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Course Description

Lean-on Bracing for Steel I-Shaped Girders
April 26, 2018

This webinar will introduce the concept of the Lean-On Bracing System, which is a method of preventing lateral torsional buckling of straight, skewed and non-skewed steel plate girder bridges. The Lean-On Bracing System mainly consists of struts that transfer forces to one or two cross-frames at each brace location. Improved structural efficiency is possible by utilizing lean-on concepts in which several girders can be braced across the width of the bridge by a single cross-frame. The benefits of Lean-On Bracing, research, design, Owner's perspective, and construction will also be highlighted in this webinar.

Learning Objectives

- Describe the concept of the Lean-On Bracing System.
- Identify the structural efficiencies with the use of lean-on bracing.
- List the benefits of lean-on bracing from a design, construction and owner's perspective.
- Identify the steps in designing lean-on bracing as presented in the design example.

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Lean-On Bracing for Steel I-Shaped Girders

Presented by
Jamie F. Farris, P.E.
Texas Dept. of Transportation
Bridge Division
Austin, TX

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Outline

- Background
- Lean-on Bracing Systems
- TxDOT Research Project 0-1772
- Implementation Study
- Designing a LOB System
- Design Example
- Owner's Perspective
- Summary

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Background

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Lateral Torsional Buckling

- Lateral torsional buckling is a mode of instability involving lateral translation of the girder accompanied by a twisting of the cross section
- Due to their low lateral stiffness, I-shaped sections are susceptible to this mode of failure – particularly during erection and construction.

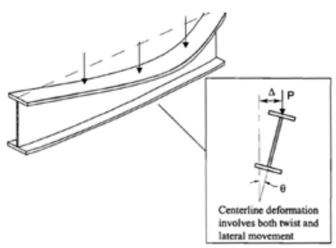

Figure 1.1 Lateral Torsional Buckling
Report 0-1772

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Lateral Torsional Buckling

- The buckling capacity is enhanced with the addition of bracing that either stops lateral movement of the compression flange or twist of the cross section.

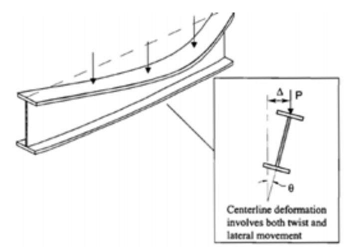

Figure 1.1 Lateral Torsional Buckling
Report 0-1772

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Lateral Torsional Buckling

- The critical stage for lateral torsional buckling occurs during deck placement when the steel section must support the entire construction load
- In steel bridge systems, the most common form of bracing are cross-frames and diaphragms that frame between adjacent girders

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Torsional Bracing

- An effective torsional brace limits the girder's ability to twist but allows the girder to translate laterally
- Buckling capacity of the steel girders can be increased by providing bracing at intermediate locations along the girder length
- Braces (cross-frames or diaphragms) increase the buckling capacity by controlling the twist of the girder cross-section, therefore they fit into a category referred to as torsional bracing

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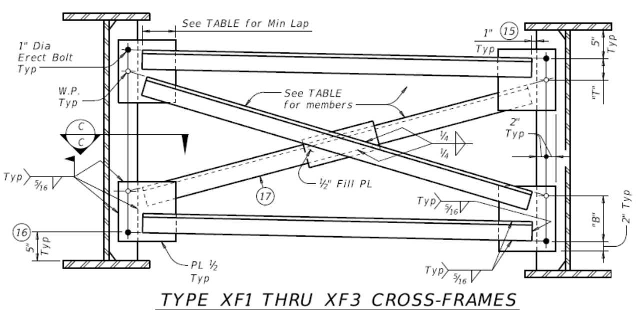
Typical Bracing Details in Texas



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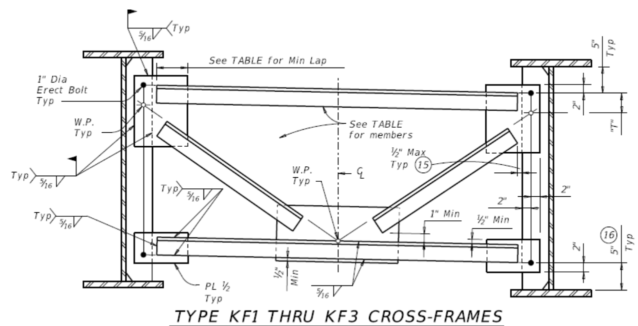
Typical Bracing Details in Texas



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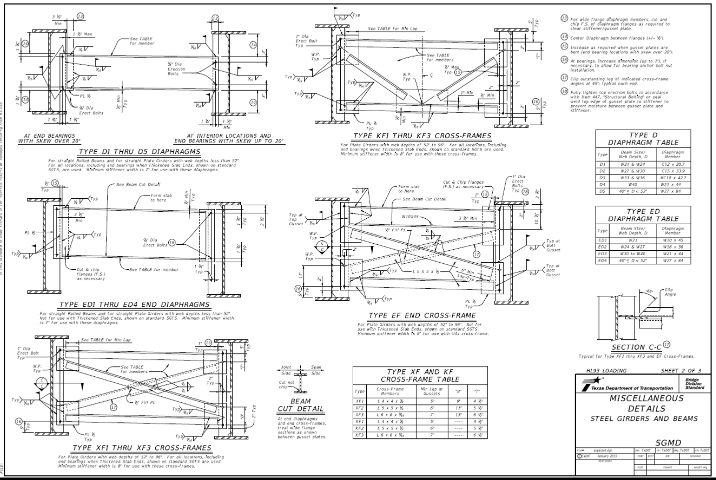
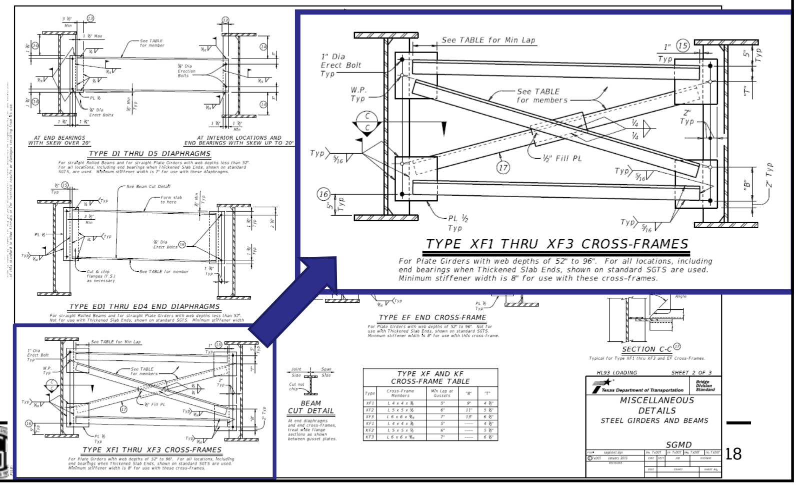




Typical Bracing Details in Texas

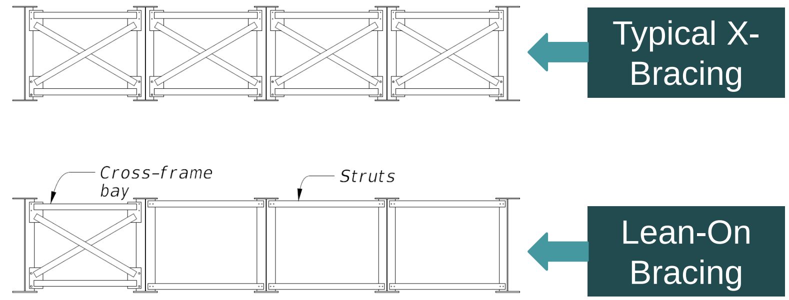
- Steel bridges are typically braced with standard cross-frames in each bay between girders

Lean-on Bracing Systems

What is Lean-On Bracing?

- New to the bridge industry, but common in the building industry
- Method of preventing lateral torsional buckling
- Designed according to the forces that are expected to occur during construction of the deck
- Consists of struts that transfer forces to one or two cross-frames at each brace location
- Cross-frames are positioned to help minimize the magnitudes of live load induced forces
- Method can be used on straight bridges with or without skew

What is Lean-On Bracing?



Benefits of Lean-On Bracing

- Fewer cross-frames
  - Decrease fabrication costs
  - Decrease erection costs
- Reduce fit up issues
- Reduced construction timeline
- Simplifies future inspections

Benefits of Lean-On Bracing

- Fewer fatigue prone details
  - Fatigue cracks – they are usually found around locations of cross-frames and diaphragms during routine inspections
  - These cracks form due to large stress concentrations in the girder due to cross-frame and diaphragm forces induced by truck traffic on the bridge
  - Particularly true for skewed bridges

Benefits of Lean-On Bracing

- Fewer fatigue prone details
  - Fatigue issues aggravated when typical cross-frame and diaphragm sizes are used instead of designing for specific application
  - The typical sized may be larger than necessary to satisfy stability requirements
  - The larger braces attract bigger LL forces due to truck traffic in the finished bridge

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Benefits of Lean-On Bracing

SUMMARY

Minimizing the number of cross-frames on the bridge can lead to better overall bridge behavior as well as reduced maintenance costs.

