Bridge Stability – An Overview of Critical Items and Checks

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Overview of Critical Stability Items

- Beams being fabricated and transported
- Beams being lifted
- Stability of partial in-place systems
- Other load effects
  - Overhang bracket concerns
  - Deck casting
- Specification requirements
  - Concrete bridges
  - Steel bridges
  - New(ish) developments in stability

Function of Bracing During Erection

- Provide stability
  - **Strength … more on this later**
  - **Stiffness …more on this later**
- Control geometry
- Primary load element for curved and skewed bridges

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Girder Bracing During Installation

- Commonly only several lines of bracing are placed during erection
- This photo shows most if not all bracing finally installed

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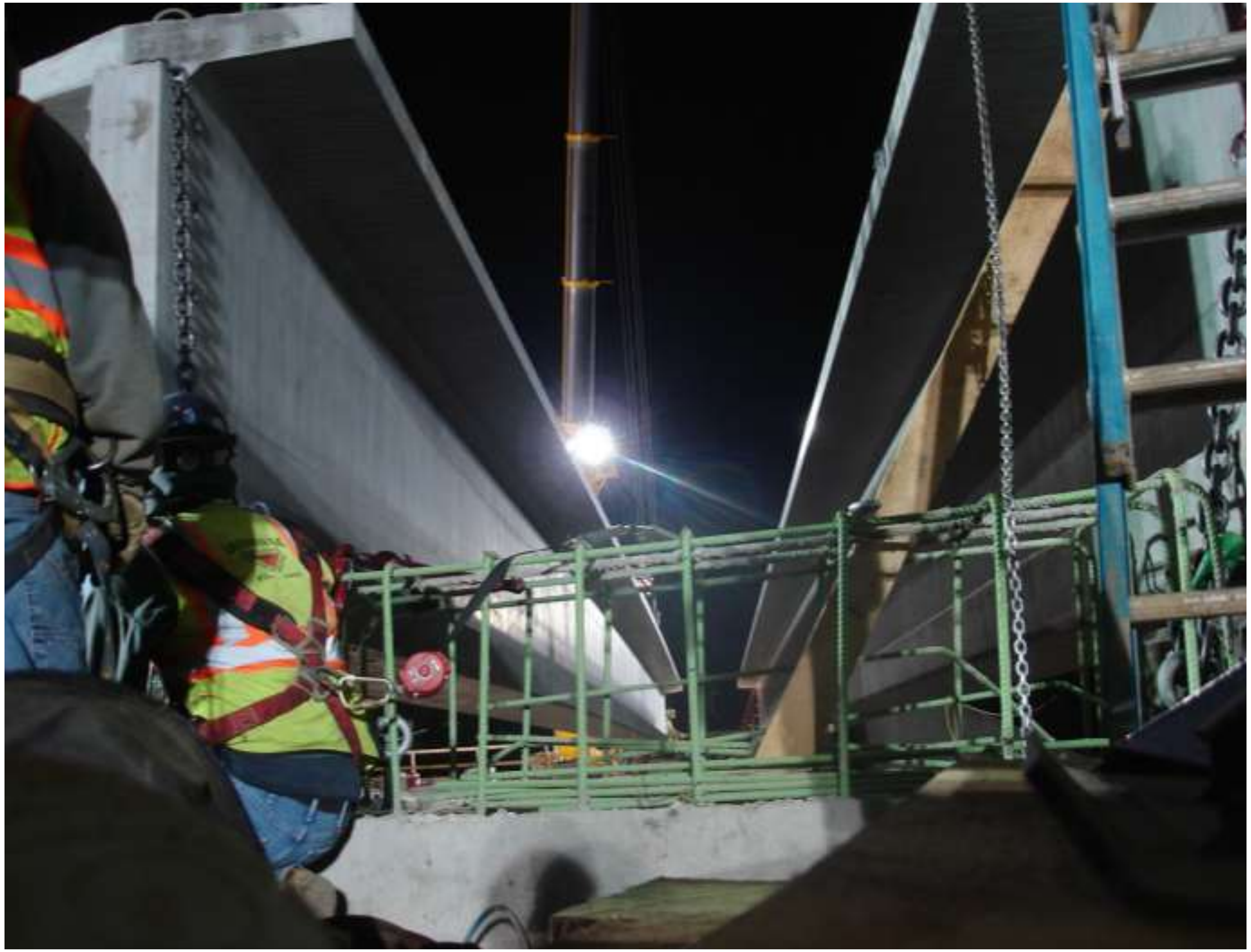
Bracing at Girder Support

- External stability of a system is essential
- Beams not only need to be connected to themselves but to the "outside world"

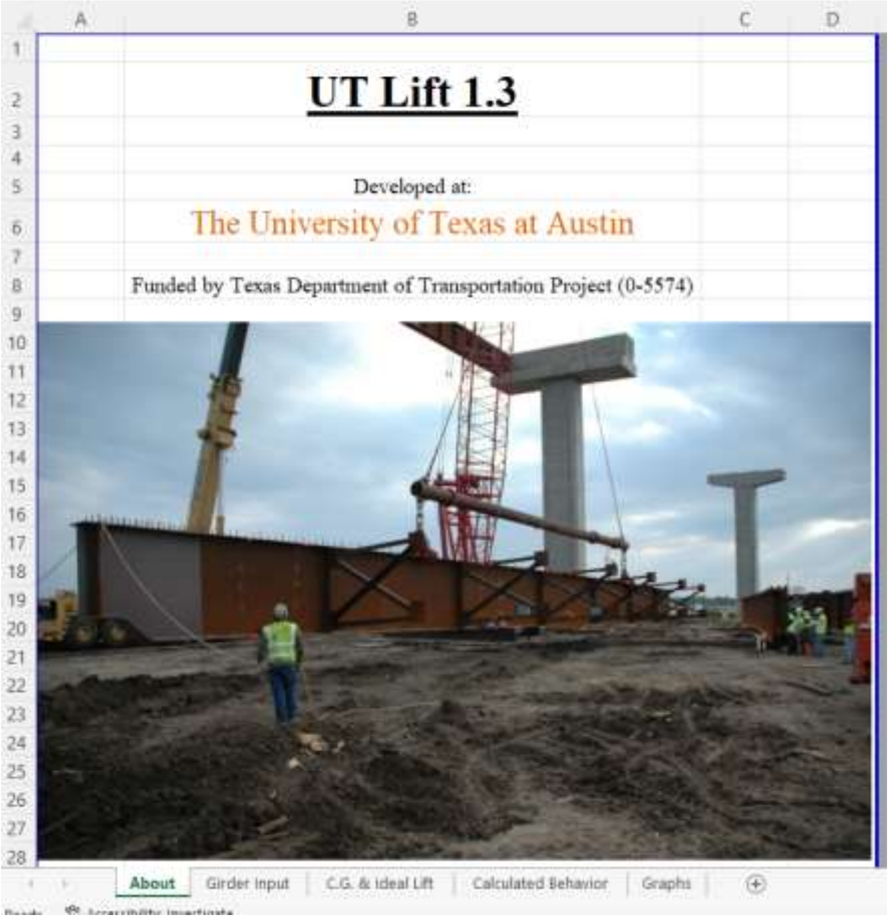
Bracing at Girder Support



Steel Girder Stability During Erection Stages

- Lifting
- Initial girder set
- First girder pair placed
- Subsequent girders placed
- Full girder and bracing installed

Setting Girder with Bracing Attached



UT Lift 1.3

Developed at:

The University of Texas at Austin

Funded by Texas Department of Transportation Project (0-5574)

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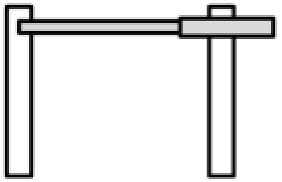
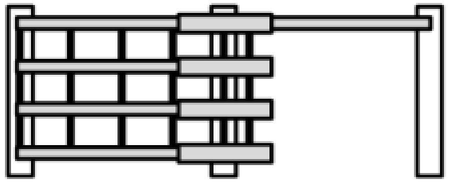
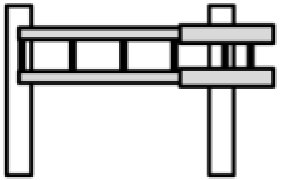
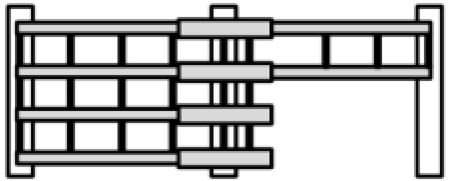
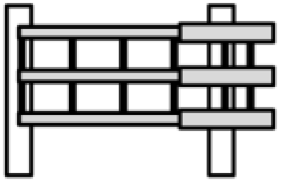
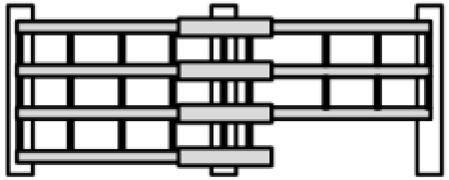
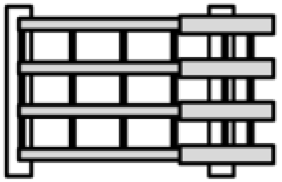
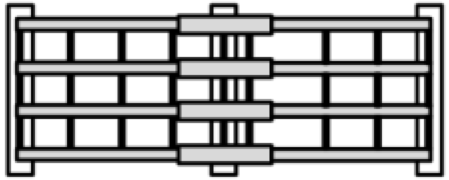
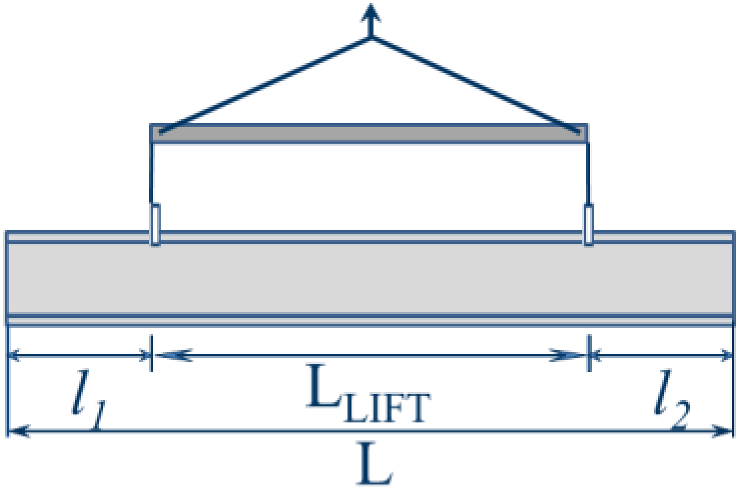
Single Girder Pick and Set

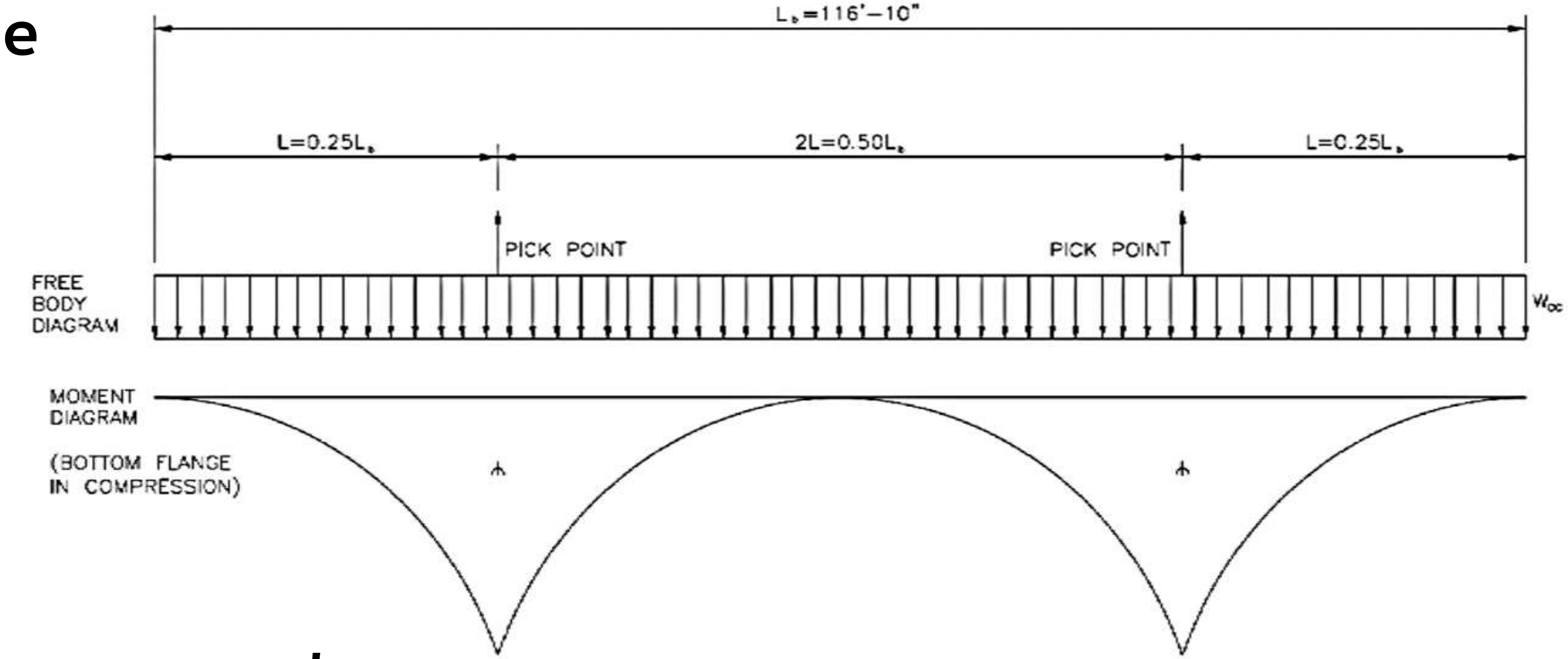
- Stability of systems evolves through the life of the construction process
- What’s most critical?
    - 1<2<3<4 seems obvious
    - What about 1 vs 5 ?
    - Need to check a few possible controlling cases

Case	Erected Girders	Case	Erected Girders
1		5	
2		6	
3		7	
4		8	

Optimal Lifting Arrangement

- Girders are most stable with overhangs of between 20-30% of the total lifted length

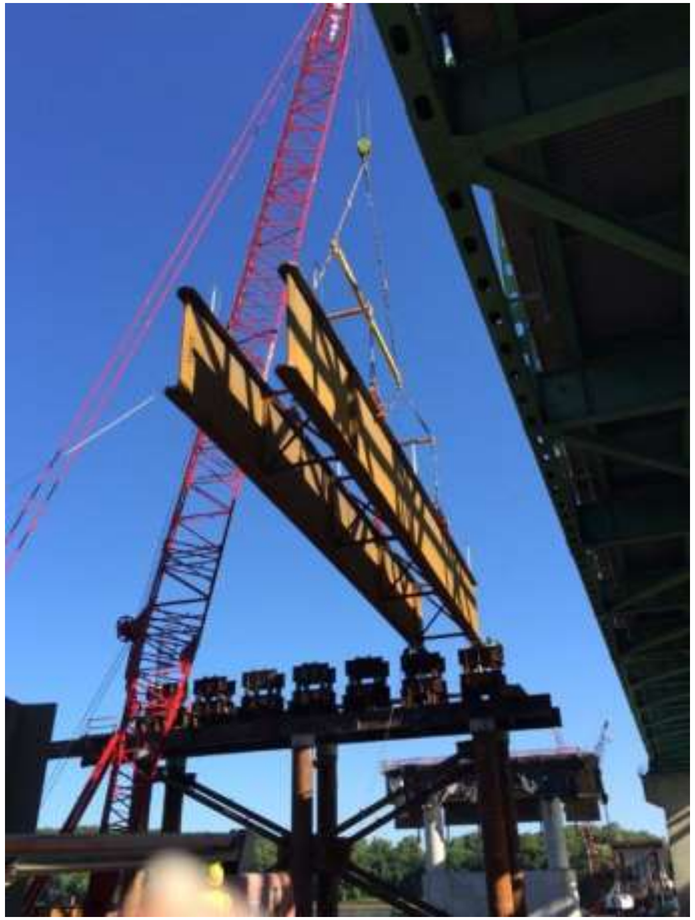




- You can't use traditional LTB equations for this system. It is totally unbraced
- Nothing in AISC / AASHTO will help you out of this jamb

