DESIGNING BRIDGES FOR VEHICULAR COLLISIONS

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Designing Bridges for Vehicular Collisions

- TYPES OF VEHICULAR COLLISIONS:
  - Over Height Impacts
  - Lateral Impacts
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- Over Height Impacts:
  - Occurs when upper portion of “load” comes in contact with lower portion of one (or more) superstructure beams/girders
  - Most frequent type of collision
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- Over Height Impacts:

Causes:
- Loads taller than legal limit (in route without a permit)
- Permits granted without proper investigation of route clearances
- Misinterpretation of the permit route
- Inaccuracies in “true” clearance vs “recorded”
- Errors in preparing/securing the load for travel
- Errors in Design Assumptions
- Overlooked Design Flaws
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- Over Height Impacts:

  Errors in Design Assumptions-
  - Avoid designing to the absolute minimum clearance (16’-6”)

  - Superstructure depths can not be predicted that precisely (especially during bridge layout phase)
  - Prohibits adding overlay to the lower roadway in the future
  - Prohibits bridge from being widened in the future (due to cross slope being extended)
  - Future loads (10,15 20+ years) will not be shorter than those of today
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- Over Height Impacts:

Errors in Design Assumptions-
- Ignoring the minimum (16’-6”) requirement for “special circumstances”

  - Discoveries (such as oil/natural gas) in a new area suddenly subject the highway to a “new breed” of traffic, which it was not designed to handle
  - Assuming that lower roadways in urban areas are not subject to over height loads
“This is a city it street...it will never see an over height load!!”
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- Over Height Impacts:

  Over looked Design Flaws-
  - Forgetting to step back and see “the big picture”
Typical PLAN of an Intersection...
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- Typical ELEVATION of the Intersection...

360.00' PRESTR CONC GIRDER UNIT (120.00'-120.00'-120.00') ~ Tx54 GIRDERS

LENGTH OF T551 RAIL = 2605.5' (LT) AND 2626.2' (RT)

TOP OF RAIL

G-1'.76' H = 14' 18'-10'' CALC MIN VERT CLEAR

PRIVATE DRIVeways

PROPOSED GROUND

H = 18'' 18'-11'' CALC MIN VERT CLEAR
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- Taking a step back...

Take a look here...
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- Taking a step back...

This end of cap hangs over the majority of the turn lane.
Looking at the Bent Cap...

Approximate clearance looks like 14’ (“H”) - 1’ (below ground) + ~1’ (on arc of bent) = 14’ +/-
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- Over Height Impacts:

One last thing........
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Over Height Impacts: “BRIDGE PROTECTIVE BEAM WRAP” Standard (BPBW)

- Issued as a Bridge Standard on July 10, 2013
- Is **NOT A REPAIR DETAIL**
- Intended for New Construction (can be used as a retrofit on some types of existing superstructure types also)
- Intended for use on Bridges with high probabilities of being impacted by over height loads
- Used at the discretion of the Engineer (no height requirement for applicability)
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- Over Height Impacts: “BRIDGE PROTECTIVE BEAM WRAP” Standard (BPBW)
  - Purpose is to prevent debris from falling on the roadway/traffic in the event that the beam is impacted
  - Is **not** intended to add strength to the beam to withstand an impact load
  - After an impact, beam needs to be inspected and appropriate repairs made just as without the BPBW
Over Height Impacts: “BRIDGE PROTECTIVE BEAM WRAP” Standard (BPBW)

- Located on the Bridge Standards page along with the issuing memo
- Contact Amy Smith (512-416-2261) for questions regarding BPBW
Lateral Impacts:

- Occurs when a vehicle (tractor-trailer) veers off the designated roadway and impacts the bridge structure (typically the column)

- Can result in very large lateral loads to bridge column
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- Lateral Impacts:
  - Magnitude of damage is variable:

Minor Damage

Loss of Substructure

Collapse
Lateral Impacts:

Causes-
- Distracted Driver
- Fatigued Driver
- Tight horizontal clearance
- Inadequate protective barrier
- Difficult to predict probability of occurrence
Lateral Impacts:

Tight Horizontal Clearances:
- Avoid locating columns immediately next to roadway (when possible)

This collision would not have occurred if the column was located farther away from the roadway.
Lateral Impacts:

Tight Horizontal Clearances:
- Avoid locating columns immediately next to roadway (when possible)

This is an Interstate Highway with columns located very near the edge of roadway.
Lateral Impacts:

Inadequate Protective Barrier:
- Many times columns must be located near the roadway and a barrier is used to protect the columns from impact.
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- Lateral Impacts:

Inadequate Protective Barrier:

Inadequate Barrier

Inadequate Barrier
Lateral Impacts:

Inadequate Protective Barrier:

No Barrier
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- Lateral Impacts:

Difficult to Predict:
- The root causes of the misdirection (driver fatigue and distraction) can force the collision to occur at a location well off of the intended path of the vehicle.
- Frequency of collisions (limited data) is not high enough to develop an accurate statistical model that includes site specific variables.
Lateral Impacts:

Difficult to Predict:
Lateral Impacts:

Difficult to Predict:

Truck was traveling WEST, crossed median, crossed East Bound Lanes and hits column.