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TxDOT Research Project 0-1772

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TxDOT Research 0-1772

- Researchers: University of Texas at Austin
- *Cross-Frame and Diaphragm Behavior for Steel Bridges with Skewed Supports*
- Objective – improve the understanding of bracing behavior of cross-frames and diaphragms in steel bridges with skewed supports
- General bracing requirements were developed and new cross-frame and diaphragm details to minimize fatigue problems at bracing locations were proposed.
- Included experimental studies

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TxDOT Research 0-1772

- Included computational studies
  - Eigenvalue buckling analysis – focuses on behavior of straight girders and does not reflect the effects of imperfections.
  - Large displacement analysis – nonlinear analysis that considers the effects of imperfections on the girder deformations and brace forces
  - FEM results were compared with the design equations that were developed to reflect the bracing requirements
- Developed a design approach for lean-on bracing systems

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TxDOT Research 0-1772

In the process of developing a design approach for bracing requirements, FEA studies with the following parameters were considered:

- Girder system (2 to 4 girder systems)
- Girder span (40 ft to 120 ft)
- Girder cross-section (singly and doubly symmetric cross-sections)
- Skew angle (0, 15, 25, 35, 45 degrees)
- Brace orientation (parallel to skewed support or normal to girders)
- Loading condition (uniform moment, concentrated load, uniformly distributed load)
- Number of intermediate braces
- Shape of imperfection

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Skewed Supports:

- Occur when the supporting abutments/bents for the girders are not normal to the girder lines, but offset by a skew angle
- Bridges with heavily skewed supports have significant lateral load transfer interaction between adjacent girders

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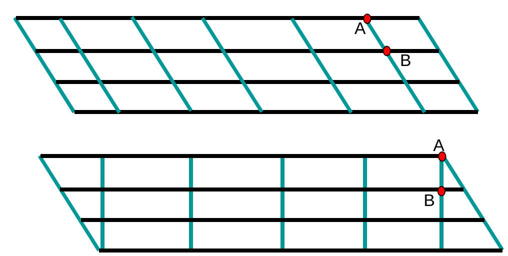
Skewed Support Configurations:



1. For Skews < 20°
2. For Skews > 20°

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Skewed Supports:

- Large forces can develop in the cross-frames or diaphragms of heavily skewed bridges from daily truck
- Can lead to fatigue problems at brace locations

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TxDOT Research 0-1772

Skewed Supports:

- Braces can be very difficult to fit-up during erection; particularly near supports
- Lean-on-bracing at skewed supports helps minimize live-load induced brace forces

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Implementation Study

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TxDOT Research 0-1772

Implementation Project:

- 3 steel plate girder bridges in Lubbock, TX were designed with the Lean-on bracing system
- Each bridge had a skew angle of approx. 60 degrees
- One bridge was instrumented with strain gages to measure the forces in the cross-frames during deck placement
- A load test was performed once the deck cured
- The measurement of the actual forces was compared with the forces predicted by the equations

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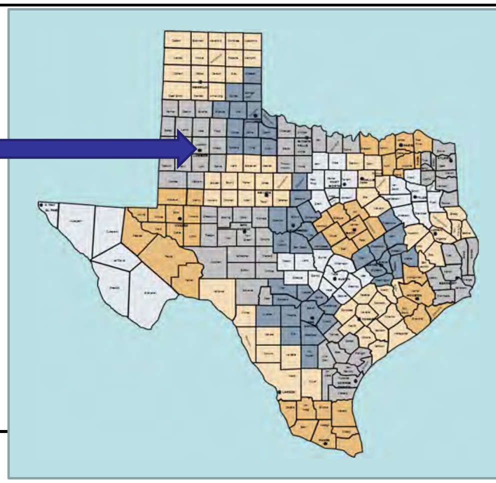
Lubbock, TX



US 82 Underpass at 9th Street - Lubbock, Texas

US 82 Underpass at 9th Street - Lubbock, Texas

- US 82 Underpass at 9th St – Lubbock, TX
- 1st of 3 structures in the U.S. erected with LOB
- 2 spans (179.6' – 168.8')
- Superstructure – 9 continuous plate girders
- Skewed approximately 54 degrees
- Gr 50 weathering steel
- Opened to traffic – Spring 2009

US 82 Underpass at 9th Street - Lubbock, Texas

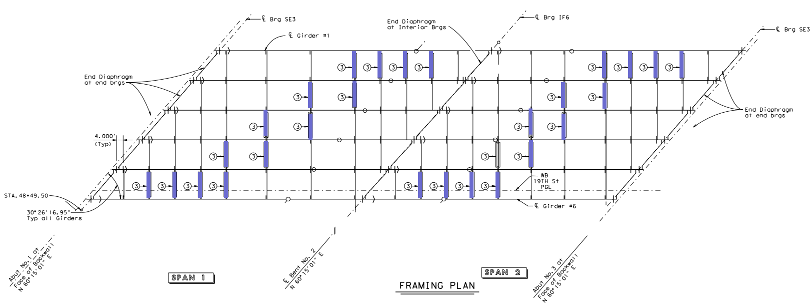
- The girders were erected without any issues
- Feedback from the iron workers was positive
- Contractor saved time in the schedule – ability to erect girders more quickly
- Fewer cross-frames = saving money

US 82 Underpass at 19th St - EB & WB - Lubbock

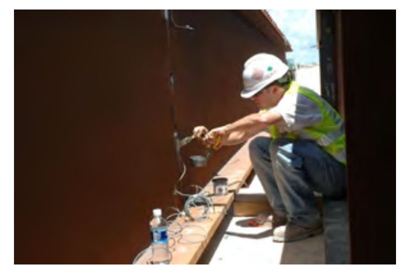
US 82 Underpass at 19th St - EB & WB - Lubbock

- Twin structures
- Two span continuous (150.5' – 139')
- 289.5ft overall unit length
- 6 girders
- 60 degree skew
- Conventional = 80 X-frames
- LOB = 28 X-frames

Framing Plan: US 82 Underpass at 19th St.



Instrumentation



Instrumentation: US 82 Underpass at 19th Street - EB & WB
Lubbock, Texas

Instrumentation

- Recorded measurements
  - Changes in strain
  - Girder rotations
  - Girder deflections
- Predicted vs. actual mid-span cross-frame forces
- Predicted vs. actual end span cross-frame forces
- The equations predicted conservative results

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Construction Photos

US 82 Underpass at 19th St.

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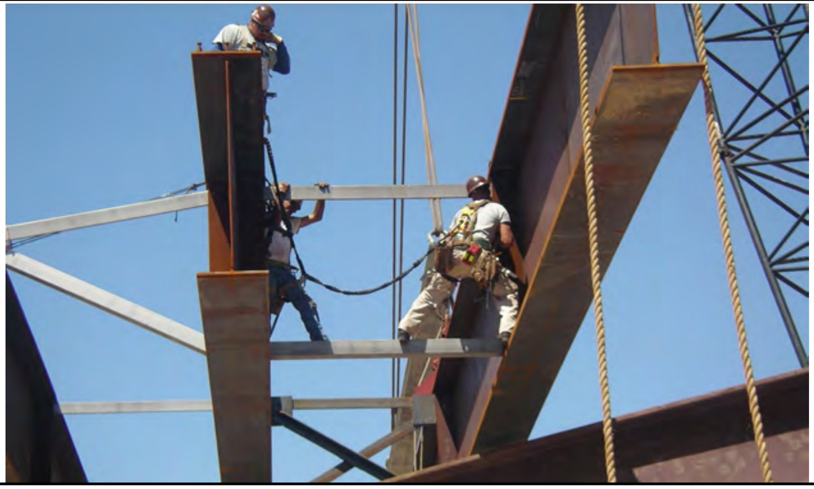
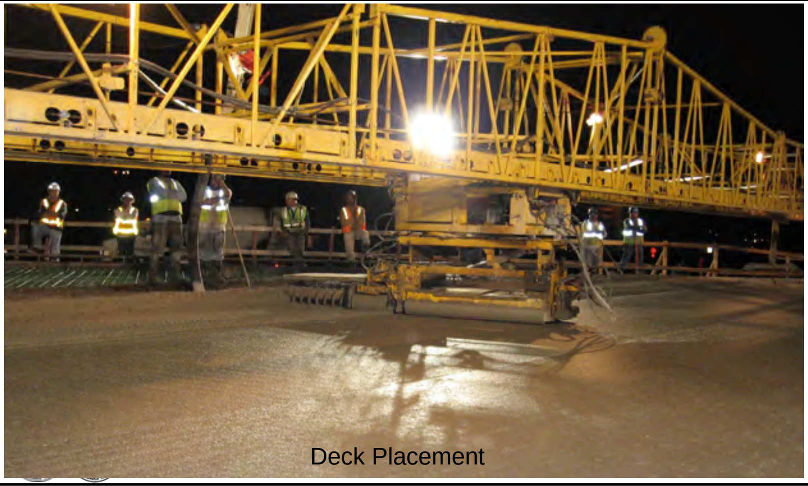


Deck Placement



Deck Placement

Deck Placement

Live Load Testing

- 19^{th} St Bridge – 11/6/07
- 6 moving load patterns and one static load pattern were performed
- 2 identical sand trucks
- The trucks were weighed before and after the tests
- Data collection of the live load test included strain, deflection, and rotation measurements

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Live Load Testing

- The moving load patterns included a forward stagger, backward stagger, four side by side patterns, and two end to end patterns.
- The trucks were held for 60-90 seconds to allow a minimum of 3 data readings
- For each pattern, the outside truck was positioned so that the outside tire was over the exterior girder
- The transverse location of the pair of vehicles on the bridge included the south side of the bridge, the middle of the bridge, and the north side of the bridge.