Setting Girder Pairs

- Setting in pairs
  - Stability is enhanced ☺
  - Weight is doubled ☹



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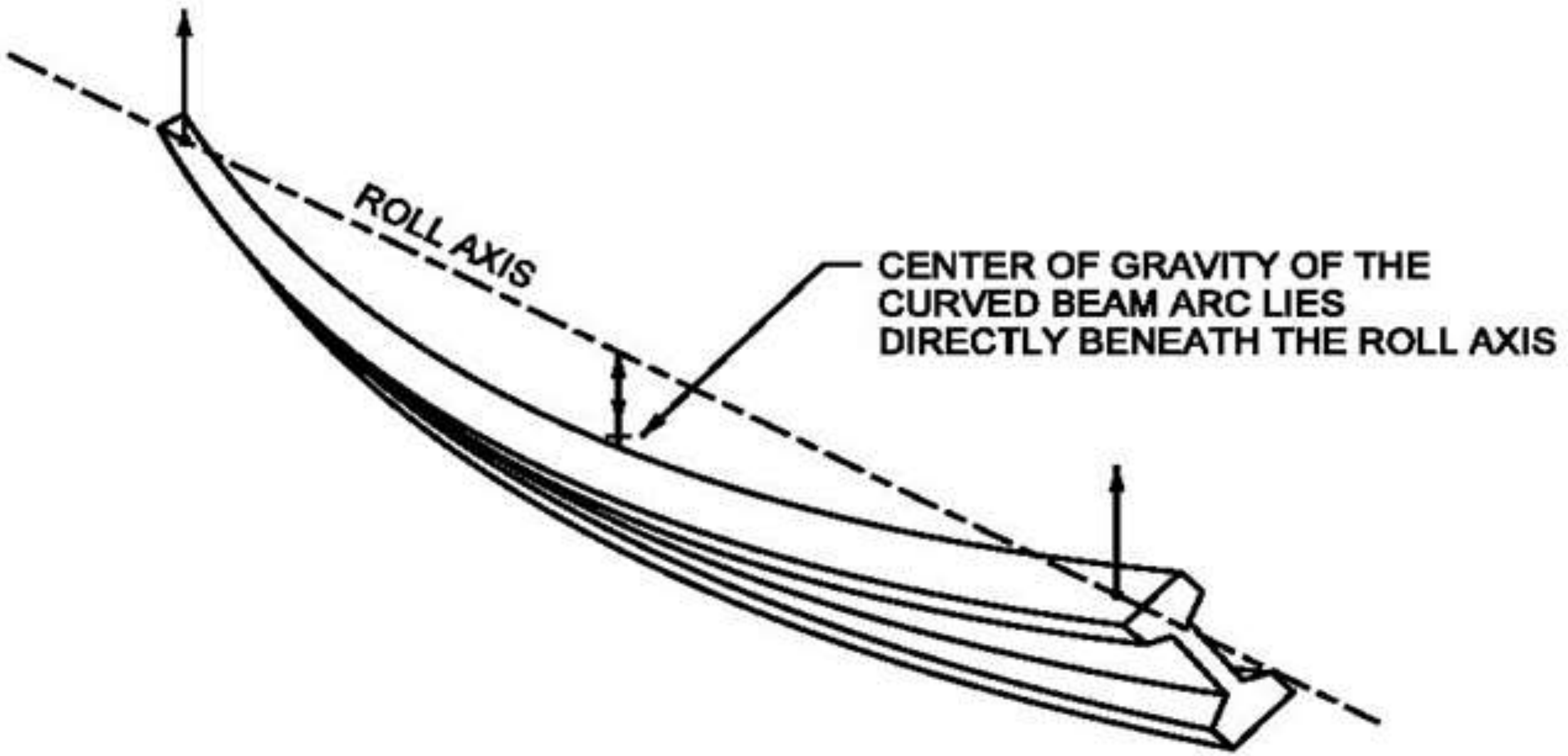
Concrete Girder Stability During Erection Stages

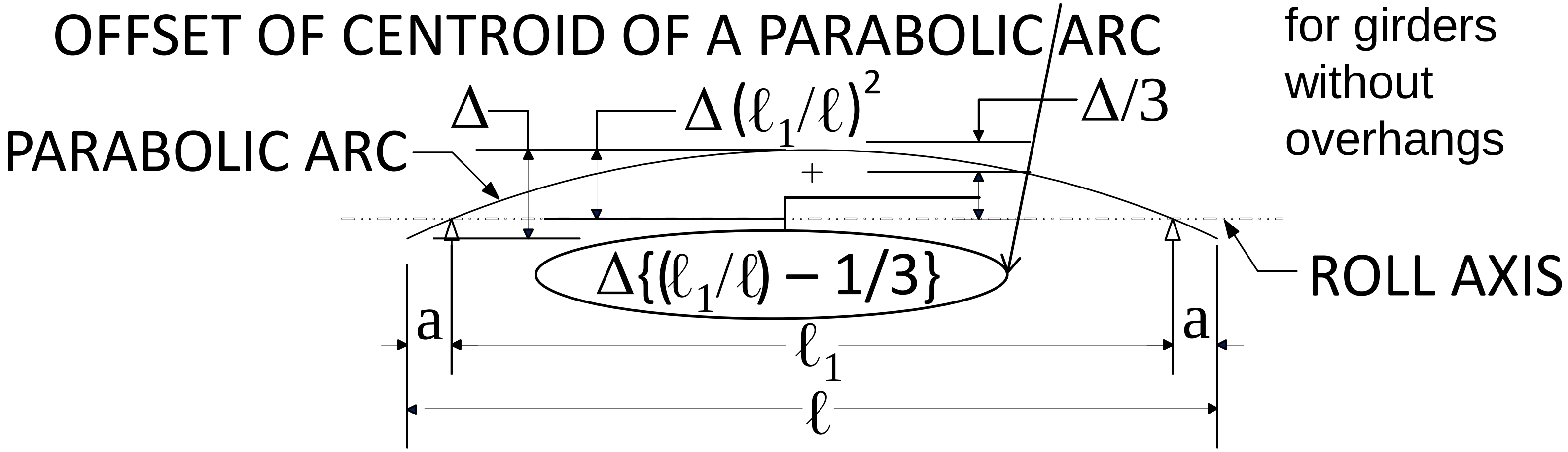
Concrete Girder Stability During Erection Stages



PERSPECTIVE OF A BEAM FREE TO ROLL AND DEFLECT LATERALLY

Roll Stability of Concrete Girders

- Initial lateral eccentricity, ei, should include at minimum:
  - 1" accidental bearing misalignment
  - PCI sweep tolerance of 1/8" per 10' of girder length
  - Offset factor on sweep = $(\ell 1/\ell)2 - 1/3$
    - See figure – also used for center of mass of cambered girder



Offset factor simplifies to 2/3 for girders without overhangs

Temporary Bracing Measures Employed During Bridge Erection

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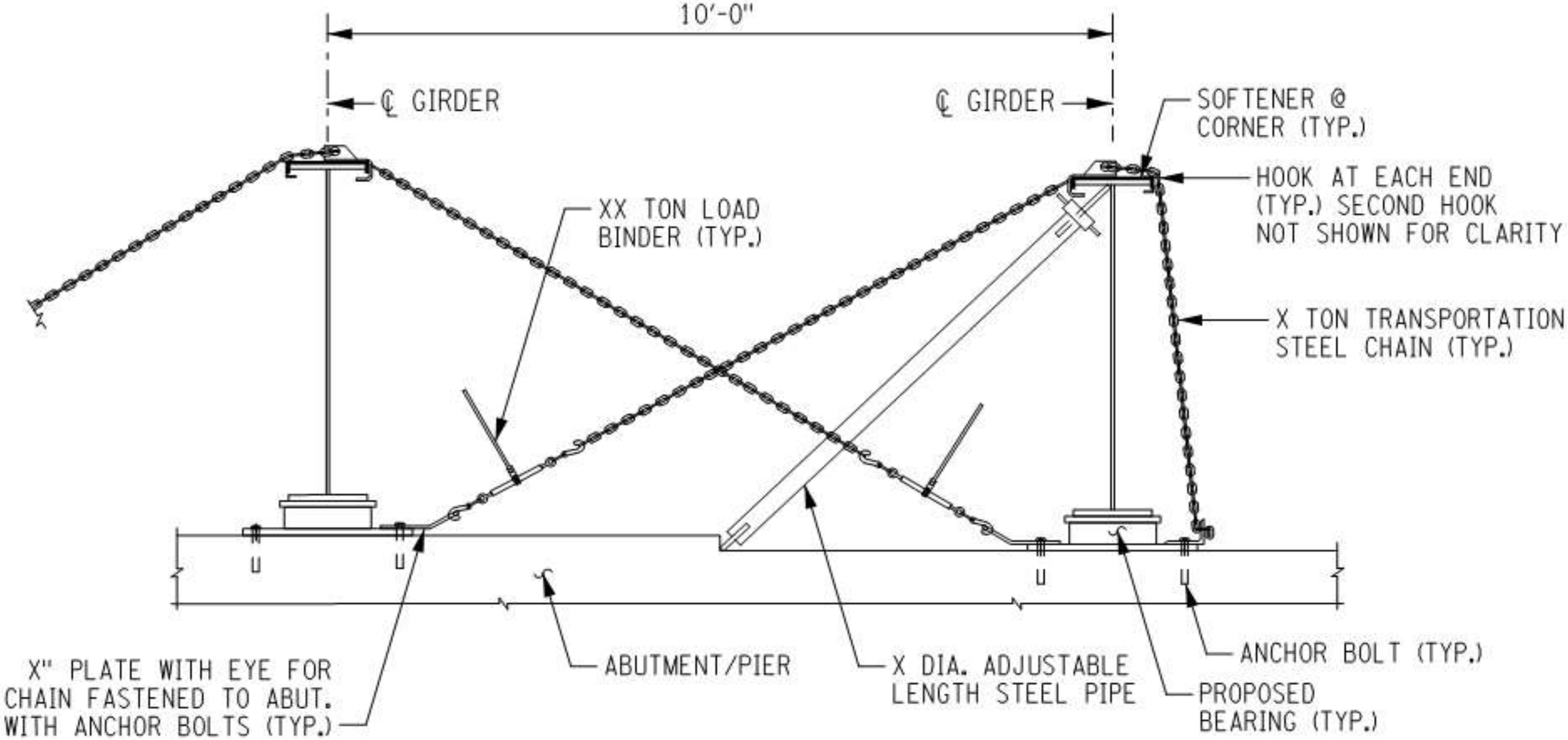
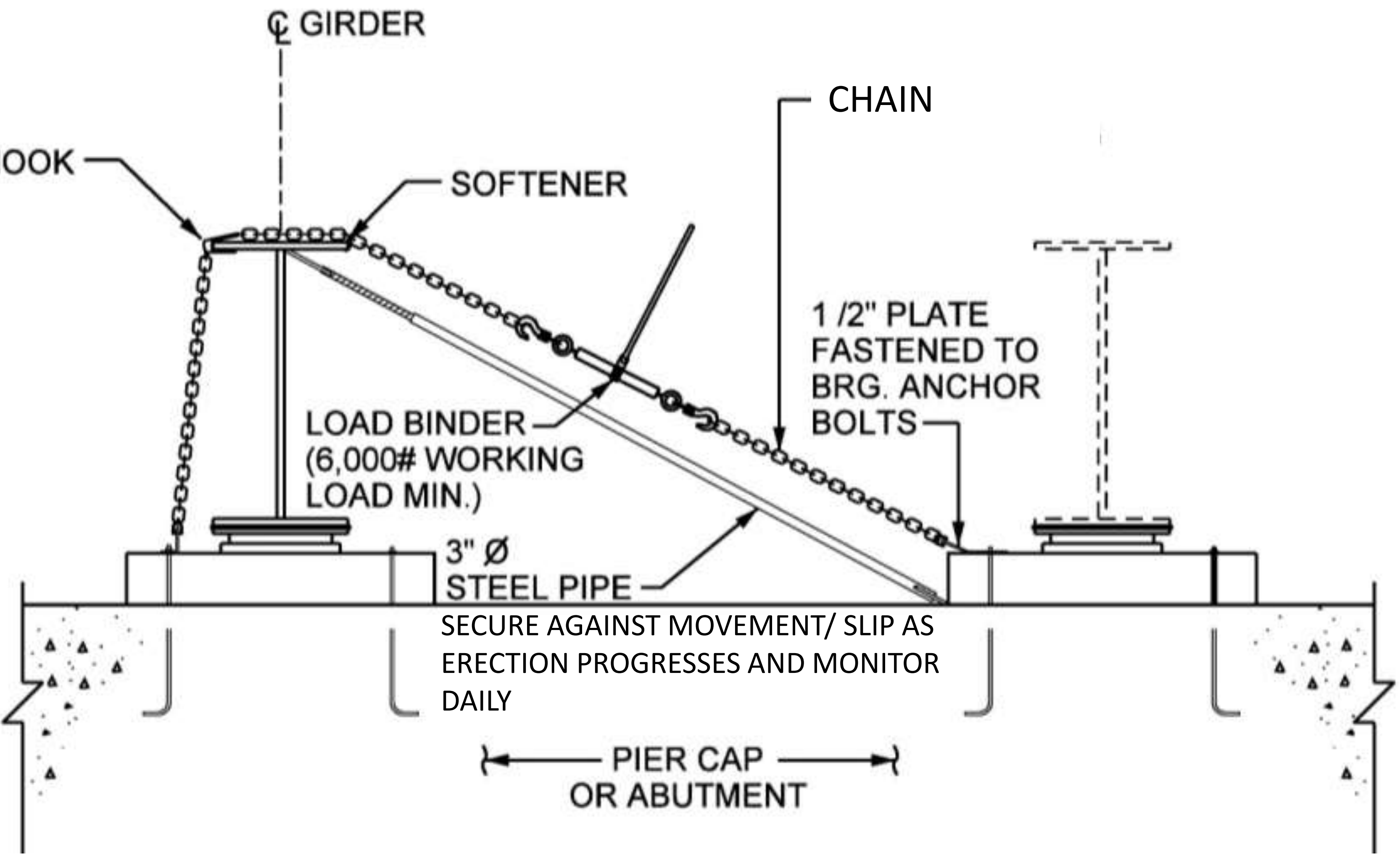
Temporary Tie Down