East Bound ➔

Impact ➔ West Bound
Lateral Impacts:

So what do we do about designing for lateral impacts???

- AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS 2012 gives us guidance in Section 3.6.5-Vehicular Collision Force
- Accomplished three (3) tasks
  - Determined a design force to represent a vehicle collision
  - Identified the primary failure mode of a column subject to a collision
  - Established criteria to evaluate the susceptibility of a given bridge to impact
Lateral Impacts:
Design Force

- Computer Simulation using a Finite Element Model (FEM)
- Several test matrices with following variables:
  - Pier Diameter (24”, 36”, 48”)
  - Impact Speed (40mph, 50mph, 60mph)
  - Cargo Type (Deformable, Rigid)

Greatest impact on force
Lateral Impacts:

Design Force
- Computer Simulation using a Finite Element Model (FEM)
- Results (2 Peaks in Force vs Time curves):
  - Engine block impact ~480 — 600 kips
  - Cargo impact ~480 — > 2000 kips (due to instability of results)
Lateral Impacts:

**Design Force**

- Computer Simulation using a Finite Element Model (FEM)
- Test Case (FEM): 36” Pier, 50 mph, deformable ballast:
  - Engine block impact ~ 580 kips
  - Cargo impact ~ 900 kips
Lateral Impacts: Design Force

- Full Scale Testing
  - Design and build a “Rigid Column” to stop the truck and measure forces
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- Lateral Impacts:
  Design Force
  - Full Scale Testing
    • Design and build a “Rigid Column” to stop the truck and measure forces
Lateral Impacts:
Design Force

- Full Scale Testing
  - Design and build a “Rigid Column” to stop the truck and measure forces
  - Select variables for full scale test (50mph, deformable)
  - Run the full scale test
Lateral Impacts:
Design Force

- Full Scale Testing
  - Results: 50-ms Average results are what we care about
  - Dynamic load is represented by an equivalent ~400 kips static load
Lateral Impacts:

Design Force

- Full Scale Testing
  - Results: 50-ms Average results are what we care about
  - Dynamic load is represented by an equivalent ~400 kips static load

  - However, refined analysis of the data (due to energy used to deflect the column elements) produce a dynamic load of 700 kips, which is represent by the static approximate load of around 600 kips

  - Max force was found to be located ~5’ above the ground
Lateral Impacts:

Failure Mode

- Examining past collisions
- Results: Shear Failure with 2 Shear Planes
Lateral Impacts:
Evaluation Criteria

AASHTO 2012, Section 3.6.5, commentary provides equation C3.6.5.1-1: $AF_{HBP} = 2(ADTT)(P_{HBP})^{365}$

- $AF_{HBP} =$ annual frequency of a given bridge pier to be hit
- $ADTT =$ the number of trucks in one day in one direction
- $P_{HBP} =$ the annual probability for a bridge pier to be hit by a heavy vehicle
Lateral Impacts:
Evaluation Criteria

AASHTO 2012, Section 3.6.5, commentary provides equation C3.6.5.1-1: \( \text{AF}_{	ext{HBP}} = 2(\text{ADTT})(\text{P}_{	ext{HBP}})^{365} \)

\( \text{P}_{	ext{HBP}} \) is based on the type of roadway:
- \( = 3.457 \times 10^{-9} \) for undivided roadways
- \( = 1.090 \times 10^{-9} \) for divided roadways in tangent sections
- \( = 2.184 \times 10^{-9} \) for divided roadways in horizontally curved sections
Lateral Impacts:

Evaluation Criteria

- From TxDOT Bridge Design Manual, if $AF_{HPB}$ is less than 0.001, do not design for vehicle collision.
- If greater than 0.001, then collision must be considered by either:
  - Provide a method to redirect or absorb the load
  - Design the column to structurally resist the load
Lateral Impacts:  
Evaluation Criteria  
- Redirecting the Load:  
  • Protect with a structurally independent, ground-mounted 54-in. tall single slope concrete barrier (or other 54-in. tall, Test Level 5 approved barrier equivalent) if within 10 ft. from component  
  • Protect with a 42-in. tall single slope concrete barrier (or 42-in tall, Test Level 5 approved barrier equivalent) if more than 10 ft. from component
Lateral Impacts:

Evaluation Criteria

- Structurally Resisting the Load:

  - 600-kip equivalent static load
  - Extreme Event II Load Combination
  - Use 1.25 load factor for all dead loads and 0.5 load factor for live load, considering live load only on the permanent travel lanes, not the shoulder lanes

  - Assume load is resisted by 2 shear planes (multi column bents)
  - Assume load is resisted by 1 shear plane (single column bents)
Lateral Impacts:

Evaluation Criteria

- Structurally Resisting the Load:

  - Usually the single column bents have sufficient mass to nominally resist the collision force.

  - The column of a single column bent does not need to be analyzed for the collision load as long as it meets all of the following criteria:
    - Gross cross section greater than or equal to 40 SF
    - Smallest dimension is greater than or equal to 5 feet
    - Transverse reinforcing of No 4’s @ 12” or No 4 spiral with 9” pitch
Questions?

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