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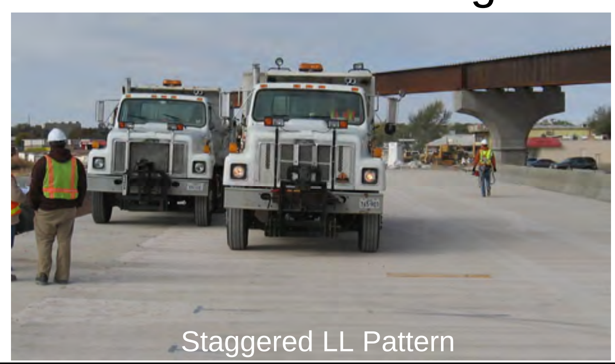
Live Load Testing



Staggered LL Pattern

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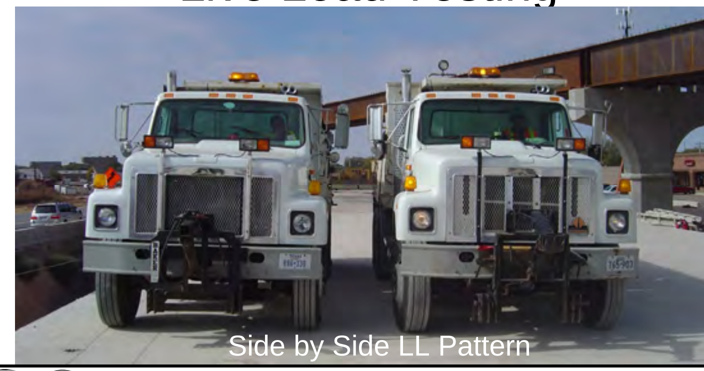
Live Load Testing

Staggered LL Pattern

Live Load Testing

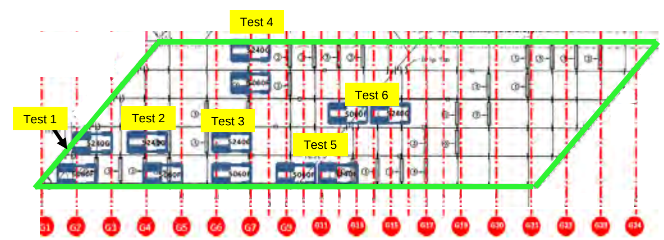


Side by Side LL Pattern

Live Load Testing

End to End LL Pattern

Live Load Testing

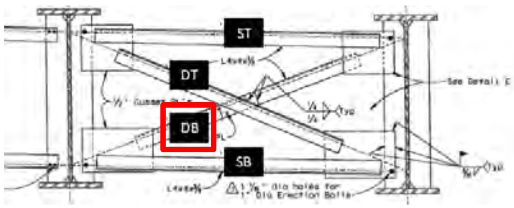


LL Grid and Test Patterns

Live Load Test Results

Forces

- The data collected indicated that the greatest change in forces occurred in the bottom diagonals of the cross frames.



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Live Load Test Results

Forces

- The measured change in forces indicate that positioning the trucks closer to the cross-frames transversely results in greater forces in the bottom diagonals, while positioning the vehicles further away transversely results in greater forces in the top diagonal.
- In general the braces experienced the greatest forces as a vehicle was placed directly over the cross frame.

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Live Load Test Results

Deflections

- The greatest change in deflection occurred during the end to end south test in Girder 6. The end to end south test placed the trucks directly over girder six.
- Each test indicated that as the trucks were moved from one side of the bridge to the other, as well as to the center of the structure, the deflections in the girder under the vehicles deflected the most.

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Live Load Test Results

Rotations

- The girders rotated as a unit and performed as expected for a lean on bracing system.
- The maximum change in rotation occurred in the end to end south test. Girder 5 rotated to the greatest angle at 0.198°.

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Designing a LOB System

Designing a Lean-on Bracing System

- Stiffness Requirements
- Strength Requirements
- AASHTO Tension and Compression Checks
- AASHTO Bolt Checks

Designing a Lean-on Bracing System

- Stiffness Requirements
- Strength Requirements
- AASHTO Tension and Compression Checks
- AASHTO Bolt Checks

Total Brace Design - Stiffness

The total stiffness of the torsional bracing system is a function of:

- Cross-frame or diaphragm stiffness
- Web distortion (cross sectional stiffness)
- In-plane stiffness of the girder

Brace System Stiffness

$$\frac{1}{\beta_b} + \frac{1}{\beta_g} + \frac{1}{\beta_{sec}} = \frac{1}{\beta_t}$$

β_b = Brace stiffness
β_g = In-plane girder stiffness
β_{sec} = Cross Section stiffness (web distortional stiffness)
β_t = Torsional system brace stiffness

Note: the Torsional System Stiffness will be smaller than the smallest component.

Torsional System Brace Stiffness

$$\beta_{ti} = \frac{1.2\,L}{C_{bb}^{\;2}\; n\; I_{eff}\; E}\left(M_u\right)^2$$

Ideal Total Stiffness

$$\beta_t = \frac{3.2\,L}{C_{bb}^{\;2}\; n\; I_{eff}\; E}\left(M_{dl} + M_{constll}\right)^2$$

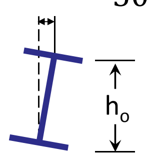
Required System Stiffness

Brace Stiffness and Strength Requirements

AISC Specification Appendix 6 Bracing Provisions:

Stiffness: $$\beta_T = \frac{2.4 L M_r^2}{n E I_y C_b^2}$$

$$\Delta_0 = \frac{L_b}{500}$$

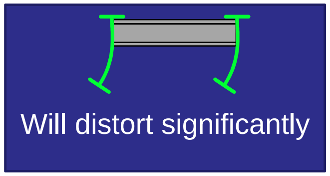


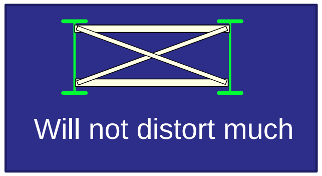
Strength (Commentary): $$M_{br} = \beta_T \theta_o = \frac{2.4 L M_r^2}{n E I_y C_b^2} \frac{L_b}{500 h_o}$$

Cross Section Stiffness

- Web distortion significantly reduces the effectiveness of torsional braces.
- The web is separated into stiffened and unstiffened regions and the overall cross sectional stiffness is the summation of the individual elements of the cross-section.

Understanding Cross Sectional Distortion, β_{sec}





- Cross-Sectional Distortion: depending on the region of the web outside of the depth of the brace, cross-sectional distortion can be significant.
- Distortion can be controlled by providing a web stiffener to increase the bending stiffness of the web.

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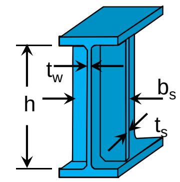
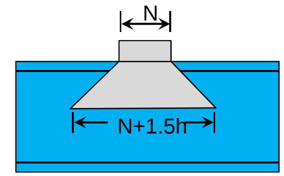
Cross-Sectional Distortion – Rolled Beams



Use at least ¾ depth stiffener



Effective Web Width for Distortion

$$\beta_{sec} = \frac{3.3E}{h}\left(\frac{t_w^3}{12}(N+1.5h)+\frac{t_s b_s^3}{12}\right)$$

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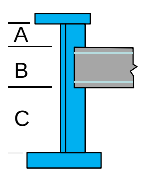
Cross-Sectional Distortion – Built-up Sections

While the previous expression works well with rolled shapes that have relatively stocky webs, most bridge girders are built-up shapes with more slender webs and the previous expression is overly conservative. The distortional behavior of these sections needs to be treated in a more general sense by considering the portions of the web independently. Consider the following beam:



Region B: No distortion along the depth of the brace due to stiffening effect of brace (same for cross-frames)

Regions A and C – will distort, but respective contributions are a function of respective depths of the web along regions A & C.

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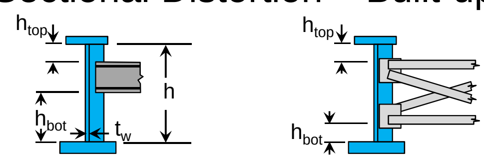
Cross-Sectional Distortion – Built-up Sections



Consider top and bottom regions separately, setting h_i = h_{top} or h_{bot}. Stiffener thickness and width = t_s, b_s.

$$\beta_i = \frac{3.3E}{h_i}\left(\frac{h}{h_i}\right)^2\left(\frac{1.5h_i t_w^3}{12}+\frac{t_s b_s^3}{12}\right)$$

$$\frac{1}{\beta_{sec}} = \frac{1}{\beta_{top}} + \frac{1}{\beta_{bot}}$$

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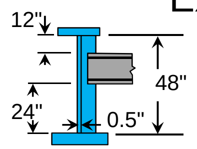
Example: Web Distortion



Find β_{sec} for web shown. The web stiffener is 6" x 0.625 ".