GIRDER TIE DOWN DETAIL 4

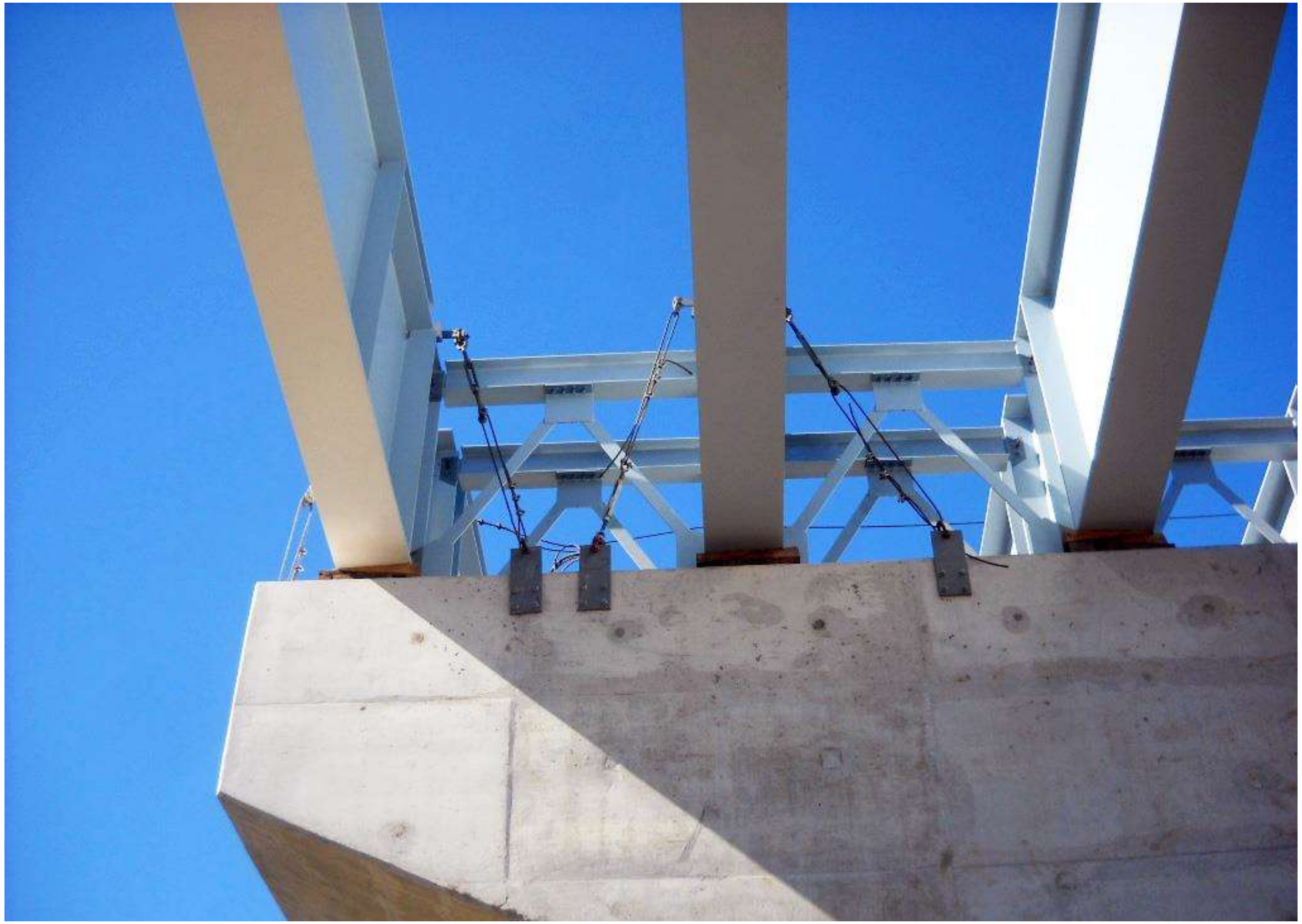
Tension Constraint Temporary Bracing



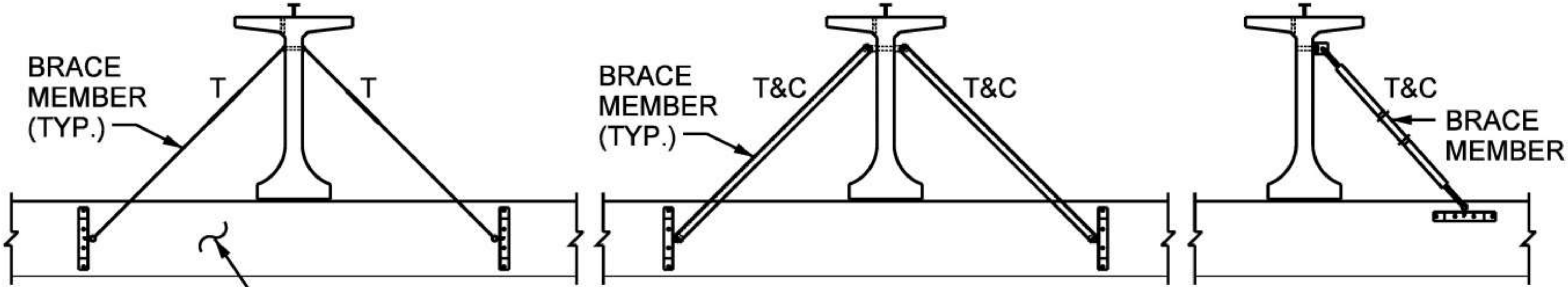
CHAIN

SECURE AGAINST MOVEMENT/ SLIP AS ERECTION PROGRESSES AND MONITOR DAILY

Girder Temporary Cable Bracing

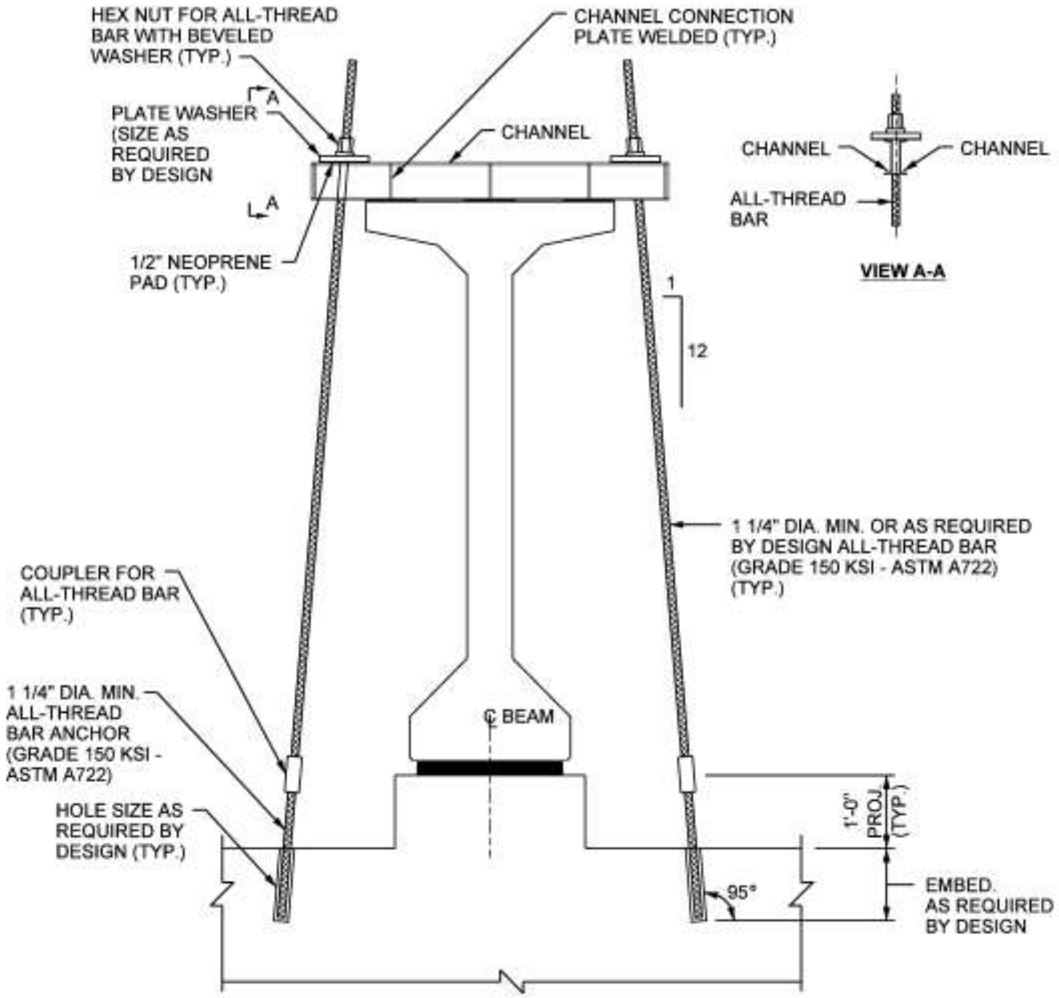


Concrete Girder Temporary Bracing



T : TENSION BRACE
C : COMPRESSION BRACE

Concrete Girder Rod Bracing to Pier



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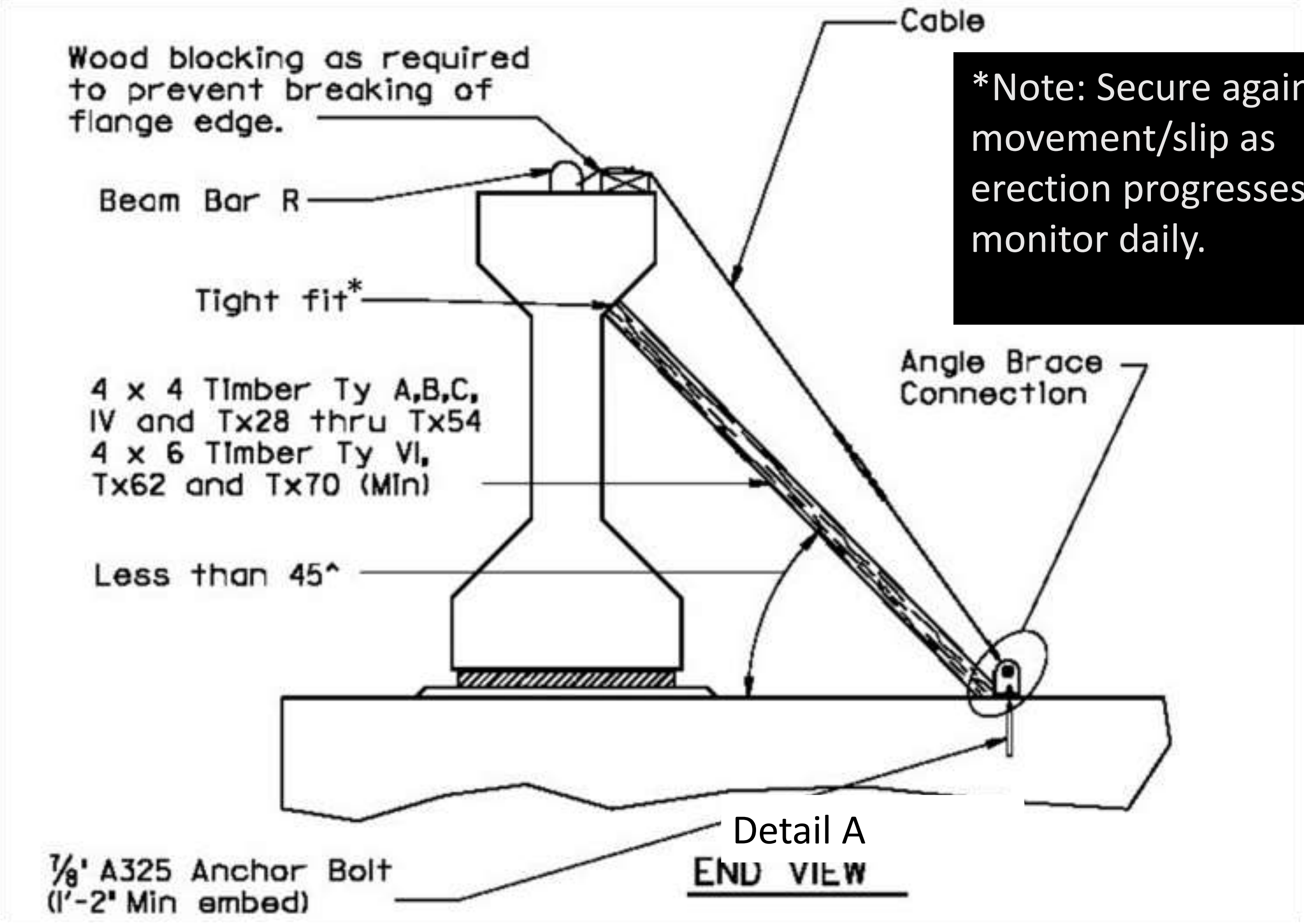
Concrete Girder Tensioning Compression Brace



*Note: Secure against movement/slip as erection progresses and monitor daily.

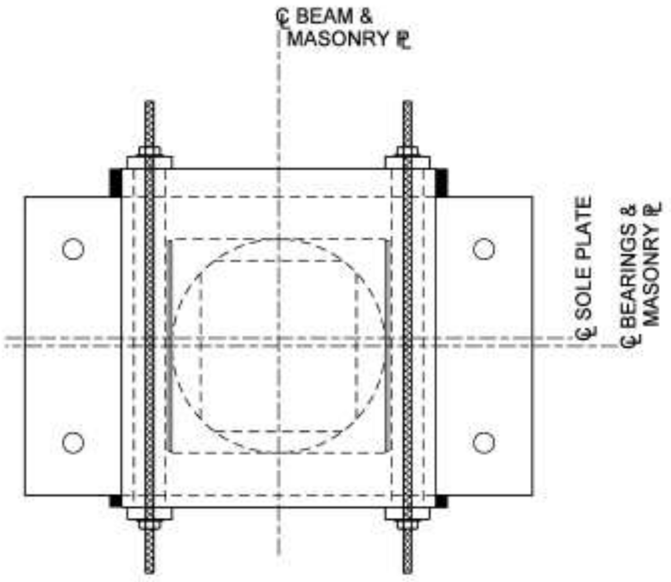
Detail A

Temporary Brace at Exterior Girders

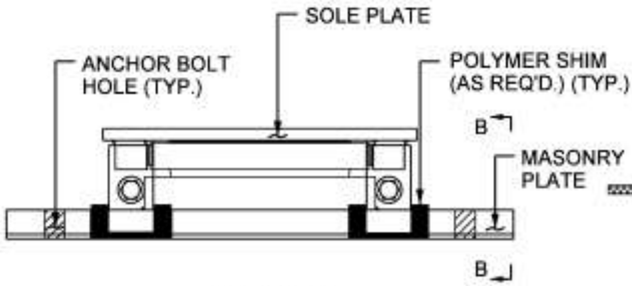
Concrete Girders X-Bracing

Multi-Rotational Bearing

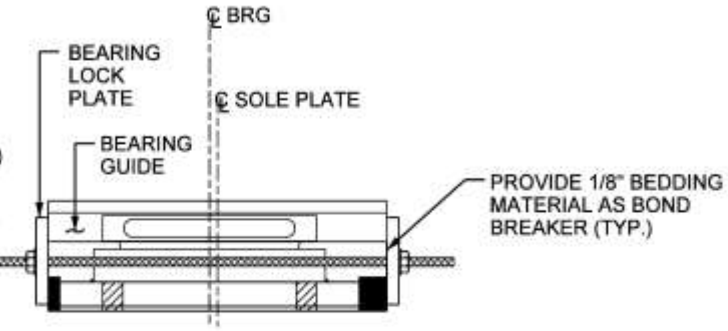
Guided Bearing Restraint



PLAN-LOCK INSTALLED

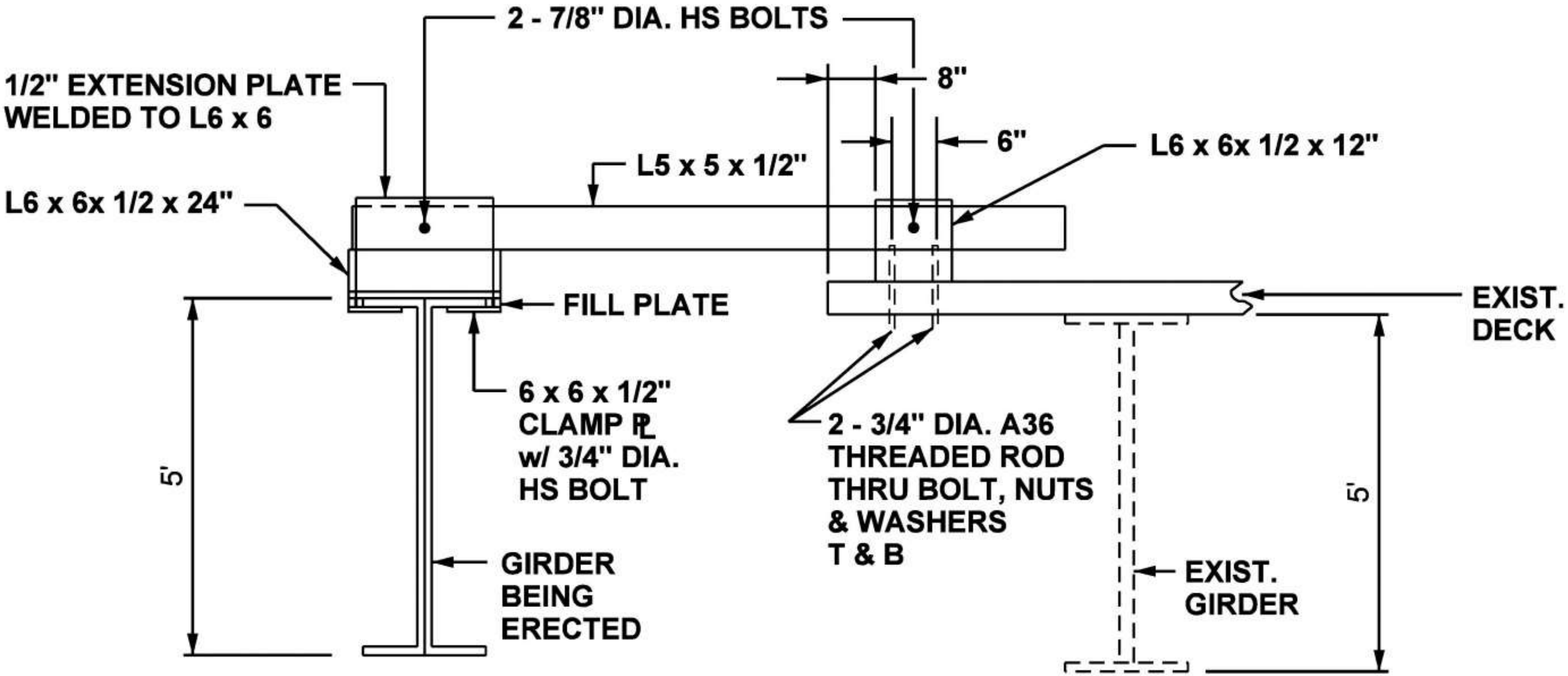


ELEVATION



SECTION B-B

Phased Construction Lateral Brace



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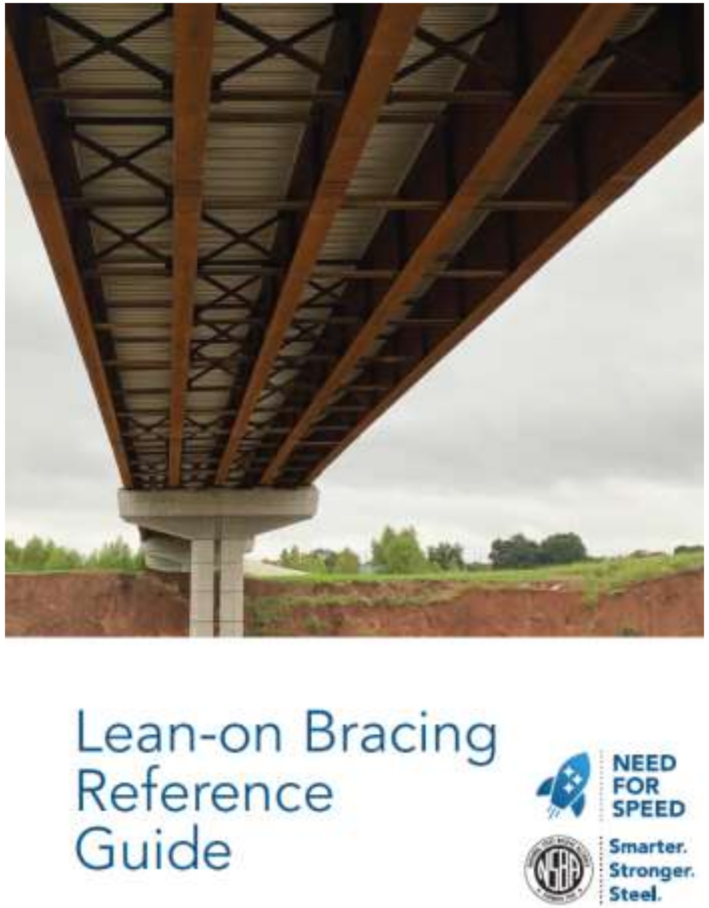
Temporary Lean-on Brace

