 spiral at 9-in maximum pitch.”

(BDM 4.7 Column Collision)
New Construction

- No vehicular collision analysis is required if the column meets all of the following:
  - Minimum Width: 5ft
  - Minimum Section: 40 Sq. ft
  - Minimum Reinforcing:
    - # 4 at 12” spacing or 9” pitch
    - \[ \geq 5' - 0'' \]
    - \[ \geq 5' - 0'' \]
    - \[ \geq 40 \text{ ft}^2 \]
HOW DO WE PROVIDE STRUCTURAL RESISTANCE?

Existing Facilities
Existing Facilities

- **Repair**
  - Concrete repair + jacketing
  - Concrete repair + add a deflection wall
  - Partial removal + replace with a bigger column

- **Preemptive**
  - Deflection Wall
Existing Facilities

- TxDOT Bridge Design Manual
- “Use of a deflection wall between the columns can be used if necessary. The Bridge Division can provide sample details for deflection walls for some bent and pier types.” (BDM 2.2 Vehicular Collision Force)
Existing Facilities

- 600 kip force
- 5 feet above ground
- 0 to 15 degrees from the direction of traffic
- Design Vehicle Deflection walls
Existing Facilities

- Design the Vehicle Deflection wall
  - Point load = 600 kip * sin(relative skew + 15 deg)
  - If the bent parallels the lower roadway: Point Load = 155 kips
  - Yield line Analysis
Existing Facilities

- Design the Vehicle Deflection wall
Existing Facilities

- Sample Details
  - Examples sheets from a previous project.
    - Needs to be tailored for specific project.
  - Analysis still required.
    - Changes in wall width and column spacing will affect capacity.
    - Changes in skew of bent relative to the lower roadway affects required capacity.
  - We plan on having working drawings in the future.
Existing Facilities

- Sample Details

![Diagram of Existing Facilities]

Definitions:
- 3\' (36\") Chanter (Typ)
- 3\' (36\") Plaster (Typ)
- 3\' (36\") Concrete (Typ)
- 3\' (36\") Grout (Typ)
- 3\' (36\") Existing (Typ)
- Deflection Wall
- 3\' (Typ)
- 6\' Max Spacing
- Bars w/ Spa = 3"

**Partial Plan**

(See "Vehicle Deflection Wall and Rail Layout" sheet for geometry)

**Notes:**
- T221 on TBF
- AT NORTH EXTERIOR COLUMN
- AT INTERIOR COLUMNS
- AT SOUTH EXTERIOR COLUMN (T221 and TBF revfl, omitted for clarity)
Existing Facilities

- Sample Details

```
 AT NORTH EXTERIOR COLUMN

 AT INTERIOR COLUMNS

 AT SOUTH EXTERIOR COLUMN

PARTIAL ELEVATION

(Res. and TRC not yet stipulated)
```
Existing Facilities

- Sample Details
Existing Facilities

- **Aesthetics**
  - No reliefs in the bottom 36”
HOW DO WE PROVIDE STRUCTURAL RESISTANCE?

Widenings
Widenings

- Shear design of new columns
  - Is it redundant?
    - How many columns are in the widening?
    - How is the widening connected to the existing bent?
- Analyze the capacity of the existing structure
  - Do you need to add a deflection wall?
  - Does a deflection wall deleteriously affect site distance at the intersection?
Widenings

- What is redundant?
  - Use your engineering judgement: will losing one column result in partial or total collapse?
WHAT IS COMING IN THE FUTURE?

Ongoing Research
Ongoing Research

- TxDOT project 0-6948
  - Should result in a 54” TL-5 barrier.
  - Should result in crash-tested TL-5 ground mounting details (spread-footing, TRF, and drilled shafts)
  - Should give us a good idea of the deflection of these rails and barriers under the TL-5 loading, so we can update our recommendations for offsetting the rails from the piers.

- Will be incorporated in the future Bridge Protection Guide expected to be released in the next few years.
WHAT QUESTIONS DO YOU HAVE ON VEHICULAR COLLISION DESIGN?

Questions?
Questions?

Are the bent designs for standard roadway widths (prestressed concrete I-girder, etc.) designed for impact loads?

    The 36” and 42” columns on the Prestressed Concrete I-Girder standard sheets have been designed for column impact loads.

Is the 15° in your figures relevant to the travel lanes or the columns?

    It is relevant to the travel lanes.

Were the prestressed concrete I-girder bent standards designed using single shear plane or double shear planes?

    Those columns are considered redundant, and the designs utilized dual shear planes.

If a different clear zone (smaller than 30”) is specified on a specific project design criteria in the roadway design section, is it also applicable to the investigation for the vehicular collision design?

    No. AASHTO LRFD Bridge Design Specifications call for a minimum of 30’.

Can you talk about why only column shear design is required, no flexural design for column bottom or drilled shafts?

    This requirement is based on the research that was used to develop the design collision forces. This is an area where research continues to be conducted, and the design requirements could change in the future.

Why doesn’t the 54” SSCB (Type 3) count as protection? Is it because there isn’t 6” clearance to column?

    The 54” SSCB (Ty 3) does not count as protection because it was never engineered or tested for MASH Test Level 5 (TL-5).
Questions?

Will the SSCB (Type 3) standard for CIP barrier around fixed objects be updated to provide the minimum recommended clearance from the back of the barrier to the column?

No. The SSCB (Type 3) will not be updated. Instead, BRG is developing an alternative that will be designed specifically for pier protection.

Is there research showing design speed is irrelevant to vehicular collision force?

Bridge Division takes a conservative stance on this issue and does not consider the reduction in speed that might occur prior to impact or due to lower speed roadways.

Will the cost of the column protection be charged to bridge or to roadway?

Column protection is under Item 420 and charged to bridge.
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