Top Region: h_{top} = 12 "

Bottom Region: h_{bot} = 24 "

Top Region: h_{top} = 12 "

$$\beta_{top} = \frac{3.3(29000)}{12"}\left(\frac{48"}{12"}\right)^2\left(\frac{1.5(12")(0.5")^3}{12} + \frac{(0.625")(6)^3}{12}\right) = 1,459,400\ \frac{k"}{rad}$$

Bottom Region: h_{bot} = 24 "

$$\beta_{top} = \frac{3.3(29000)}{24"}\left(\frac{48"}{24"}\right)^2\left(\frac{1.5(24")(0.5")^3}{12} + \frac{(0.625")(6)^3}{12}\right) = 185,400\ \frac{k"}{rad}$$

Total: $$\frac{1}{\beta_{sec}} = \frac{1}{1,459,400} + \frac{1}{185,400} \rightarrow \beta_{sec} = 164,500\ \frac{k"}{rad}$$

Note: $\beta_{sec} < \beta_{top}$ and β_{bot}

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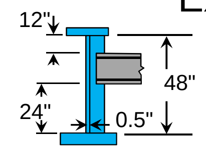
Example: Web Distortion



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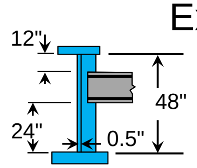
Example: Web Distortion



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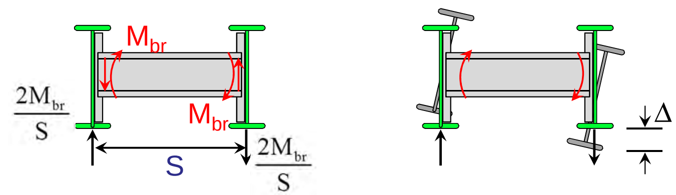
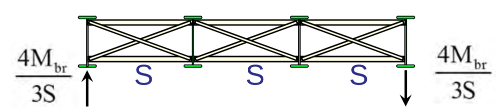
In-Plane Girder Stiffness



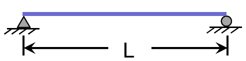


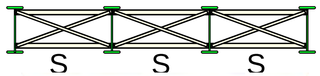
Wider System:
Smaller Shear and
Stiffer System

84

In-Plane Girder Stiffness

In-plane girder stiffness - function of the stiffness of the individual girders as well as the number of girders across the width of the bridge:





$$\beta_g = \frac{N_g S^2 E I_x}{L^3}$$

$$N_g = \frac{24\,(n_g - 1)^2}{n_g}$$

n_g	N_g
2	12
3	32
4	54
5	77

n_g = # of girders

In-Plane Girder Stiffness

$$\beta_g = \frac{12\,(n_g - 1)^2 S^2 E I_x}{n_g L^3}$$

For Lean-on systems

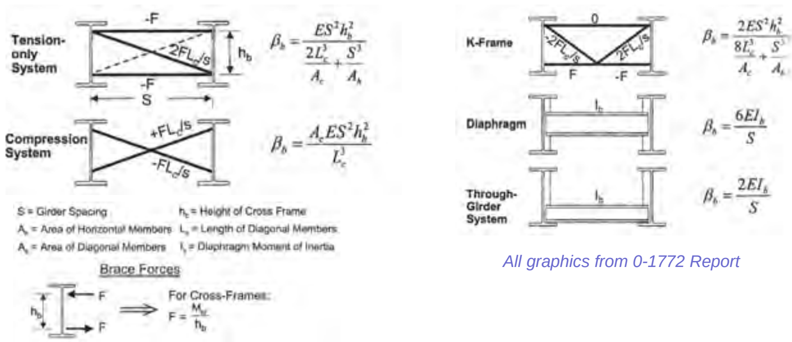
n_g = number of girders

S = girder spacing

L = span length

I_x = moment of inertia about the x − axis

Provided Brace Stiffness



$\beta_b = \dfrac{ES^2h_b^2}{\dfrac{2L_c^3}{A_c} + \dfrac{S^3}{A_h}}$ (Tension-only System)

$\beta_b = \dfrac{A_c ES^2 h_b^2}{L_c^3}$ (Compression System)

$\beta_b = \dfrac{2ES^2h_b^2}{\dfrac{8L_c^3}{A_c} + \dfrac{S^3}{A_h}}$ (K-Frame)

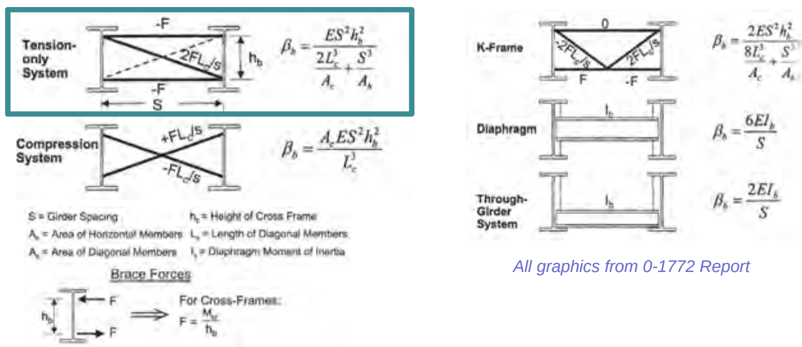
$\beta_b = \dfrac{6EI_b}{S}$ (Diaphragm)

$\beta_b = \dfrac{2EI_b}{S}$ (Through-Girder System)

$F = \dfrac{M_{br}}{h_b}$

All graphics from 0-1772 Report

Provided Brace Stiffness



$\beta_b = \dfrac{ES^2h_b^2}{\dfrac{2L_c^3}{A_c} + \dfrac{S^3}{A_h}}$ (Tension-only System)

$\beta_b = \dfrac{A_c ES^2 h_b^2}{L_c^3}$ (Compression System)

$\beta_b = \dfrac{2ES^2h_b^2}{\dfrac{8L_c^3}{A_c} + \dfrac{S^3}{A_h}}$ (K-Frame)

$\beta_b = \dfrac{6EI_b}{S}$ (Diaphragm)

$\beta_b = \dfrac{2EI_b}{S}$ (Through-Girder System)

$F = \dfrac{M_{br}}{h_b}$

All graphics from 0-1772 Report

Provided Brace Stiffness

$$\beta_{b1} = \frac{E\,S^2\,{h_b}^2}{\dfrac{n_{gc}\,{L_d}^3}{A_d} + \dfrac{S^3\left(\frac{n_{gc}}{2}\right)^2}{A_c}}$$

Braces at Mid-span

For Lean-on systems

$$\beta_{b1} = \frac{E\,S^2\,{h_b}^2}{\dfrac{n_{gc}{L_d}^3}{A_d} + \dfrac{S^3\left(n_{gc}-1\right)^2}{A_c}}$$

Braces at Supports

n_{gc} = number of girders per cross-frame
A_d = area of diagonal angle
A_c = area of horizontal angle

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Provided Brace Stiffness

$$\beta_{b1} = \frac{E\,S^2\,{h_b}^2}{\dfrac{n_{gc}\,{L_d}^3}{A_b} + \dfrac{S^3\left(\frac{n_{gc}}{2}\right)^2}{A_b}}$$

Braces at Mid-span

For Lean-on systems

$$\beta_{b1} = \frac{E\,S^2\,{h_b}^2}{\dfrac{n_{gc}{L_d}^3}{A_b} + \dfrac{S^3\left(n_{gc}-1\right)^2}{A_b}}$$

Braces at Supports

n_{gc} = number of girders per cross-frame
$A_d = A_c = A_b$ = area of brace angles

90

Provided Brace Stiffness

$$\beta_{b1} = \frac{E\,S^2\,{h_b}^2}{n_{gc}\,{L_d}^3 + S^3\left(\frac{n_{gc}}{2}\right)^2}\,A_b$$

Braces at Mid-span

For Lean-on systems

$$\beta_{b1} = \frac{E\,S^2\,{h_b}^2}{n_{gc}{L_d}^3 + S^3\left(n_{gc}-1\right)^2}\,A_b$$

Braces at Supports

n_{gc} = number of girders per cross-frame
A_b = area of brace angles

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Provided Brace Stiffness

$$\beta_{b1} = \frac{E\,S^2\,{h_b}^2}{n_{gc}\,{L_d}^3 + S^3\left(\frac{n_{gc}}{2}\right)^2}\,A_b$$

Braces at Mid-span

For Lean-on systems

$$\beta_{b1} = \frac{E\,S^2\,{h_b}^2}{n_{gc}{L_d}^3 + S^3\left(n_{gc}-1\right)^2}\,A_b$$

Braces at Supports

n_{gc} = # of girders per crossframe
N_c = # of crossframes at ea. brace location
$n_{gc} = \frac{n_g}{N_c}$

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Brace Area Required for Stiffness

$$\beta_{b2} = \frac{1}{\left(\frac{1}{\beta_t}\right) - \left(\frac{1}{\beta_g}\right) - \left(\frac{1}{\beta_{sec}}\right)}$$