Lean-on Bracing … Sidebar

- Hot off the presses from NSBA
- Design guide for use of lean on bracing in permanent structures
- Provides significant economy in completed bridges

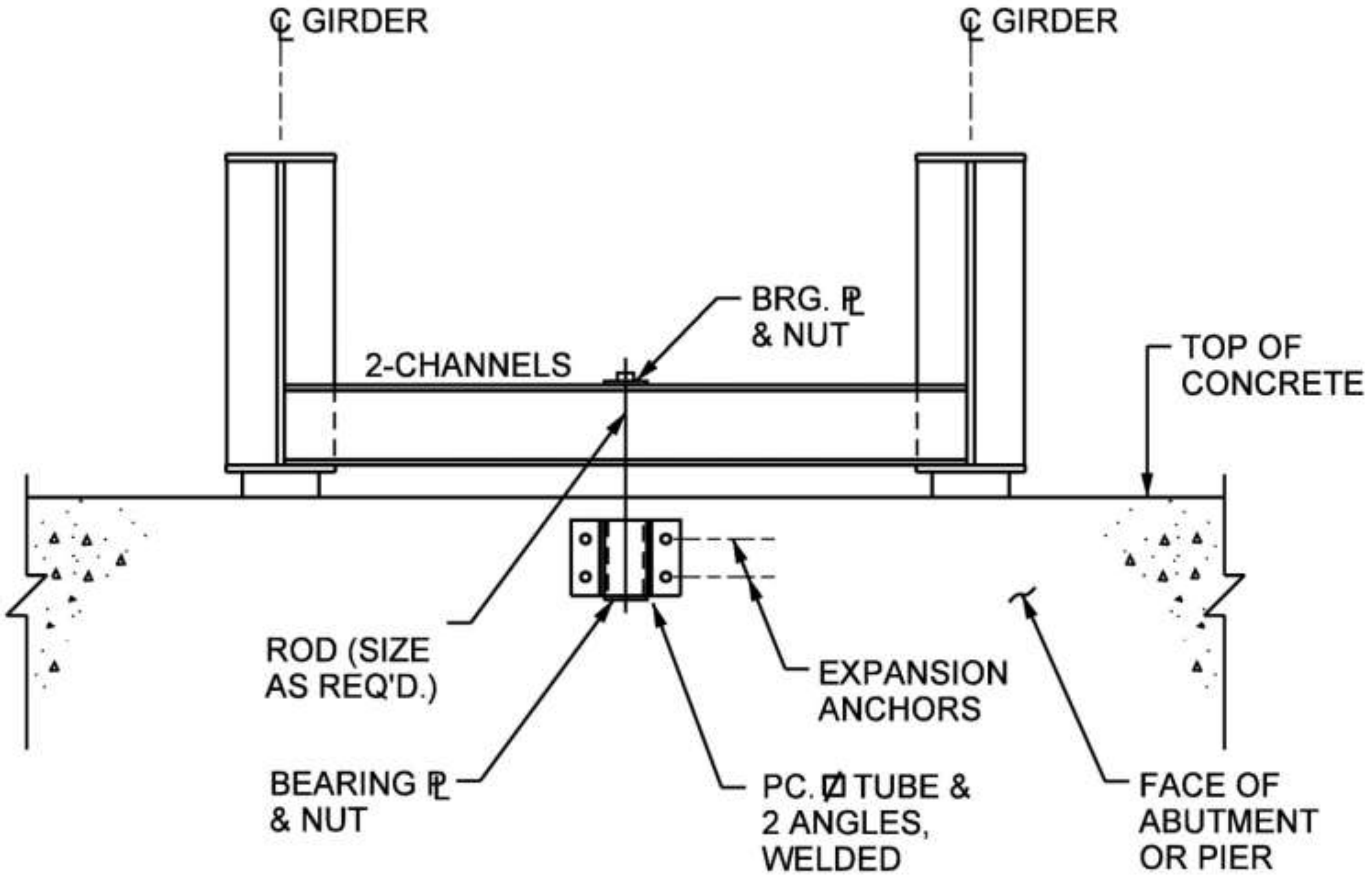


Lean-on Bracing
Reference
Guide

NEED
FOR
SPEED

Smarter.
Stronger.
Steel.

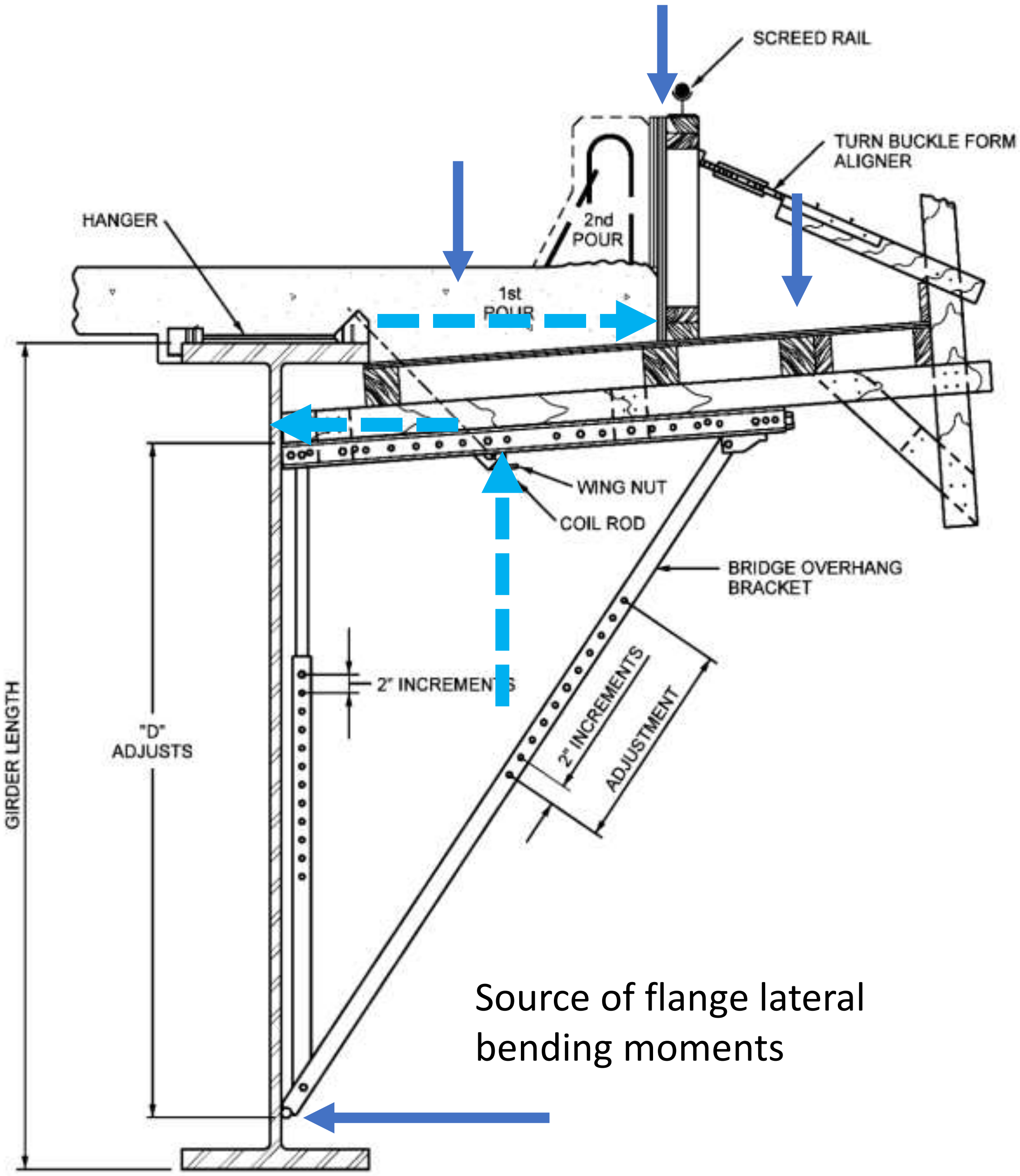
Hold-down Using a Member Supported on Bottom Flanges



Deck Concrete Placement

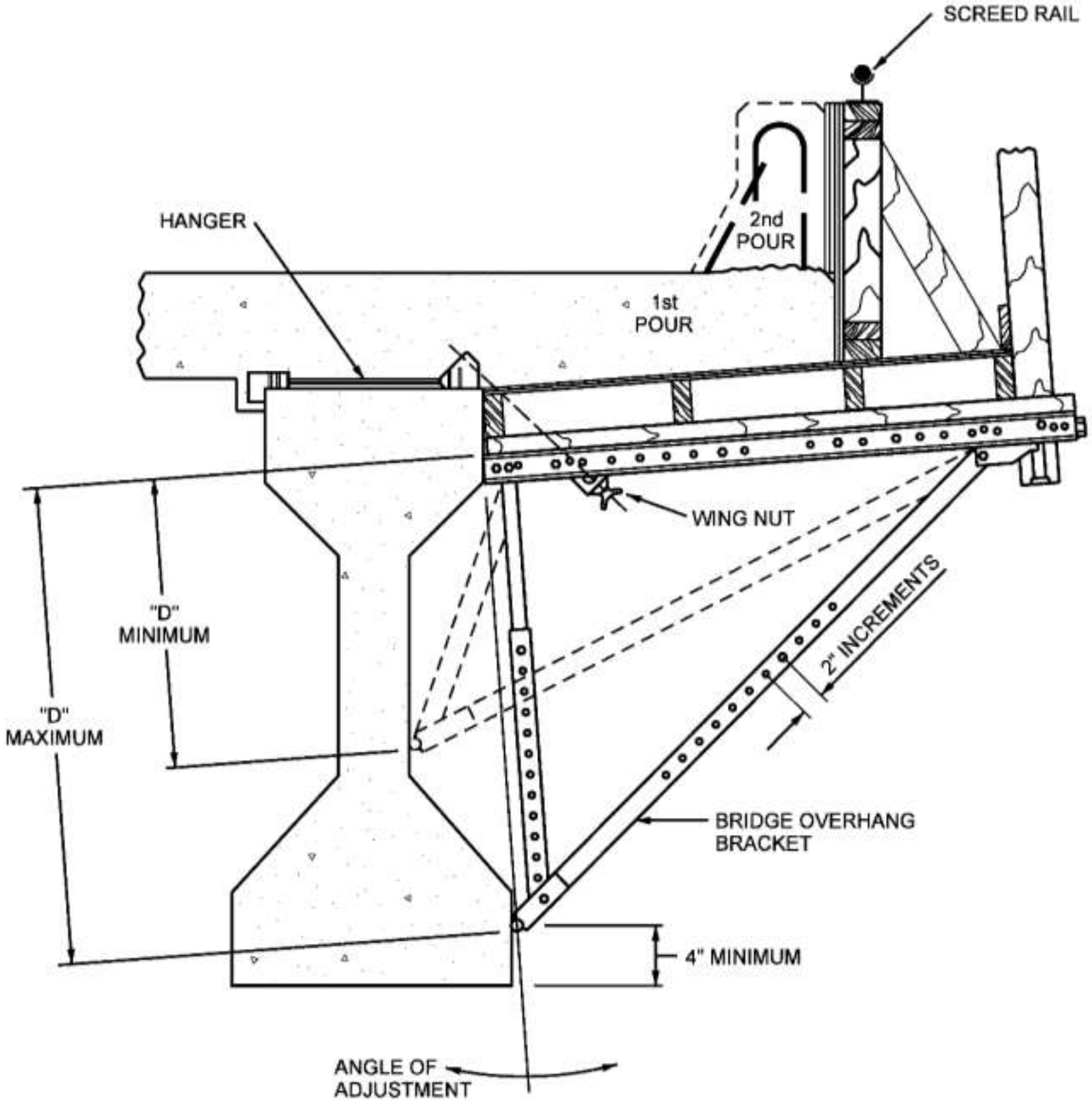
Overhang Brackets on Box Girder

Typical Bracket for Steel Girder

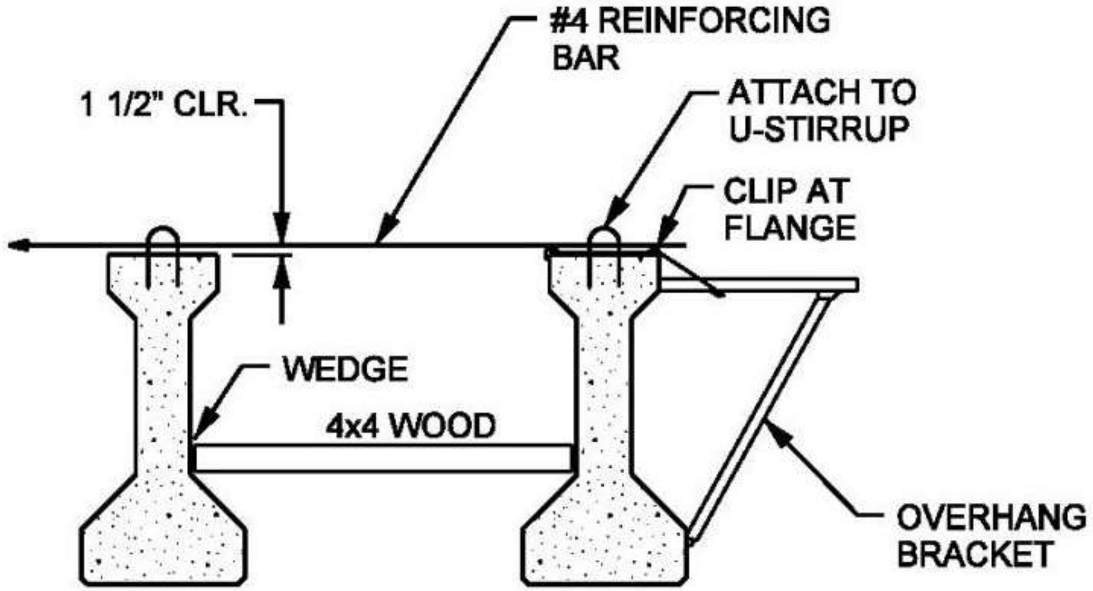


Source of flange lateral bending moments

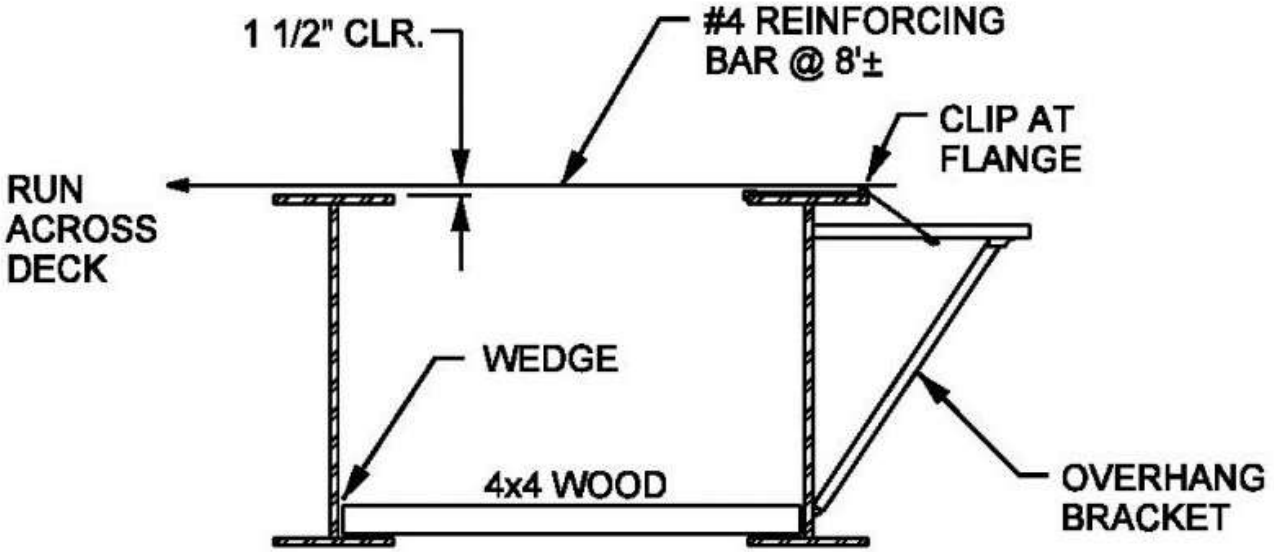
Overhang Bracket on Concrete Girder



Overhang Bracket Bracing Examples



OVERHANG BRACING - CONCRETE



OVERHANG BRACING - STEEL

System / Global Buckling Effects

Guidance for Designers

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Global Buckling Capacity in Steel Girder Systems

System (Global) Buckling Mode

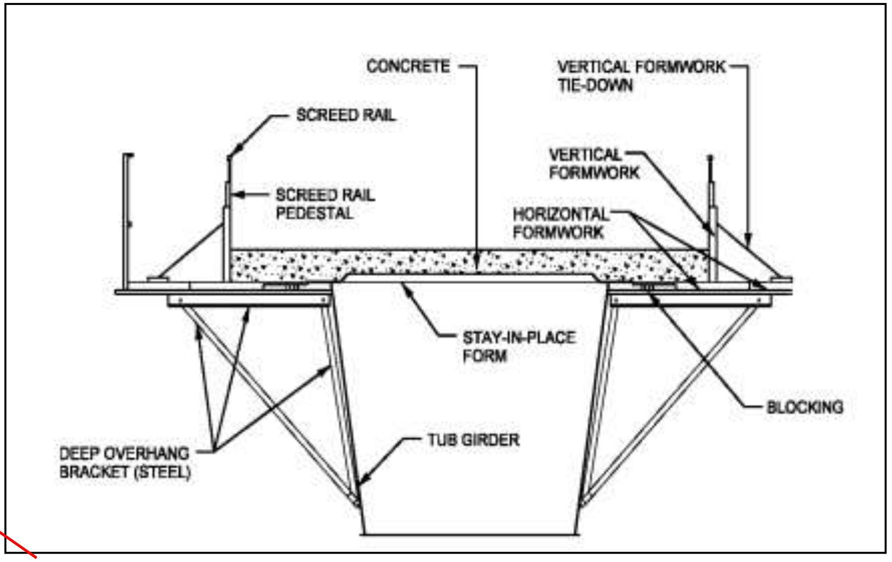
- What is the system buckling mode and how does this mode differ from conventional LTB?