Required Stiffness

$$\beta_{b1} = \frac{E\,S^2\,h_b^{\,2}}{n_{gc}L_d^{\,3} + S^3(n_{gc}-1)^2}$$

Provided Stiffness

$$A_b = \frac{\beta_{b2}}{\beta_{b1} N_c}$$

N_c = # of cross-frames at each brace location

n_{gc} - # of girders per cross-frame

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Designing a Lean-on Bracing System

- Stiffness Requirements
- Strength Requirements
- AASHTO Tension and Compression Checks
- AASHTO Bolt Checks

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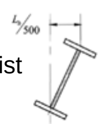
Strength Requirements

$$\Phi_o = \frac{L_b}{500\,h}$$ ← Assumed Initial Twist



$$M_{br} = F_{br}\,h_b = \beta_t\,\Phi_o$$ ← Moment in the Brace

$$F = \beta_t \frac{\Phi_o}{h_b}$$ ← Force in the Brace

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Strength Requirements

$$\Phi_o = \frac{L_b}{500\,h}$$ ← Assumed Initial Twist

OR INITIAL IMPERFECTION

$$M_{br} = F_{br}\,h_b = \beta_t\,\Phi_o$$ ← Moment in the Brace

$$F = \beta_t \frac{\Phi_o}{h_b}$$ ← Force in the Brace

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Strength Requirements

Critical Imperfection (0-1772)

- The critical imperfection that can be reasonably expected to occur in practice generally consists of a cross-sectional twist resulting from a lateral displacement of one flange while the other flange remains straight
- Research 0-1772 used FEM results on a W14x22 section that was studied in lab investigations to help define the critical twist on the cross-section.
- Several different distributions of the twist were investigated

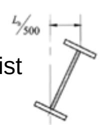
Strength Requirements

Critical Imperfection (0-1772)

- A practical value for maximum lateral flange displacement for both plate girders and rolled sections can be obtained using a value $L_b/500$
- This max. lateral displacement is consistent with the sweep tolerances for rolled sections and results in the same imperfection that is assumed in the torsional bracing provisions in AISC LRFD
- To maximize the brace forces, the maximum initial twist should generally occur near the brace closest to the point of maximum beam moment with zero twist at adjacent points.

Strength Requirements

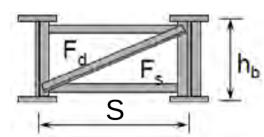
$$\Phi_o = \frac{L_b}{500\ h}$$ ← Assumed Initial Twist



$$M_{br} = F_{br}\, h_b = \beta_t\, \Phi_o$$ ← Moment in the Brace

$$F = \beta_t \frac{\Phi_o}{h_b}$$ ← Force in the Brace

Angle Forces



$$F_d = \frac{n_g\, F\, L_d}{S}$$ ← Force in Diagonal

$$F_S = (n_g - 1)\frac{F}{N_c}$$ ← Force in Struts at Supports

$$F_S = \left(\frac{n_g}{N_c 2}\right) F$$ ← Force in Struts at Mid-Span

N_c = # of cross-frames at each brace location

n_g - # of girders

Designing a Lean-on Bracing System

- Stiffness Requirements
- Strength Requirements
- AASHTO Tension and Compression Checks
- AASHTO Bolt Checks

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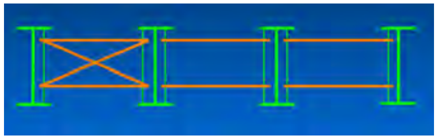
Tension, Compression, Bolt Checks

- Tension Checks
  - AASHTO 6.8.2
- Compression Checks
  - AASHTO 6.9.4.1.2
  - AASHTO 6.9.4.4
- Bolt Checks - Struts
  - AASHTO 6.13.2

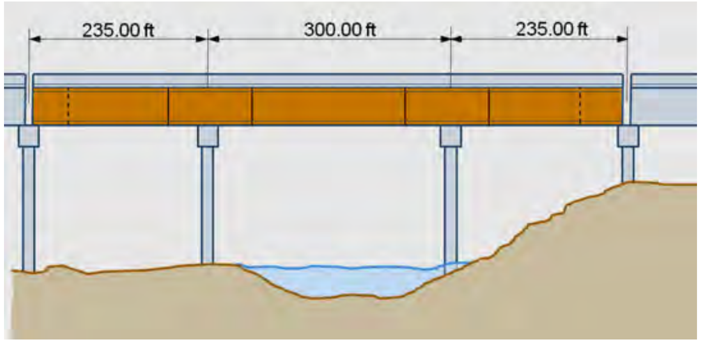


102

Design Example

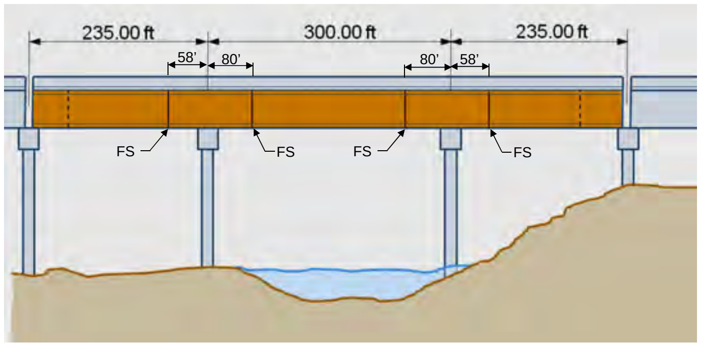
103

Design Example



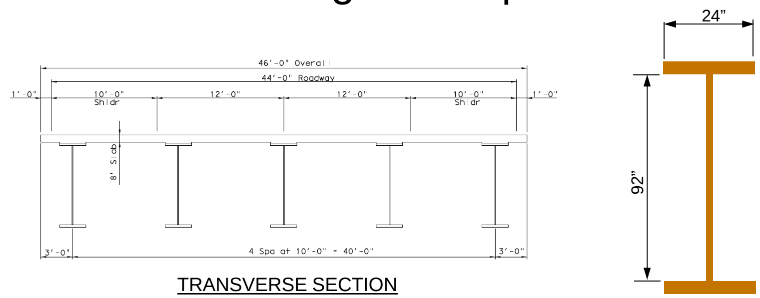
104

Design Example



105

Design Example



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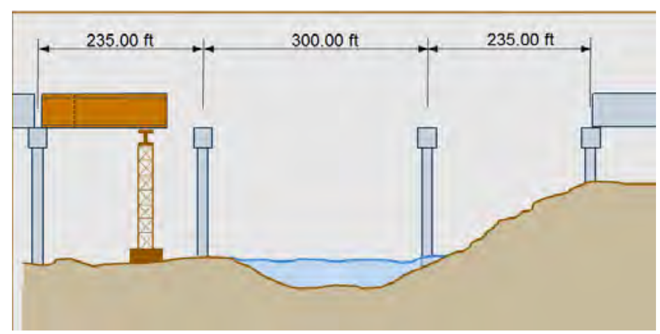
Developing the Framing Plan

- Should take into account how the bridge girders will be erected or develop a LOB framing plan with various girder erection scheme options
- Talk to contractors and construction experts to determine most likely lifting sequence and crane placement