Global Buckling of Narrow Steel Units

- Designer uses unbraced length L_b for girder buckling
  - L_b = distance between cross-frames
  - Cross-frame locations are brace points (**more on this later**)
- Girder systems with large length-to-width ratio
  - Susceptible to system mode of buckling
  - Spacing of cross-frames does not impact behavior significantly in system mode

History of Global (System) Buckling

- Marcy Pedestrian Bridge (2002) – consisted of a single box girder with no top lateral truss.
- Girder had closely spaced internal K-frames (behaved very similar to a twin I-girder system)



Girder failed due to buckling

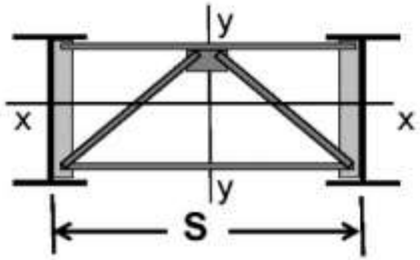
History of Global (System) Buckling

Contractor concerns about excessive lateral flexibility

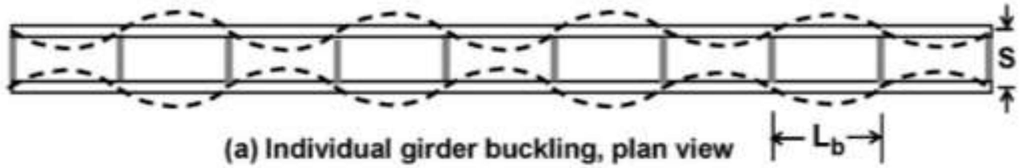
3 Span Continuous Girders (135.5′-184.7′-203.9′)

Global Buckling of Narrow Steel Units

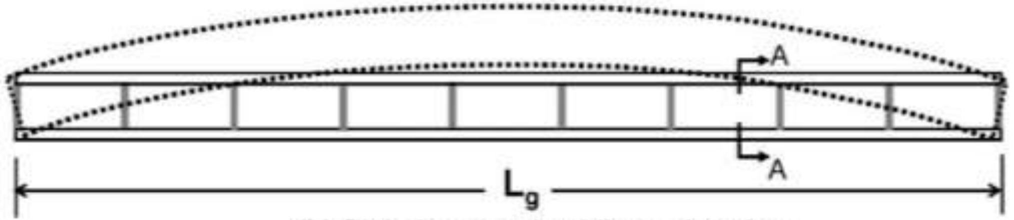
- For a twin-girder system: L_b vs. L_g
    - Bracing spacing controls individual girder lateral-torsional buckling
    - Bracing size and spacing doesn't control system buckling



(c) System cross section A-A

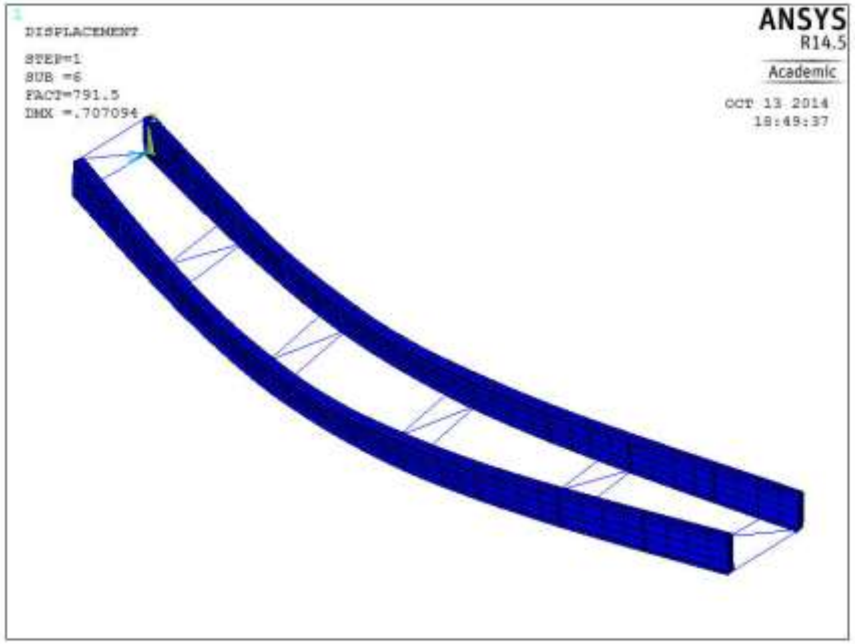


(a) Individual girder buckling, plan view

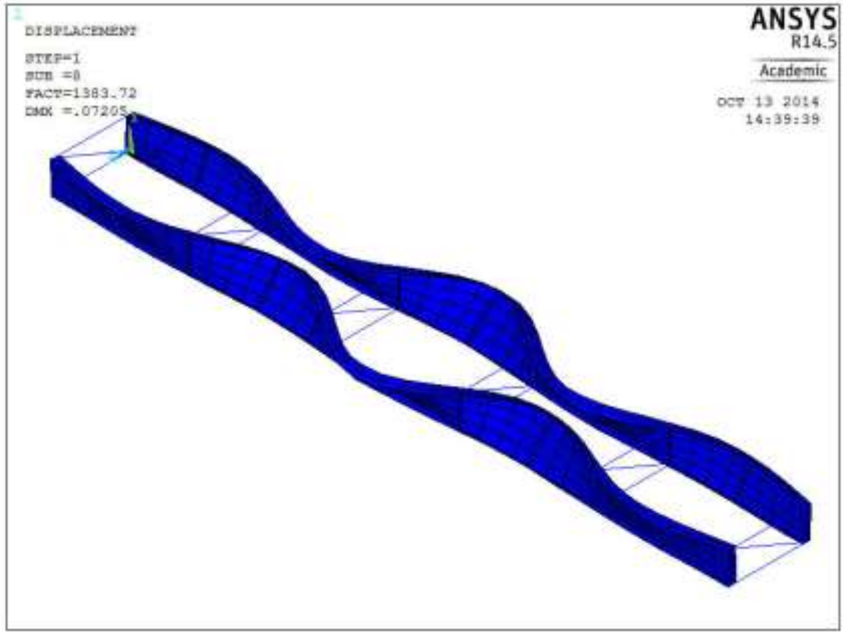


(b) Global system buckling , plan view

Global Buckling of Narrow Steel Units



Global Buckling
(M_{cr} = 792 k-ft)



Buckling Between Cross-Frames (M_{cr} = 1384 k-ft)

System Buckling for 2 and 3 Girder Systems

AASHTO Eqn. 6.10.3.4.2-1:

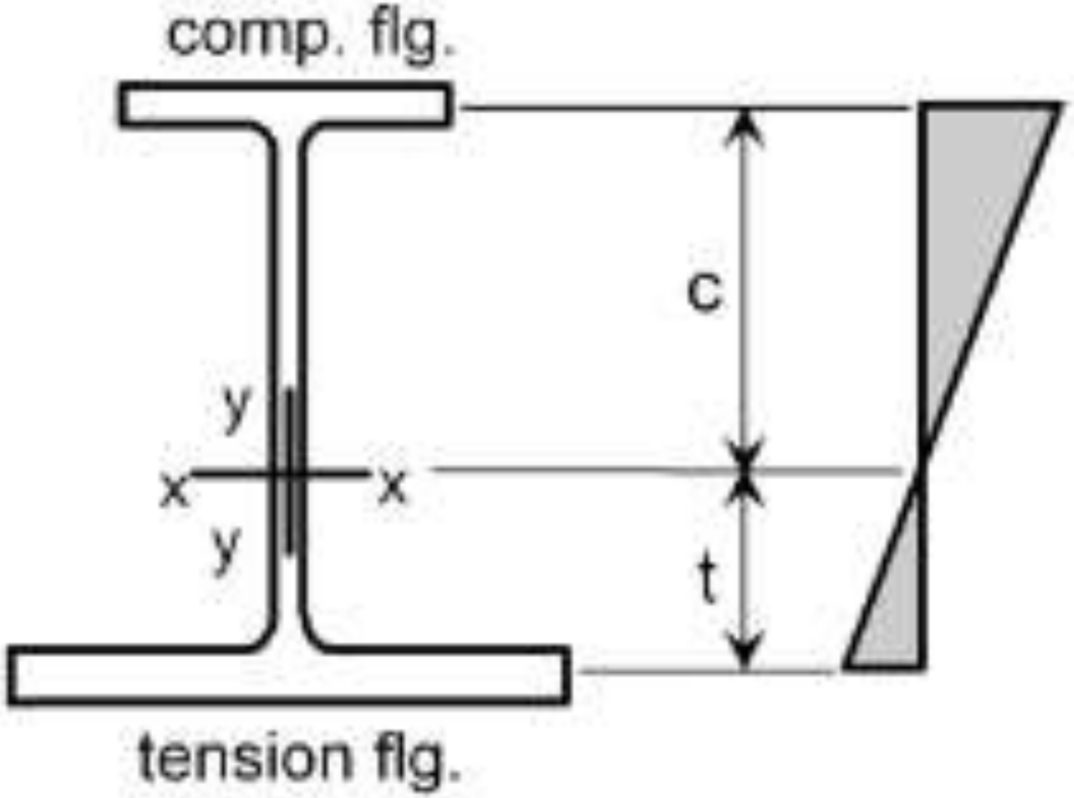
$$M_{gs} = C_{bs}\frac{\pi^2 w_g E}{L^2}\sqrt{I_{eff} I_x}$$

- Where:
  - Mgs = nominal buckling resistance of the **girder system** (k-in)
  - w_g= spacing of twin girders (in) or for 3 girder system use spacing between the two exterior girders
  - E = modulus of elasticity of steel girder (ksi)
  - L = length of span under consideration (in)

System Buckling for 2 and 3 Girder Systems

- Where:
  - C_{bs} = system moment gradient modifier
    = 1.1 for simply-supported units
    = 2.0 for continuous-span units
  - Ix = Non-composite single girder strong-axis moment of inertia
  - For non-prismatic girder properties – AASHTO recommends a length-weighted average for Ix, and $Ieff$.

Effective Moment of Inertia



$$I_{eff} = I_{yc} + (t/c) I_{yt}$$

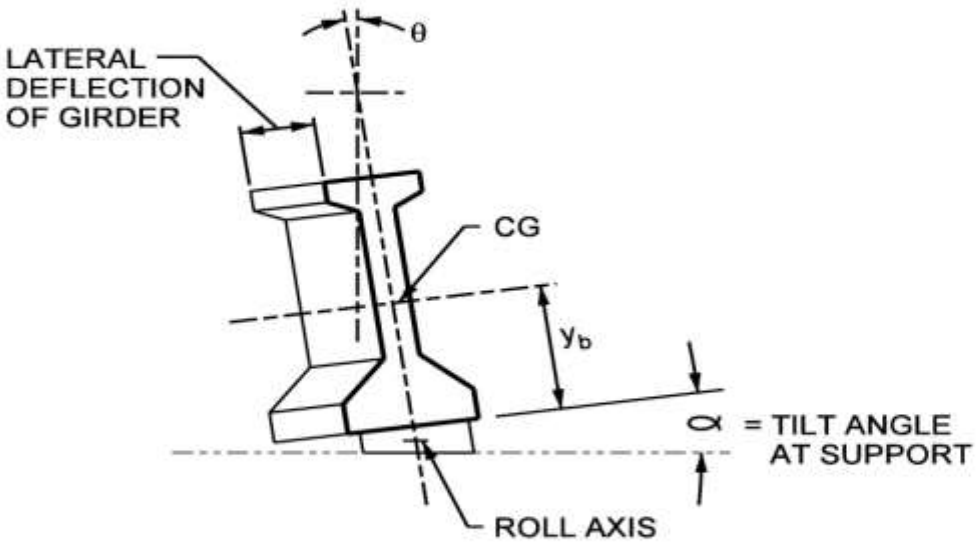
Global Buckling of Narrow Steel Units

- Considering all of the girders across the width of the unit within the span, the sum of the largest total factored moments during deck placement should not exceed 70% of Mgs.
- Alternatives:
  - Add flange level lateral bracing
  - Revise the unit to increase system stiffness
  - Evaluate the amplified girder second-order displacements and verify they are within Owner-specified tolerances
  - Amplification can also occur under steel-only dead load as the buckling limit is approached

Roll Stability of Concrete Girders

Rollover Causes

- Initial girder rotation compounded by:
  - Lack of flatness of PPC bottom flange
  - Roll flexibility of bearings…
  - Leading to increased girder rotation



Note: Figure adapted from Mast (1993)

Red Mountain Freeway Bridge Collapse, 2007

Roll Stability of Concrete Girders

- Precast concrete girders during erection (after setting)
  - Simply supported condition (span = bearing-to-bearing)
  - Deck not poured yet (erection in progress)
  - No continuous lateral support from deck slab
  - Elastomeric bearings allow rotation about both axes

Roll Stability Influences

- Bearing slope and bearing type
- Bearing skew relative to girder centerline
- Girder imperfections
- Rollover controls stability, not lateral-torsional buckling
    - PPC girders do not crack under self-weight
    - Relatively large Iy and J: no LTB

P-Δ Effect

- Rotation (imperfection) causes:
  - Component of girder weight to be…
  - Applied about weak axis of girder, which…
  - Causes lateral deflection and…
  - Further shifts girder center-of-gravity, which…
  - Causes further lateral deflection

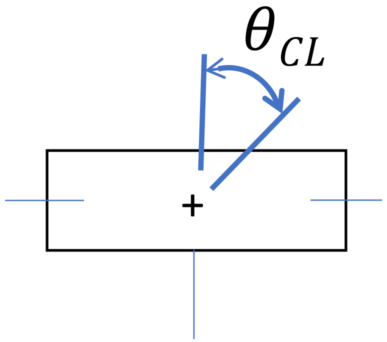
Simply-Supported Girder Rollover

- Determined primarily by support properties
- Elastomeric bearing pads
  - Rotational stiffness constant $K\theta$ (from pad's vertical stiffness)
  - Girder camber and roll effects create…
  - Uneven load distribution to bearing pad, which…
  - Reduces its stiffness (similar results from skew)

Support Properties

- For bearing pads set at skew to girder
  - Additional uneven load distribution in pad…
  - Further reduces its effective stiffness
  - Bearing stiffness modification factor accounts for skew (suggested values from FDOT):