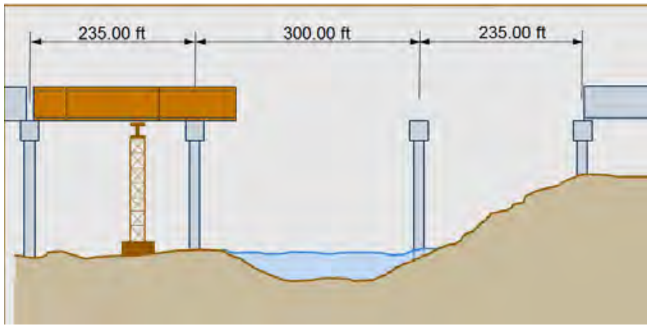
107

Assumed Order of Girder Erection



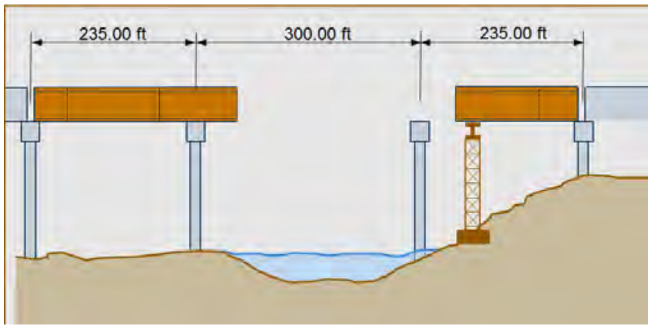
108

Assumed Order of Girder Erection



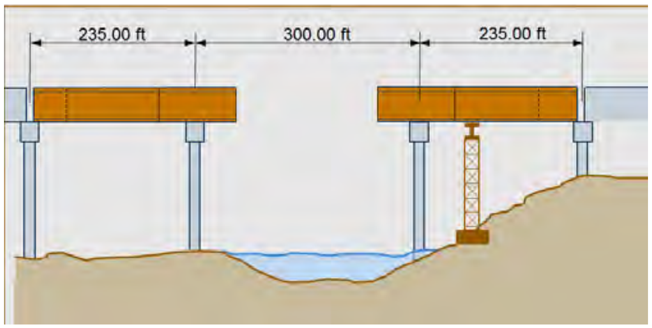
109

Assumed Order of Girder Erection



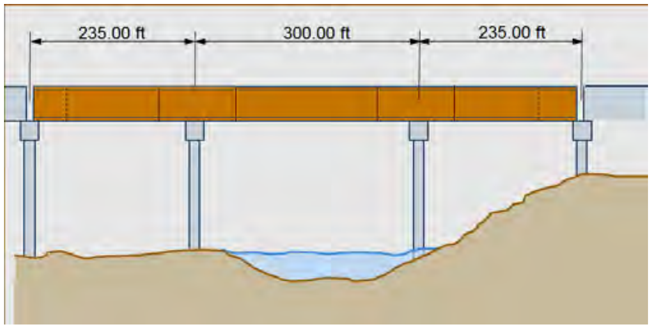
110

Assumed Order of Girder Erection



111

Assumed Order of Girder Erection



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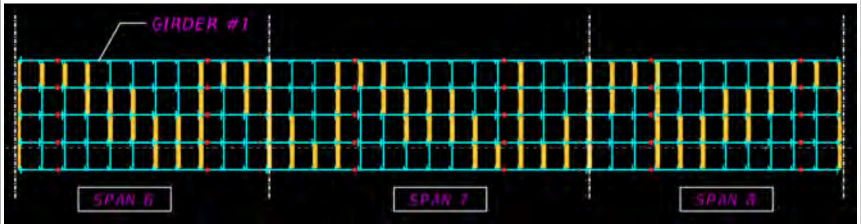
Assumed Order of Girder Erection

1. Erection can start at the first bent or last bent with the below LOB system:
   - At first bent, beginning with Girders 1, then 2-5
   - At the last bent (4th), beginning with Girders 1, then 2-5



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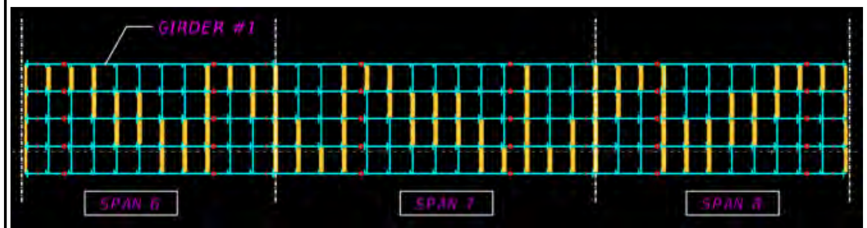
Assumed Order of Girder Erection

2. Drop in span in the center span, beginning with Girders 1, 2-5



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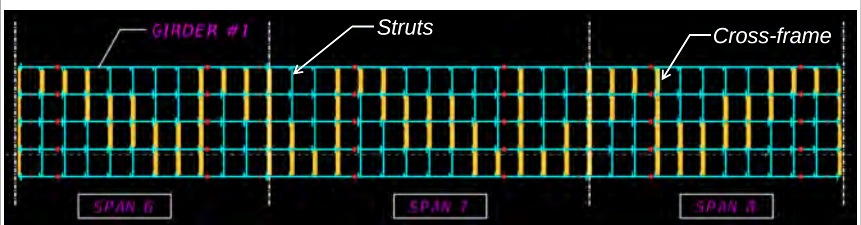
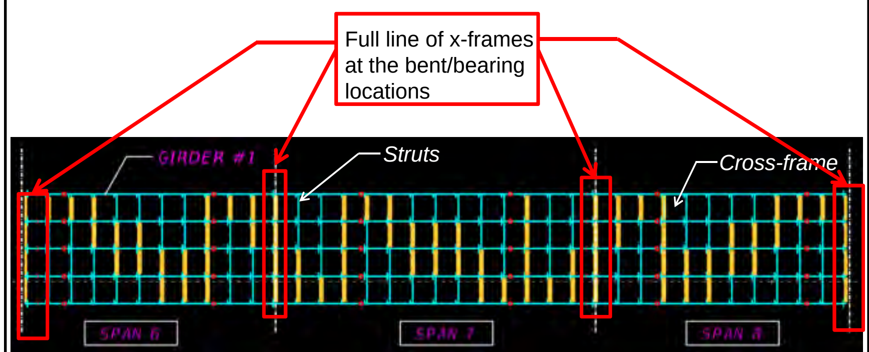
Framing Plan



115

Framing Plan



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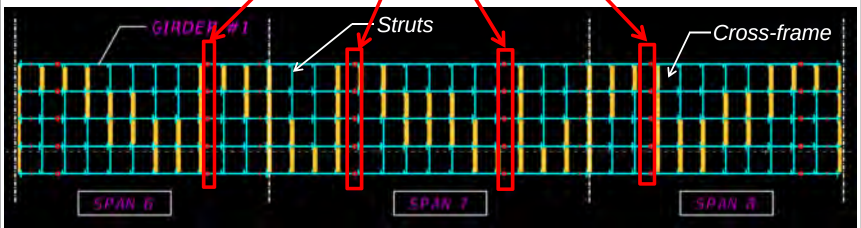
Framing Plan

Full line of x-frames at the splice locations



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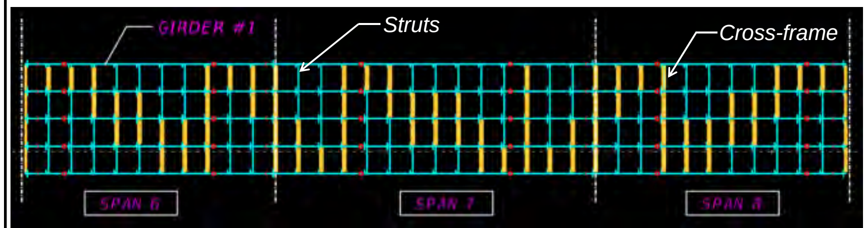
Framing Plan



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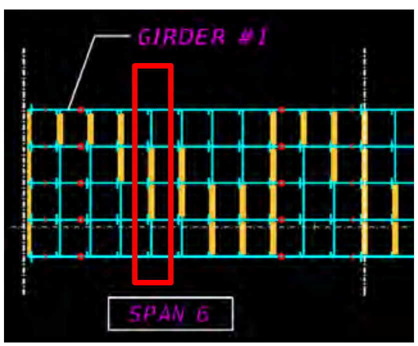
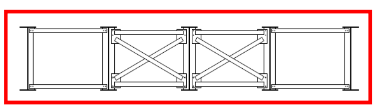
Design Example





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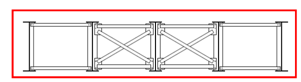
Design Example



- Girder geometry
- Bridge geometry
- Stiffener geometry
- Steel properties
- Strut bolts
- Brace geometry
- Angle properties
- Girder section properties

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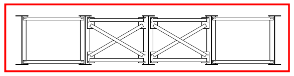
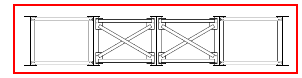
Design Example



GIRDER GEOMETRY				BRIDGE GEOMETRY			
D_w	92	in		n_g	5		# of Girders
t_w	0.6875	in		S	120	in	Girder Spacing
b_{tf}	24	in		L	235	ft	Span Length
t_{tf}	1.5	in		L_b	21.273	ft	Unbraced Length
b_{cf}	24	in		n	10		# of brace locations in the span
t_{cf}	1	in		N_c	2		# of cross-frames at each bracing
I_x	172587	in^4					location
y_b	47	in		W_{bridge}	46	ft	Bridge width
C_{bb}	1						

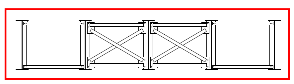
Design Example



STIFFENER GEOMETRY				MOMENTS		
bs	8	in		M_{TOTAL}	10265.4	k-ft
ts	0.5	in				
STEEL PROPERTIES						
E	29000	ksi				
F_y	50	ksi				
F_u	70	ksi				
ϕ_y	0.95		AASHTO 6.5.4.2			
ϕ_u	0.8					
ϕ_s	0.8					
ϕ_c	0.9					
ϕ_{bb}	0.8					
F_{ub}	120	ksi				
U	0.6		AASHTO Table 6.8.2.2-1			

STRUT BOLTS			
n_b	2		No. of bolts on struts
d_b	1	in	Bolt diameter
N_{slip}	1		No. of slip planes
R_p	0.9		Reduction factor for holes [AASHTO 6.8.2.1-2]
P_t	51	k	Min required bolt tension [AASHTO Table 6.13.2.8-1]
K_h	1		Hole size factor [AASHTO Table 6.13.2.8-2]
K_s	0.33		Surface condition factor [AASHTO Table 6.13.2.8-3]
A_{bolt}	0.785	in^2	

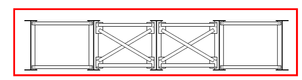
Design Example



STIFFENER GEOMETRY				MOMENTS		
bs	8	in		M_{TOTAL}	10265.4	k-ft
ts	0.5	in				
STEEL PROPERTIES						
E	29000	ksi				
F_y	50	ksi				
F_u	70	ksi				
ϕ_y	0.95		AASHTO 6.5.4.2			
ϕ_u	0.8					
ϕ_s	0.8					
ϕ_c	0.9					
ϕ_{bb}	0.8					
F_{ub}	120	ksi				
U	0.6		AASHTO Table 6.8.2.2-1			

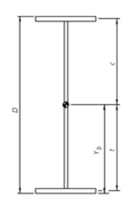
Construction Loads
Load Factor = 1.4
- Construction LL and DL
- Deck forms
- Screed rail
- Railing
- Walkway
- Finishing machine
- Etc..