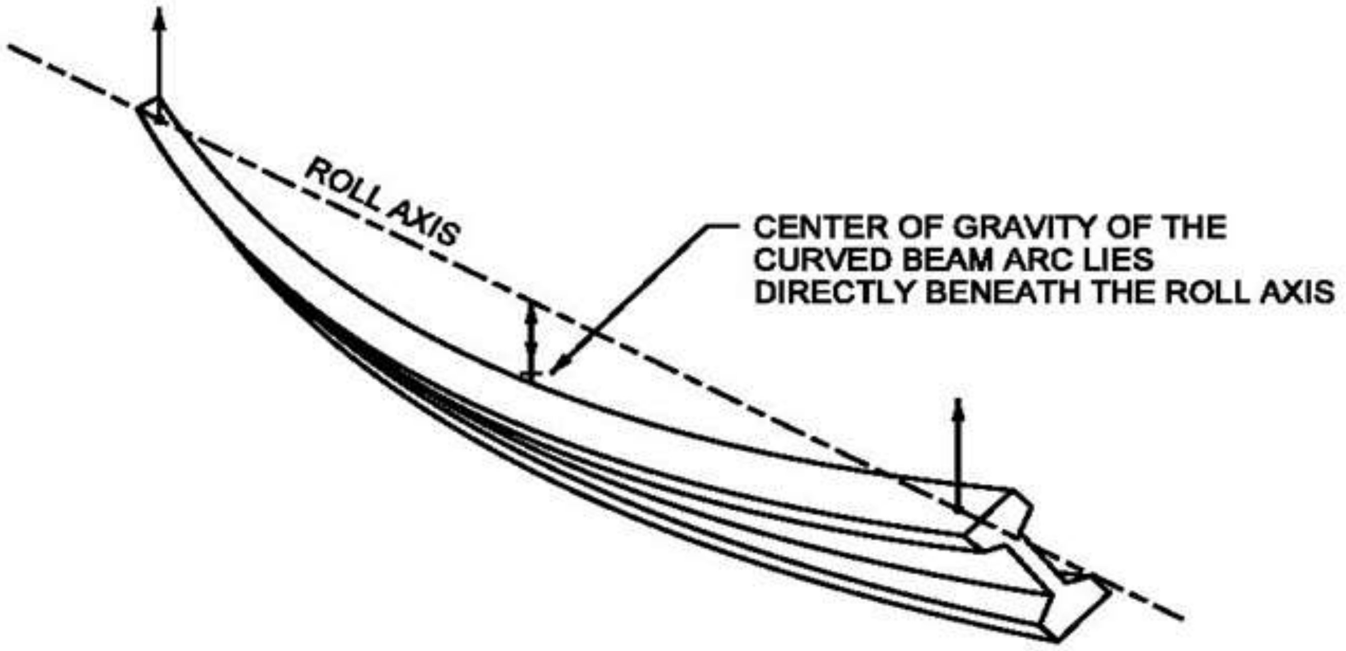
Skew Angle (º)	0	15	30	45	60
Stiffness Modifier	1	0.40	0.32	0.26	0.21



- Bearing pad stiffness not linear with load
  - Pad less stiff under girder self-weight than…
  - Normal service load combination (full dead + live)

Concrete Girder Stability During Erection Stages

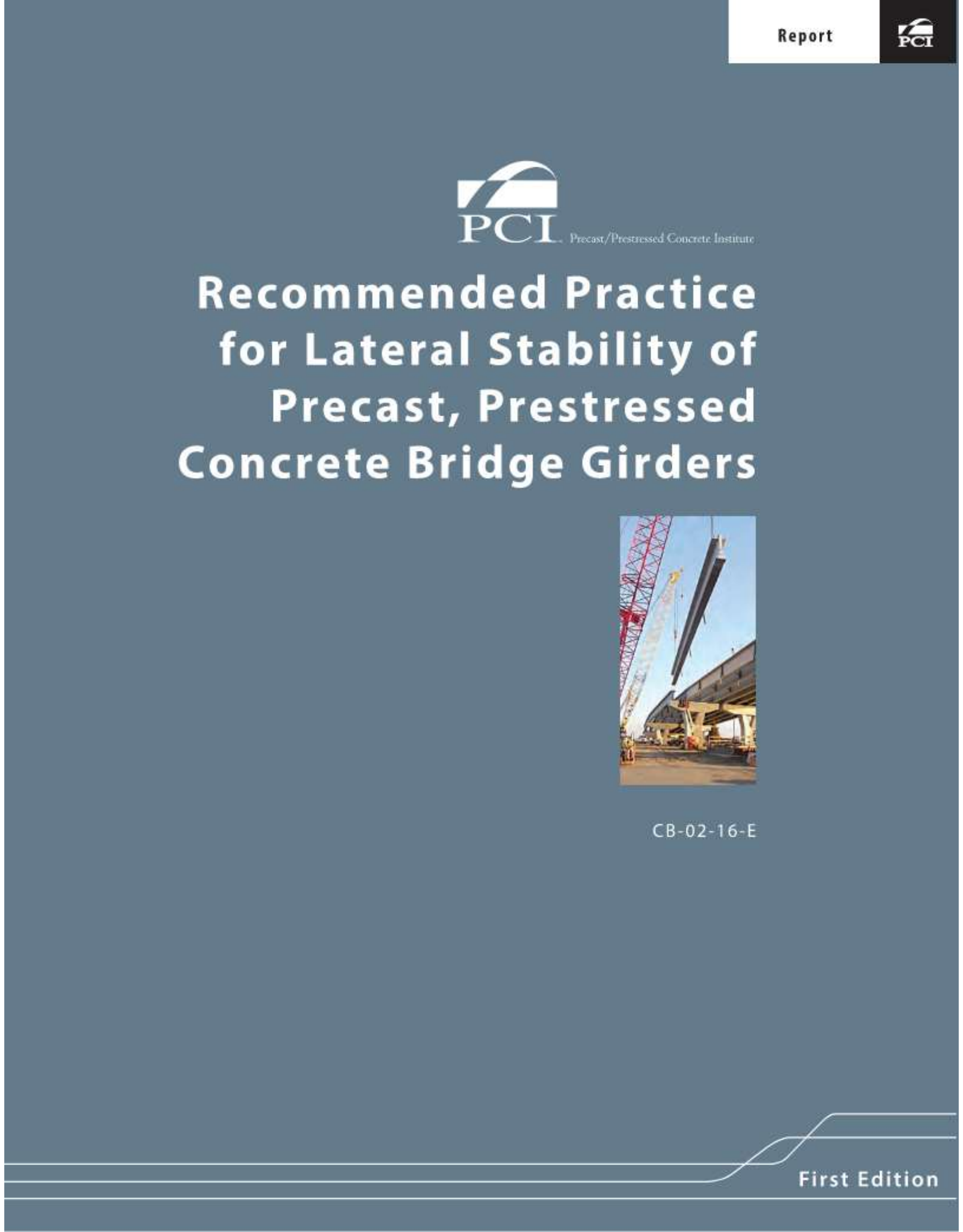
- LRFD 5.5.4.3 "*Buckling and stability of precast members during handling, transportation, and erection shall be investigated*"
- C5.5.4.3 "*This consideration does not make the designer responsible …, means and methods*" See PCI "Recommended Practice for Lateral Stability of Precast Prestressed Concrete Girders"



PERSPECTIVE OF A BEAM FREE TO ROLL AND DEFLECT LATERALLY

PCI Recommended Practices

Referenced by AASHTO as a guide for this issue



Report

PCI Precast/Prestressed Concrete Institute

Recommended Practice for Lateral Stability of Precast, Prestressed Concrete Bridge Girders

CB-02-16-E

First Edition

Girder Lifting

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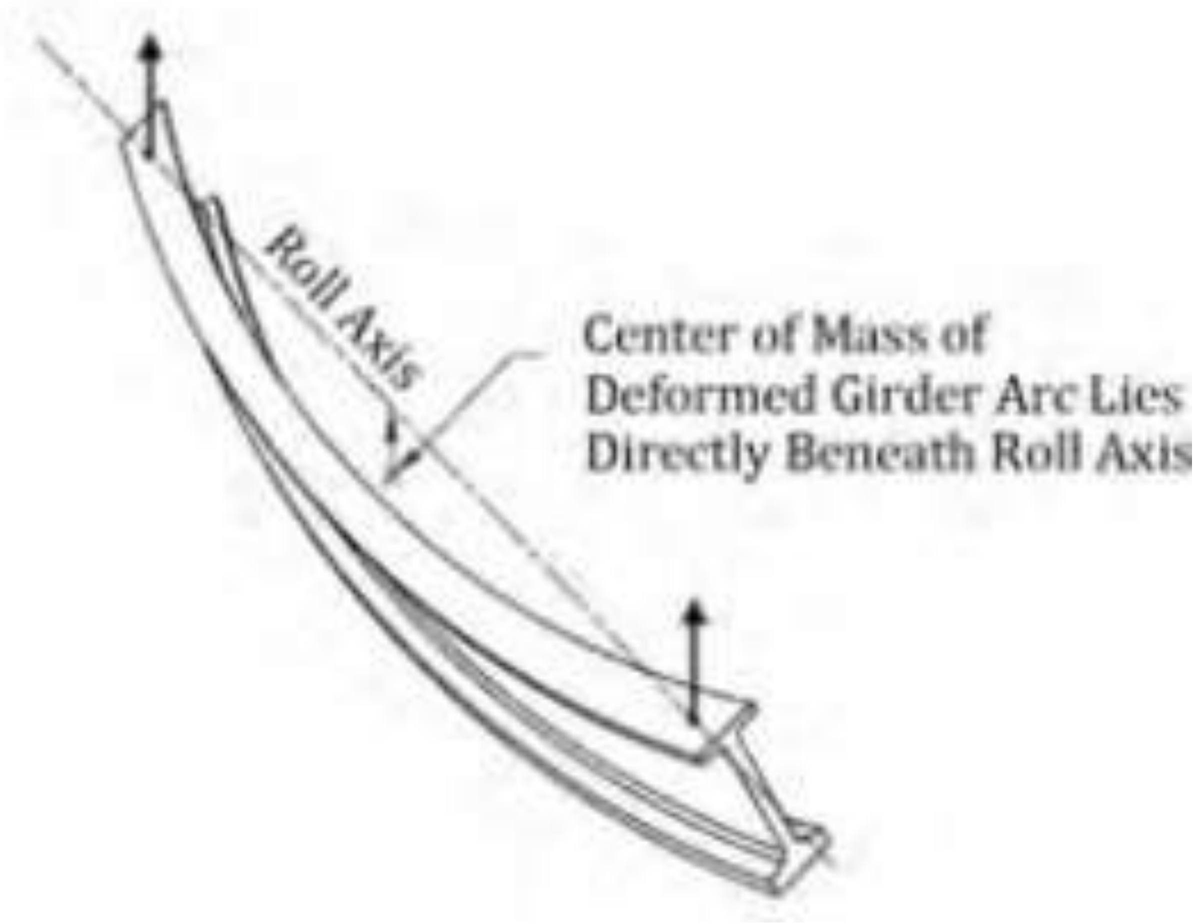
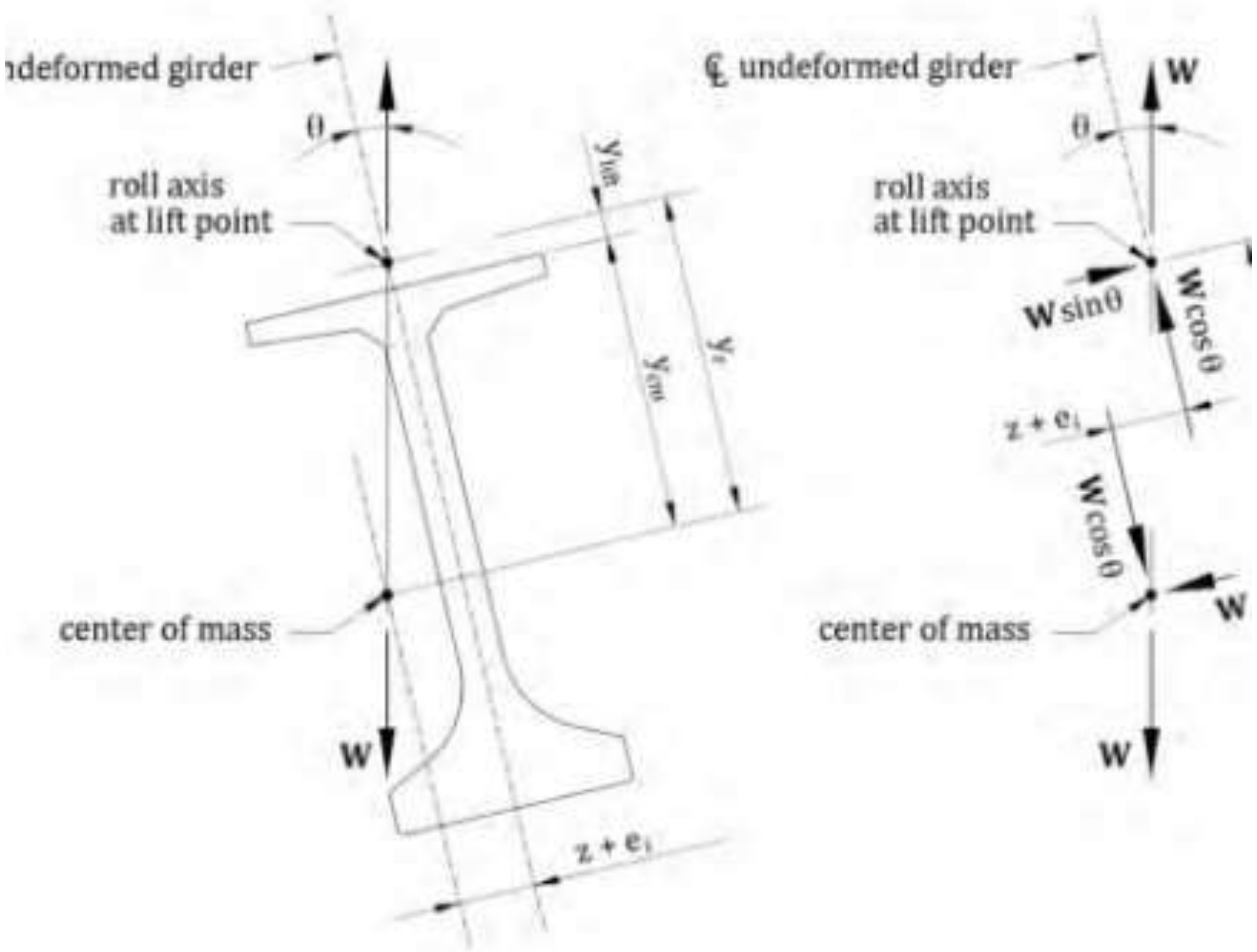
Roll Deformations