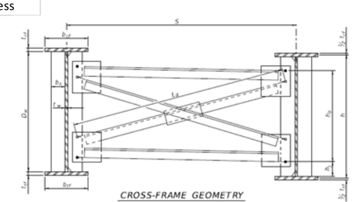
Design Example



BRACE GEOMETRY				ANGLE PROPERTIES			
L_d	124.2	in		A_g	6.45	in^2	Angle area
h_j	5	in		r_z	1.18	in	
h_b	82	in		r_x	1.85	in	
				A_t	0.5625	in	Angle thickness

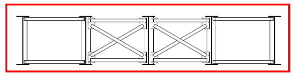
GIRDER SECTION PROPERTIES			
D	94.5	in	$D = D_w + t_{tf} + t_{cf}$
c	51.1	in	$c = D - 0.5t_{cf} - y_b$
t	42.15	in	$t = y_b - 0.5t_{tf}$
h	93.25	in	$h = D_w + 0.5t_{cf} + 0.5t_{tf}$
I_{yc}	1152	in^4	$I_{yc} = (1/12)\ t_{cf} b_{cf}^{\ 3}$
I_{yt}	1728	in^4	$I_{yt} = (1/12)\ t_{tf} b_{tf}^{\ 4}$
I_{eff}	2577.3	in^4	$I_{eff} = I_{yc} + I_{yt}\ (t/c)$





Design Example

Torsional Brace Design - Stiffness

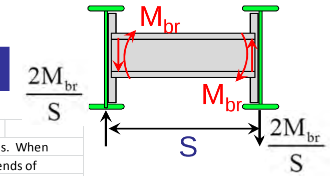


The total stiffness of the torsional bracing system is a function of:

- Cross-frame or diaphragm stiffness
- Web distortion (cross-sectional stiffness)
- In-plane stiffness of the girder

Design Example

In-Plane Girder Stiffness



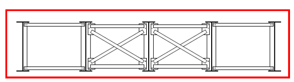
In Plane Girder Stiffness

The in-plane flexibility of the girders reduces the effectiveness of the torsional braces. When internal moments develop in the torsional brace, vertical shears also develop at the ends of the brace. These shears are transferred to the girders as an upward load on one girder and a downward load on the other girder. These forces cause one of the girders to displace upward while the other girder displaces downward, resulting in a rigid body rotation of the brace. The rotation of the girders reduces the effectiveness of the cross-frame or diaphragm [1772-1].

$$\beta_g = \frac{12(n_g - 1)^2 S^2 E\, I_x}{n_g L^3}$$ = 123,410.6 kip-in/rad

Design Example

Cross Section Stiffness



Cross Section Stiffness

Web distortion significantly reduces the effectiveness of torsional braces. The web is separated into stiffened and unstiffened regions and the overall cross sectional stiffness is the summation of the individual elements of the cross-section.

$$\beta_{sec} = 3.3\left(\frac{E}{h_i}\right)\left(\frac{h}{h_i}\right)^2\left[\frac{1.5\, h_i t_w^3}{12} + \left(\frac{t_s b_s^3}{12}\right)\right]$$ = 143,374,949 kip-in/rad

Design Example

Cross Section Stiffness

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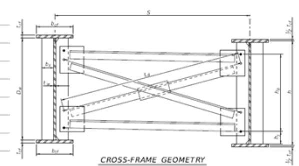
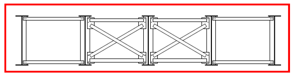


Design Example

Brace Stiffness



Brace Stiffness

The below equation predicts the stiffness of cross-frame braces in a lean on system, where the cross-frame is located at the middle of the bridge (across the width of the bridge).

$$n_{gc} = \frac{n_g}{N_c}$$

$$\beta_{b1} = \frac{E\,S^2 h_b{}^2 A_b}{n_{gc} L_d{}^3 + S^3 \left(\frac{n_{gc}}{2}\right)^2}$$ = 228,672 A_b kip-in/rad

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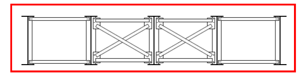
Design Example

Required System Stiffness



Required System Stiffness

$$\beta_t = \frac{3.2\,L}{c_{bb}{}^2 n\, I_{eff} E}\left(M_{DL} + M_{const\_LL}\right)^2$$ = 183,207 kip-in/rad

$$\beta_{b2} = \frac{1}{\left(\frac{1}{\beta_t}\right) - \left(\frac{1}{\beta_g}\right) - \left(\frac{1}{\beta_{sec}}\right)}$$ = 377,116 kip-in/rad

$$A_b = \frac{\beta_{b2}}{\beta_{b1} N_c}$$ = 0.82 in²

? $A_g \geq A_b$ OK

$$A_b = \frac{\beta_{b2}}{\beta_{b1} N_c}$$ = 0.82 in²

? $A_g \geq A_b$ OK

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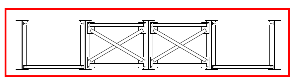
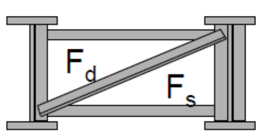
Design Example

Torsional Brace Design - Strength



TORSIONAL BRACE DESIGN - STRENGTH

Assumed Initial Twist $= \Phi_o = \frac{L_b}{500\,h}$	= 0.0055		
$F = \beta_t \frac{\Phi_o}{h_b}$	= 12.2	k	
Max Diag Force(tension) $= F_d = \frac{n_g F L_d}{N_c S}$	= 31.7	k	Diagonal
Max Horiz Force(compress) $= F_s = \left(\frac{n_g}{2}\right)\frac{F}{N_c}$	= 15.3	k	Strut



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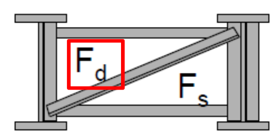
Design Example

Tension Check

Tension Checks - AASHTO 6.8.2

ϕP_{ny}	306.375	k	$\phi P_{ny} = \phi_y F_y A_g$	AASHTO 6.8.2.1-1
	?$\phi P_{ny} \geq F_d$	OK		
A_n	5.8	in²	$A_n = A_g - 1(d_b + 0.125in)\,A_t$	
ϕP_{nu}	175.9	k	$\phi P_{nu} = \phi_u F_u A_n U R_p$	AASHTO 6.8.2.1-2
	?$\phi P_{nu} \geq F_d$	OK		



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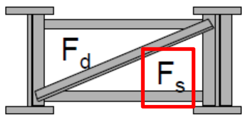
Design Example

Compression Check

Compression Checks - AASHTO 6.9.4.1.2 & 6.9.4.4		
k	1.0	
L_c	118.3	in
L_c/r_x	64.0	



For equal-leg angles and unequal-leg angels connected through the longer leg:

If $\frac{L_c}{r_x} \le 80$, $\left(\frac{k\,L_c}{r}\right)_{eff} = 72 + 0.75\,\frac{L_c}{r_x}$ AASHTO 6.9.4.4-1

If $\frac{L_c}{r_x} > 80$, $\left(\frac{k\,L_c}{r}\right)_{eff} = 32 + 1.25\,\frac{L_c}{r_x}$ AASHTO 6.9.4.4-2

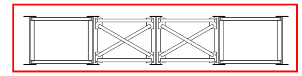
$\left(\frac{k\,L_c}{r}\right)_{eff} = 120.0$

ϕP_n 115.5 k $\quad \phi P_n = \phi_c \frac{\pi^2 E}{\left(\left(\frac{kL_c}{r}\right)_{eff}\right)^2} A_g$

$?\phi P_n \ge F_s$ OK

Design Example

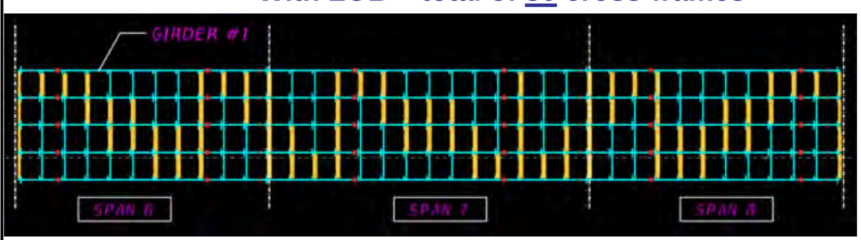
Bolt Checks - Struts



Bolt Checks - AASHTO 6.13.2				
Shear Resistance				
R_r	57.3	k	$R_r = \phi_s\, 0.38\, F_{ub}\, N_{slip}\, n_b\, A_{bolt}$	AASHTO 6.13.2.7-2
	$?R_r \ge F_s$	OK		(Threads included in shear plane)
Slip Resistance				
R_n	33.7	k	$R_n = K_h\, K_s\, N_{slip}\, P_t\, n_b$	AASHTO 6.13.2.8-1
	$?R_n \ge F_s$	OK		
Bearing Resistance				
R_r	142.8	k	$R_r = \phi_{bb}\, 2.4\, d\, t\, F_u$	AASHTO 6.13.2.9-1
	$?R_r \ge F_s$	OK		

Design Example

Framing Plan: Without LOB – total of <u>148</u> cross-frames
With LOB – total of <u>80</u> cross-frames



Design Example - Summary

- Equations and design assumptions from 0-1772 were used to develop a spreadsheet to check the stiffness
- This check would be completed for each line of braces across the width of the bridge
- For this example, only **<u>80</u>** full cross-frames were utilized for the entire 3 spans, when otherwise there would have been **<u>148</u>**

Example – Partial LOB System

- In the previous example, cross-frames were removed throughout the entire bridge.
- Another alternative is to only remove cross-frames and provide a LOB system in problematic areas

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Example – Partial LOB System

- Lake Conroe, Texas
- SH 105 Overpass
- 465 ft. steel plate girder unit (125' – 215' -125')
- 3 spans at ~43 degree skew
- Width = 191.42 ft (built in 2 phases)

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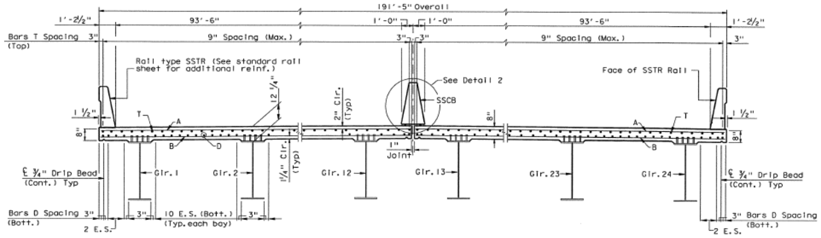
Example – Partial LOB System



Transverse Section

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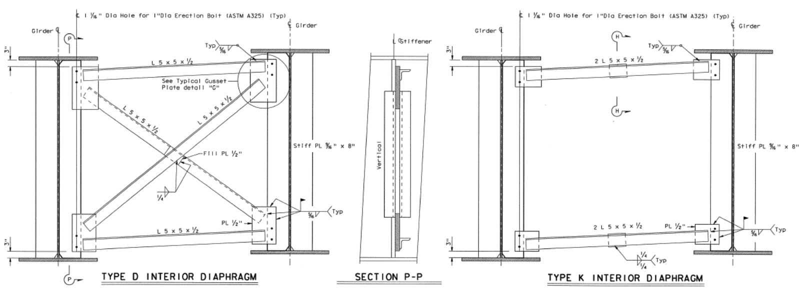
Example – Partial LOB System



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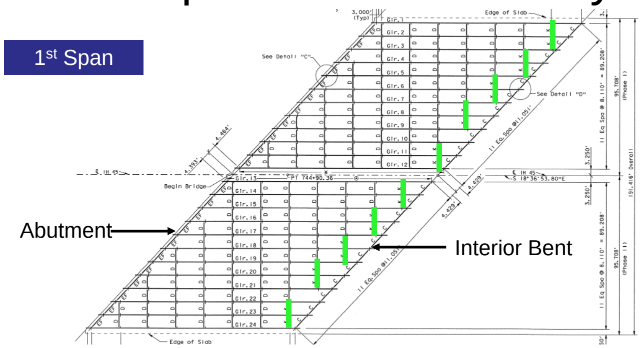
Example – Partial LOB System



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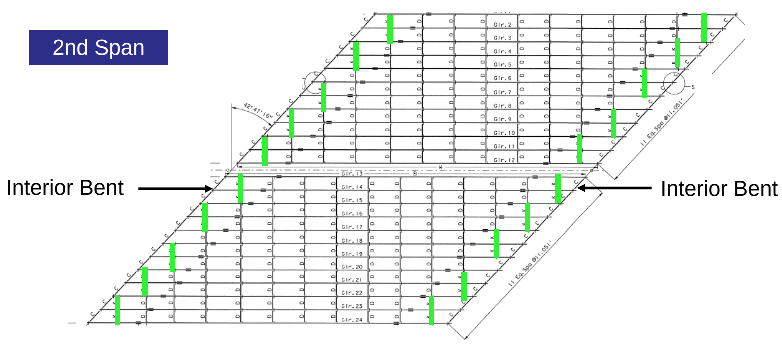
Example – Partial LOB System



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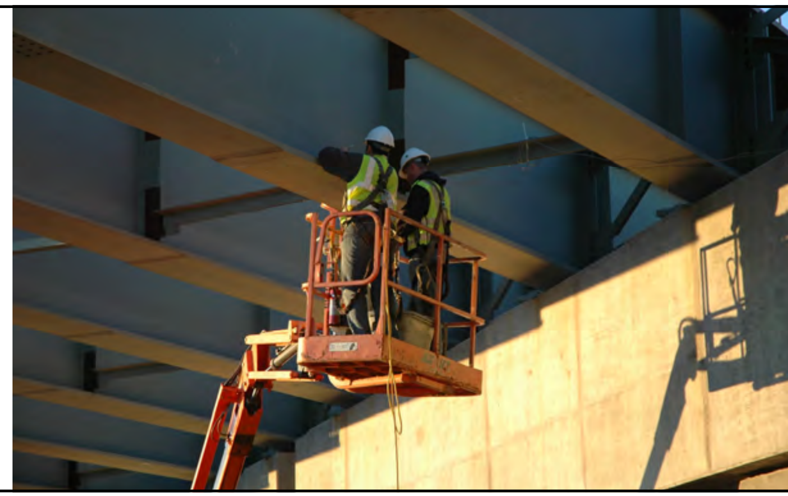


Owner's Perspective

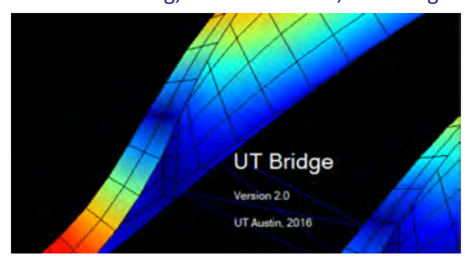
Owner's Perspective

- The use of a lean-on bracing system is allowed for straight girder bridges according to the TxDOT Bridge Design Manual – LRFD (Policy Manual) – Chapter 3, Section 14
- TxDOT encourages it's use for the right bridge projects
- Saves fabrication costs and erection time, which is a huge benefit

UT Bridge Version 2.2 Released in February 2018

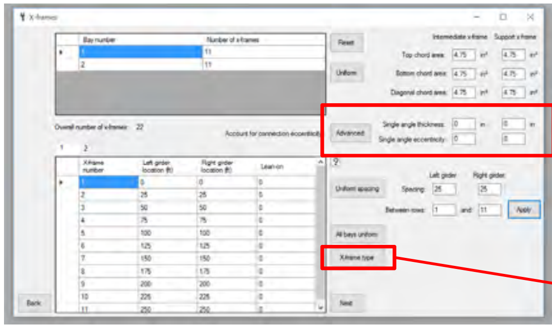
Version 1.0 – Jason Stith, Brian Petruzzi, and Jun Kim (2009)
Version 2.0, 2.1, 2.2 – Paul Biju-Duval (2017-2018)

Co-PIs: Todd Helwig, Eric Williamson, Mike Engelhardt, Karl Frank, and Tricia Clayton



Download at:
http://fsel.engr.utexas.edu/facilities/software/ut-bridge

UT Bridge Version 2.2 Released in February 2018



R-Factor

Cross-Frame Properties and Spacing

X-Type,
K-Type,
Lean On

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Summary

- Benefits of LOB - Leads to fewer cross-frames
  - Decreases fabrication costs
  - Decreases erection costs
  - Reduces fit up issues
  - Reduces the construction timeline
  - Simplifies future inspections and maintenance
  - Fewer fatigue prone details

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Summary

- Design of Lean on Bracing should be considered for the right projects
- The design method is not difficult and is a conservative method for torsional bracing
- LOB can be used on straight bridges with a normal support or skewed support

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Summary

- When developing the Framing Plan, designers should take into account the sequence of girder erection or develop a plan with various options
- For heavily skewed bridges, the LOB concept can be applied to specific problematic locations on the bridge. LOB doesn't have to be applied to an entire bridge.

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Summary

- For more in-depth information, read TxDOT Research Report 0-1772 at https://library.ctr.utexas.edu/digitized/texasarchive/phase1/1772-1.pdf

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Acknowledgements

- Dr. Todd Helwig; University of Texas
- Michelle Romage-Chambers; TxDOT
- Researchers at the University of Texas
- TxDOT Lubbock District
- Lubbock Construction Photos by: Will Barnett, Todd Helwig, Anthony Battistini, and Jeremiah Fasl

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Questions?

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PDH Certificates

Within 2 business days…

- You will receive an email on how to report attendance from: registration@aisc.org.
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don’t forget to check the boxes next to each attendee’s name!

PDH Certificates

Within 2 business days…

- Reporting site (URL will be provided in the forthcoming email).
- Username: Same as AISC website username.
- Password: Same as AISC website password.

There's always a solution in steel.

Thank You

Please give us your feedback!
Survey at conclusion of webinar.