Perspective View of a Hanging Girder

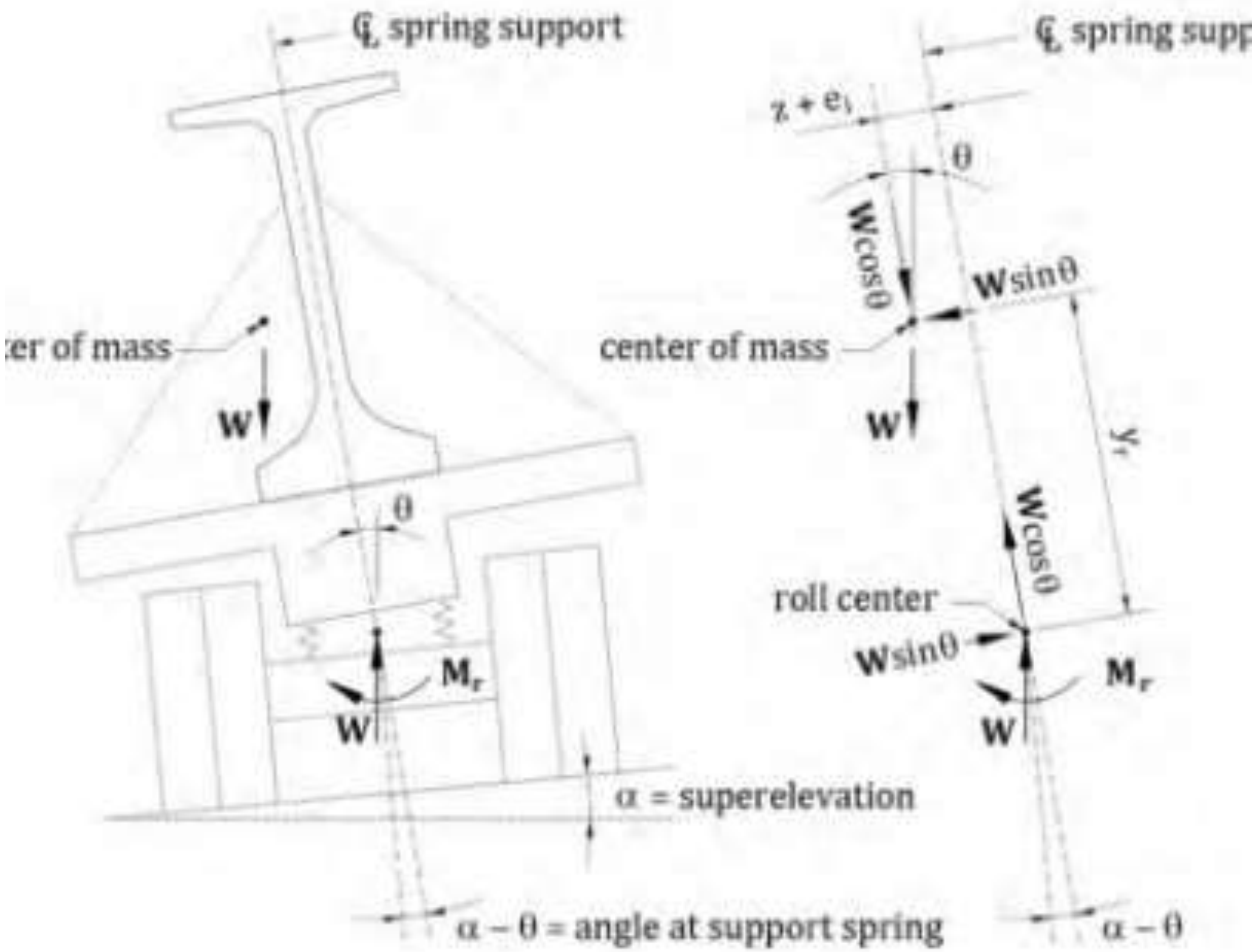


Statics of Hanging Beams

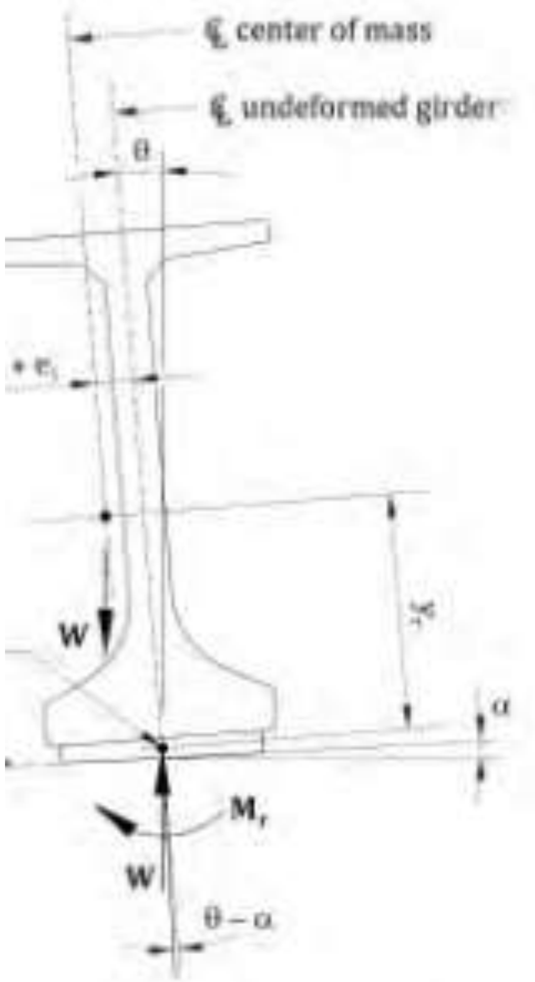


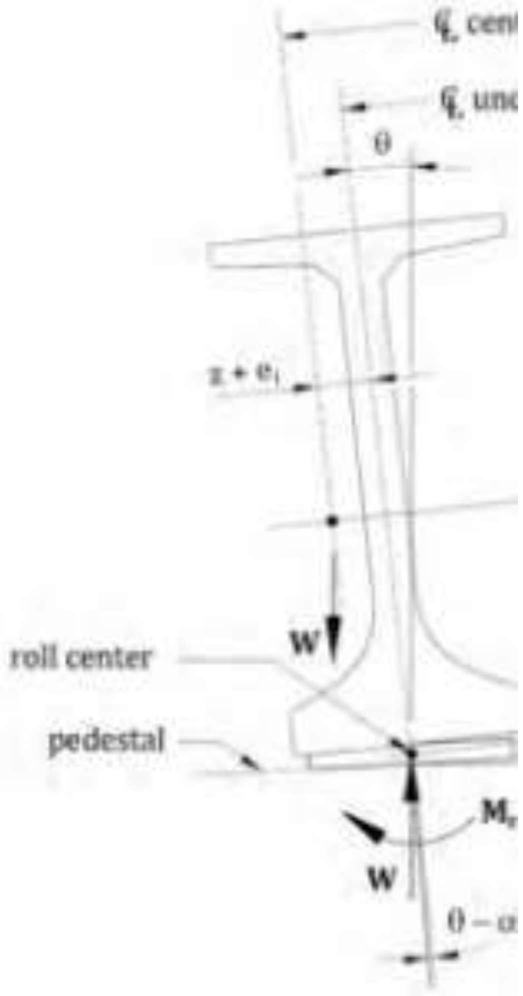
Transportation Stability

Transportation Stability



Seated Girder Stability





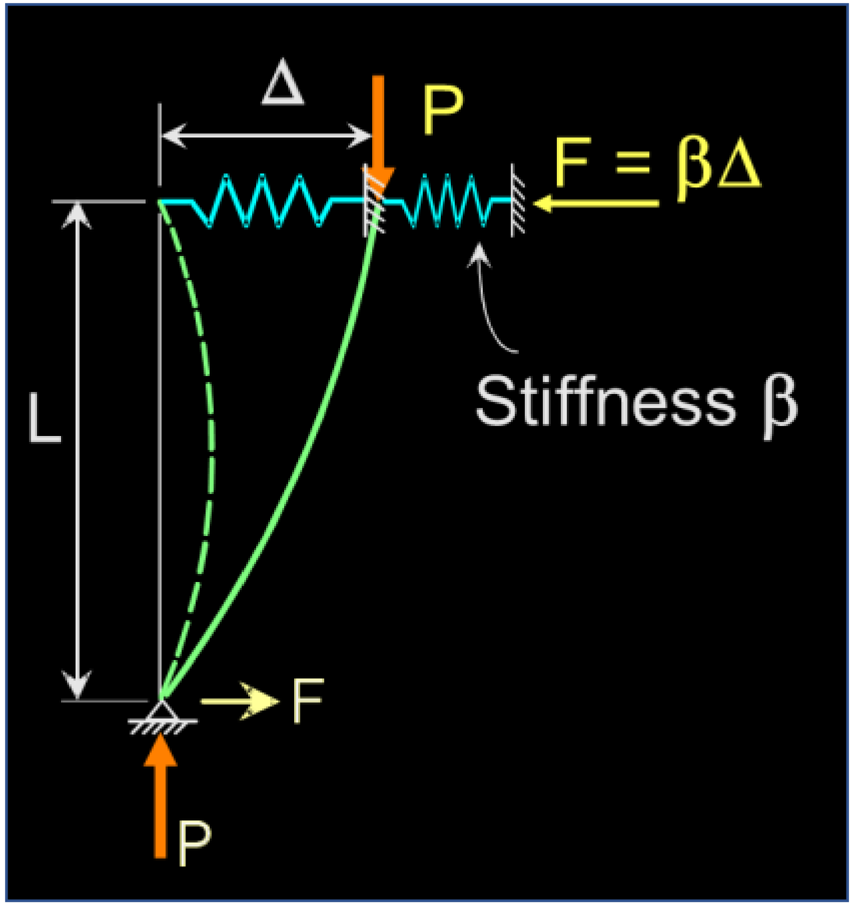
Technical Basis for Bracing Requirements

Requirements for Bracing Systems

- Bracing plays a major role in the stability of the structural system.
- Effective bracing must satisfy both **strength** and **stiffness** to have a safe system.
- Provisions outlined in the following slides allow engineers to verify the adequacy of the bracing.

Simple Stability Bracing System

- Consider the following Simple System



Summing moments about base

Equilibrium in displaced position:

$$\boldsymbol{P\Delta - (\beta\Delta)L = 0}$$

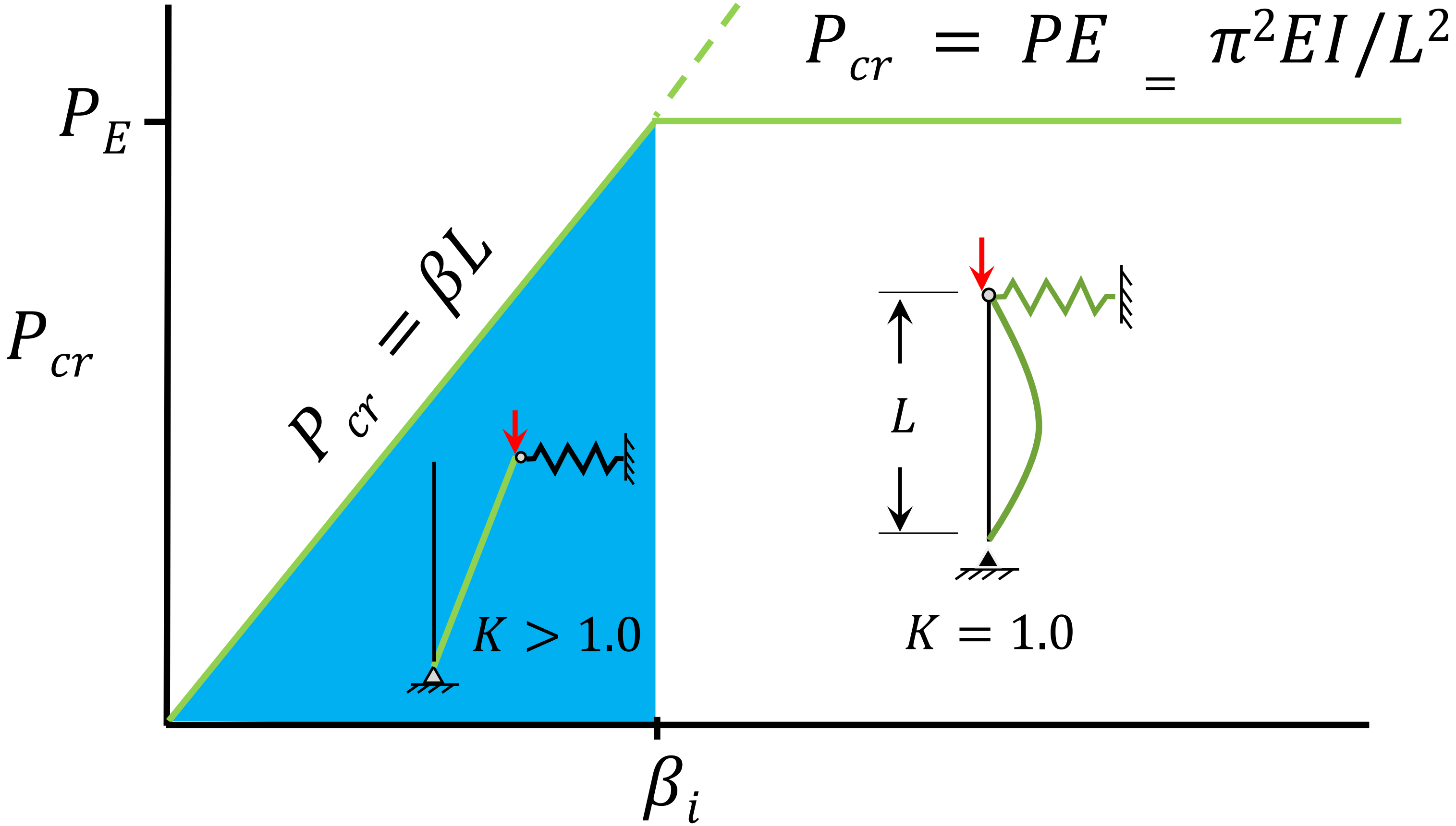
$$\boldsymbol{P\Delta = (\beta\Delta)L}$$

$\boldsymbol{\beta}\Delta L > P\Delta$ no sidesway

$\boldsymbol{\beta}\Delta L < P\Delta$ sidesway

$$\boldsymbol{\beta}L = P_{\boldsymbol{cr}}$$

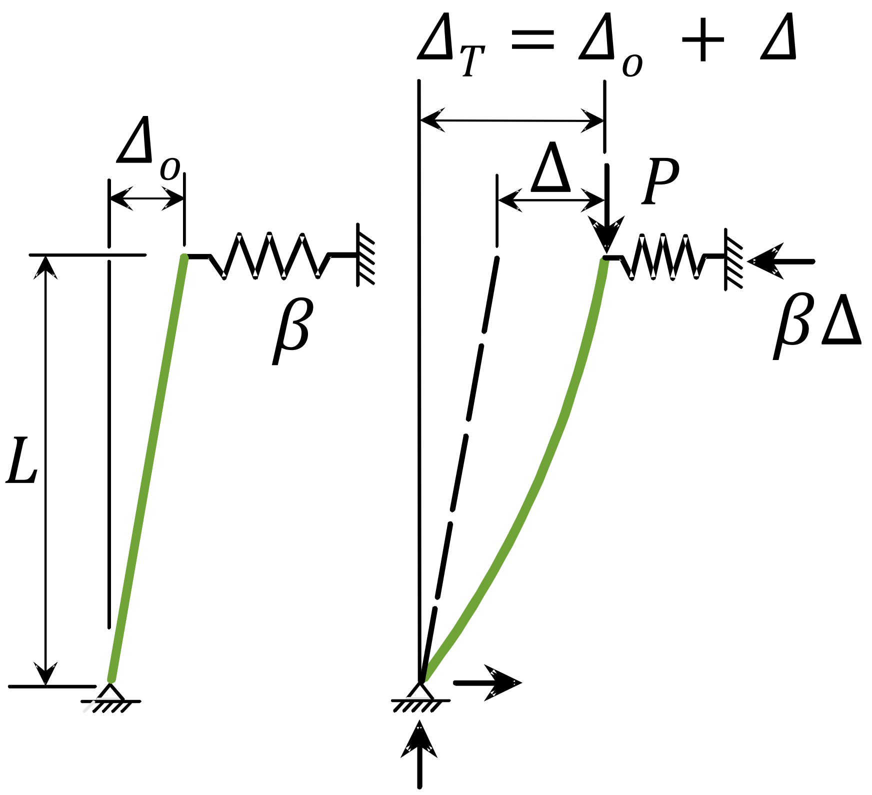
Ideal Brace Stiffness



Ideal Brace Stiffness

$$\beta_i = PE/L$$

Real Columns – Brace Stiffness



No Axial Load

Axial Load Applied

Equilibrium:

$$P\Delta_T = (\beta\Delta)L = \beta L(\Delta_T - \Delta_o)$$

$$\Delta_T = \frac{\Delta_o}{1 - \frac{P}{\beta L}}$$

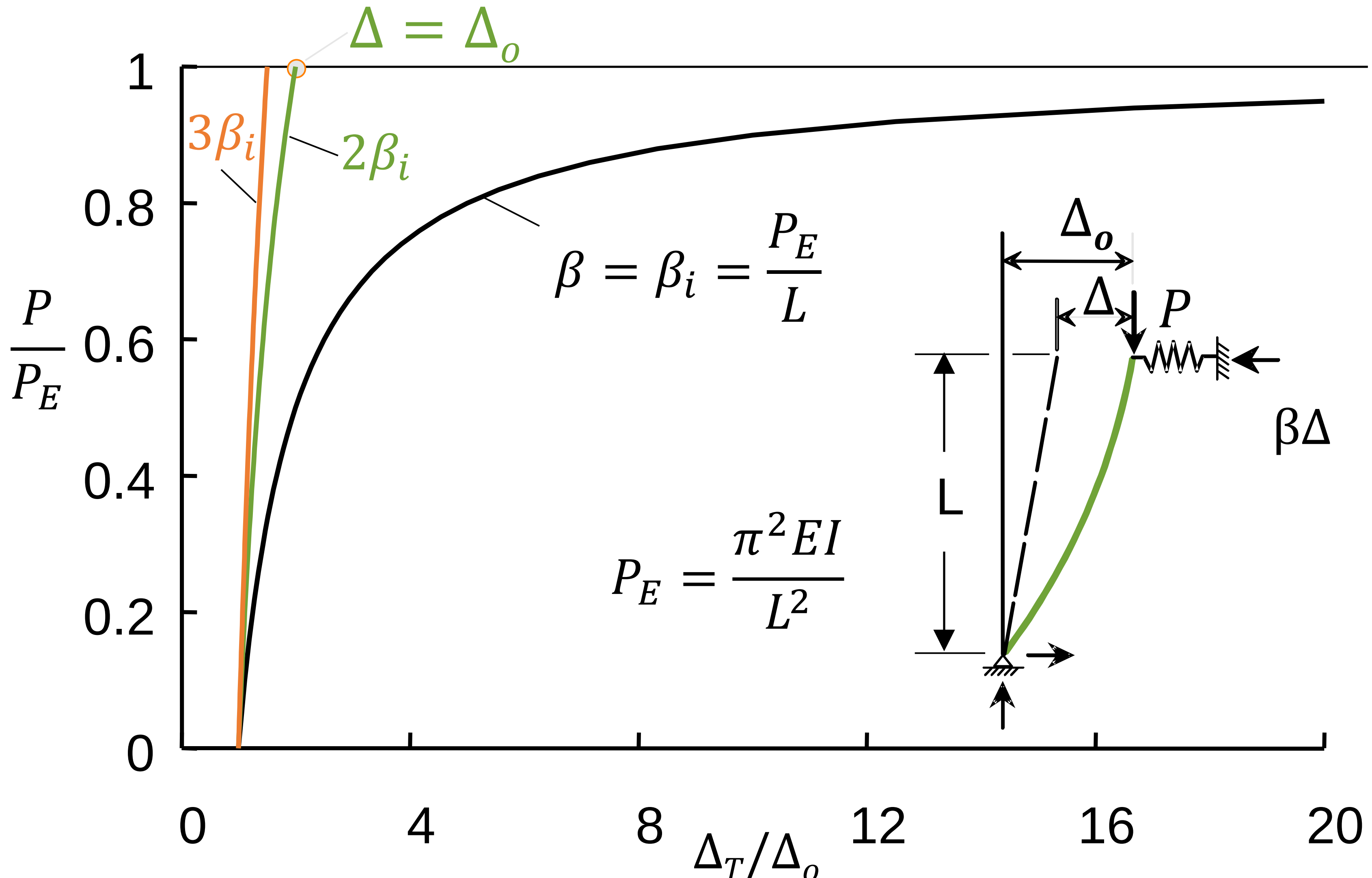
If $\beta = \beta_i = PE/L$:

$$\Delta_T = \frac{\Delta_o}{1 - \frac{P}{P_E}}$$

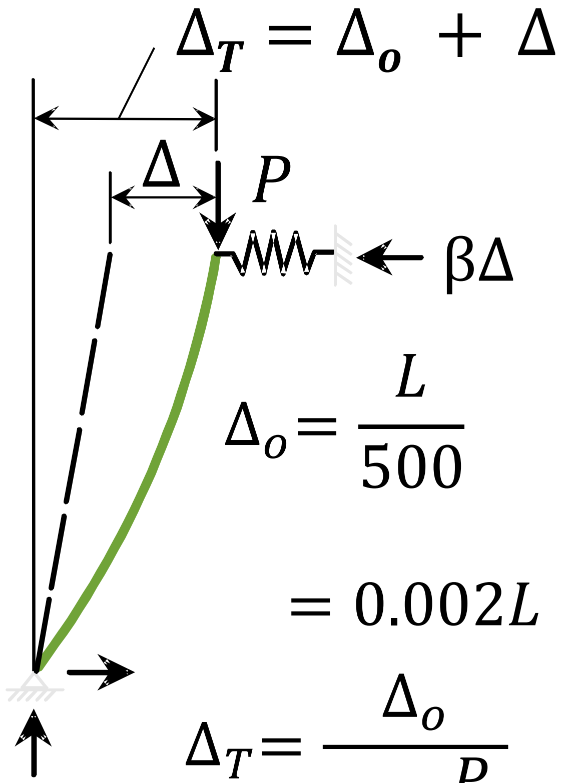
If $\beta = 2\beta_i = 2PE/L$:

$$\Delta_T = \frac{\Delta_o}{1 - \frac{P}{2P_E}}$$

Real Columns – Brace Stiffness



Real Columns – Brace Strength



$$\Delta_o = \frac{L}{500}$$

$$= 0.002L$$

$$\Delta_T = \frac{\Delta_o}{1 - \frac{P}{\beta L}}$$

$$F_{br} = (\beta\Delta)$$
$$= \beta(\Delta_T - \Delta_o)$$

$$F_{br} = \beta\left(\frac{\Delta_o}{1 - \frac{P}{\beta L}} - \Delta_o\right) = \beta\Delta_o\left(\frac{\frac{P}{\beta L}}{1 - \frac{P}{\beta L}}\right)$$

For Δ_o=0.002L:

$$\frac{F_{br}}{P} = \left(\frac{0.002}{1 - \frac{P}{\beta L}}\right)$$

If $\beta = \beta_i = PE/L$:

$$\frac{F_{br}}{P} = \left(\frac{0.002}{1 - \frac{P}{P_E}}\right)$$

If $\beta = 2\beta_i = 2PE/L$:

$$\frac{F_{br}}{P} = \left(\frac{0.002}{1 - \frac{P}{2P_E}}\right)$$

$$F_{br} = 0.004P \; at \; P = PE$$

AISC Bracing Design Provisions

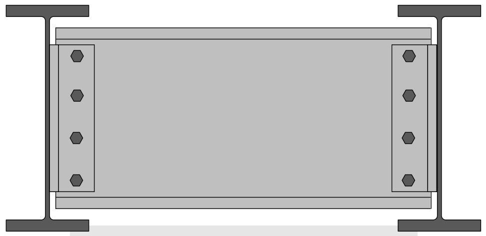
Torsional Bracing of Beams

The fundamental concept with torsional bracing is:

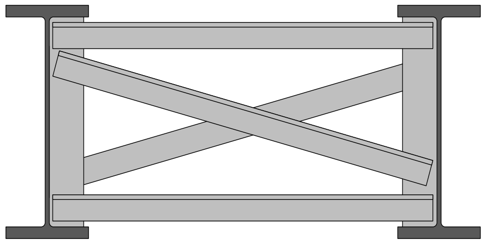
The beam or girder is fully braced at a location if twist is prevented.

Stiffness requirement

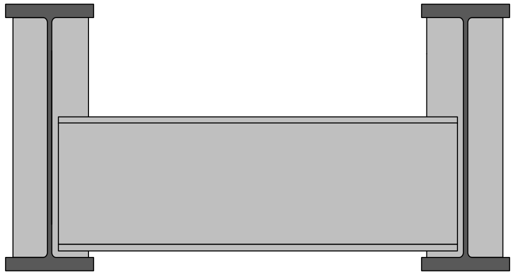
$$(\beta_T)_{act} \geq (\beta_T)_{req}$$



Diaphragms



Cross-Frames



Through-Girders

Torsional Stability Bracing Requirements

Stiffness requirement

$$(\beta_T)_{act} \geq (\beta_T)_{req}$$

- Actual (provided by the brace) > Required (to stabilize a beam to carry a certain moment, for a given span, and with certain section properties)

AISC Provisions – Required Stiffness

- AISC Bracing Provisions: Stiffness Requirements for Nodal Torsional Bracing – Equation A-6-11a:

L = Span of beam/girder

M_u = Maximum factored moment w/in unbraced length L_b

ϕ_{br}= Bracing stiffness resistance factor = 0.80

n= Number of intermediate bracing lines

C_b= Moment gradient factor

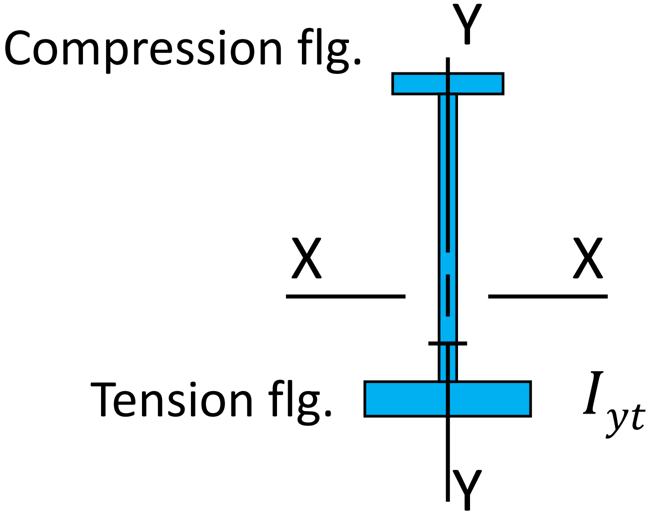
E = Modulus of elasticity of beam

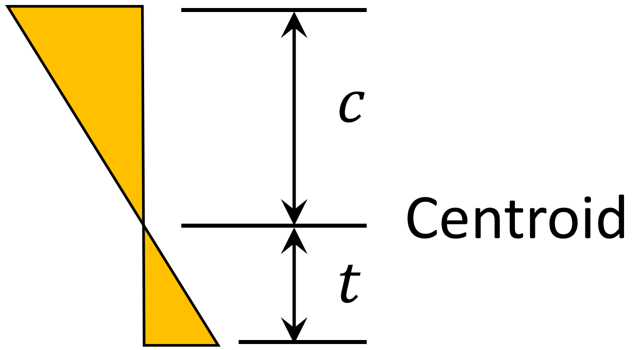
I_{yeff} = Effective moment of inertia (see next slide)

$$\boxed{\beta_T = \frac{2.4LM_u^2}{\phi_{br}nC_b^2EI_{yeff}}}$$

AISC Provisions – Required Stiffness

Stability bracing of beams is significantly impacted by the size of the compression flange. Since bridge girders often consist of singly-symmetric sections, I_{yeff} accounts for the compression flange size versus the tension flange size:





$$I_{yeff} = I_{yc} + \frac{t}{c} I_{yt}$$

Note: $I_{yeff} = I_y$ for doubly symmetric shape

What About Provided Stiffness

- We have a springs-in-series problem
  - Crossframes have flexibility
  - They connect to connection plates which MAY have flexibility
  - They connect to girders which can deflect and rotate and thus have flexibility

Total Bracing Stiffness

- Actual torsional bracing stiffness of the entire system:

$$(\beta_T)_{act} = \frac{1}{\left(\frac{1}{\beta_b} + \frac{1}{\beta_{sec}} + \frac{1}{\beta_g}\right)}$$

Springs in series

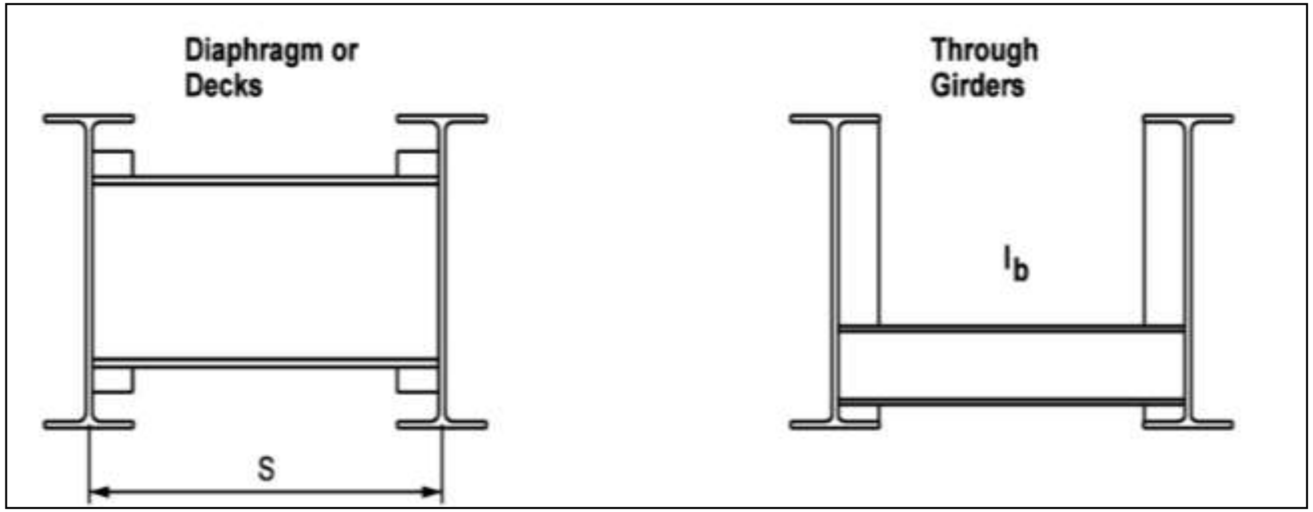
$$\frac{1}{k_{total}} = \frac{1}{\frac{1}{k1} + \frac{1}{k2} + \frac{1}{k3}}$$

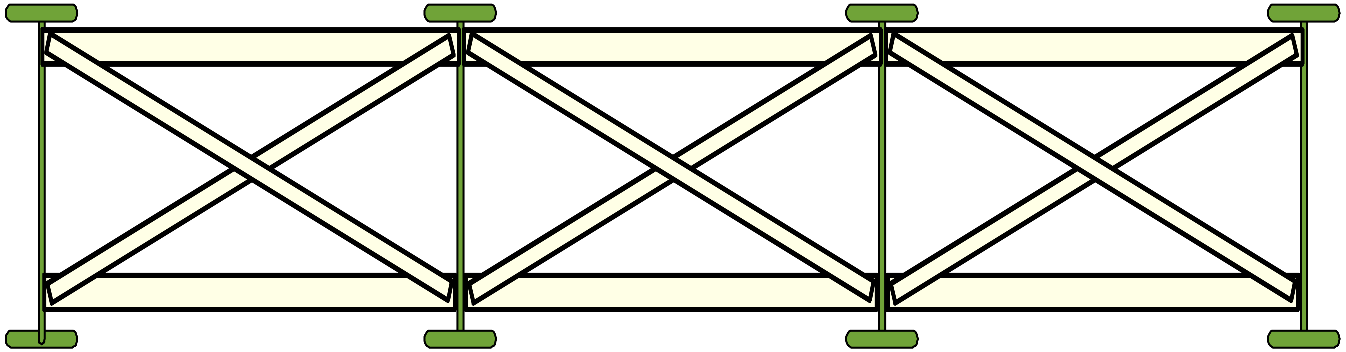
$(\beta_T)_{act}$ = Total system stiffness
β_b = Stiffness of cross-frame or diaphragm
β_{sec} = Cross-sectional stiffness (web and connection plate)
β_g = In-plane stiffness of the girder system

Cross-frame Types

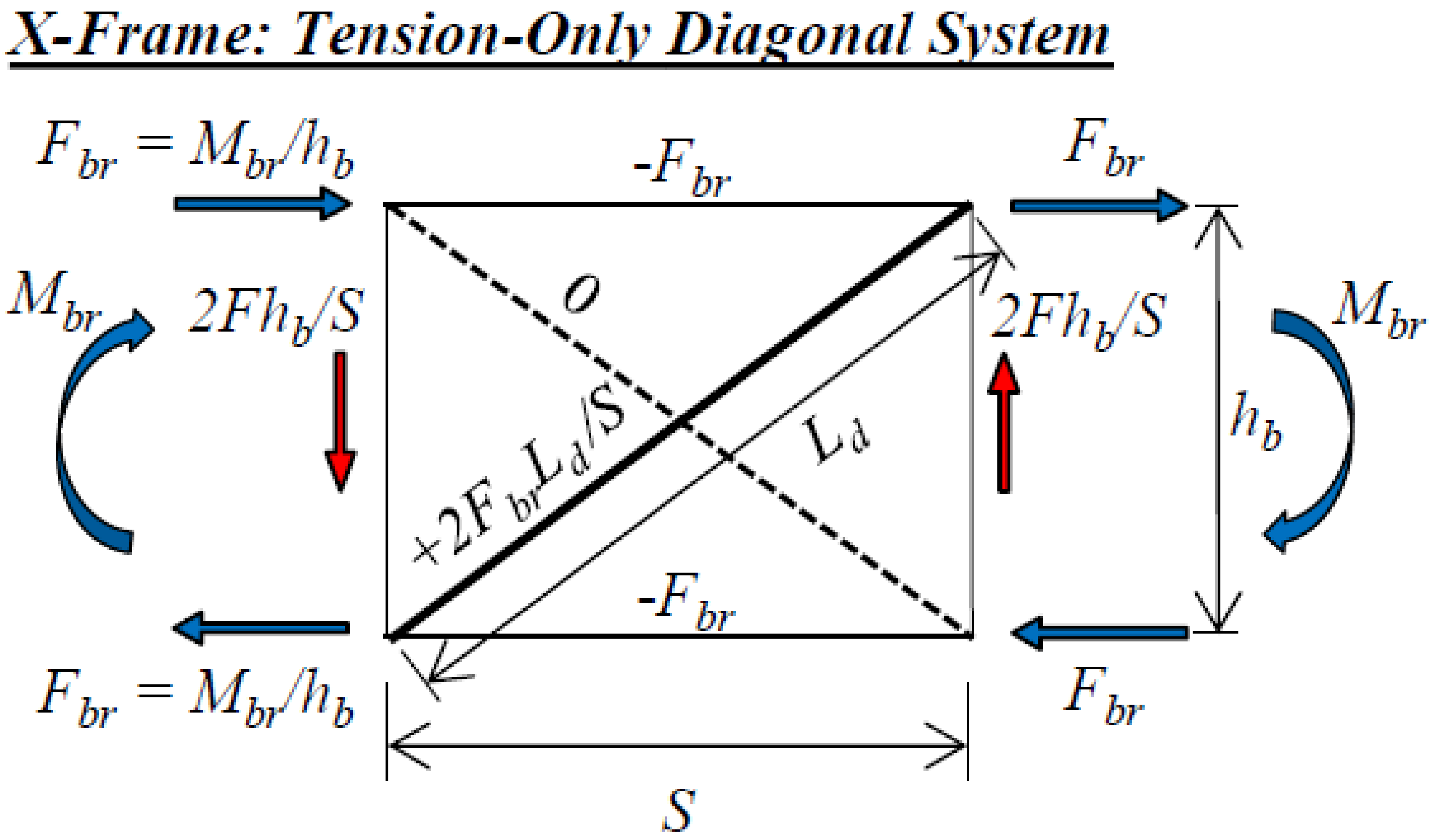
- Tension-Only Diagonal System
- Compression Diagonal System
- K-Brace System
- Solid diaphragms

Component of Provided Stiffness – Bracing Stiffness, β_b



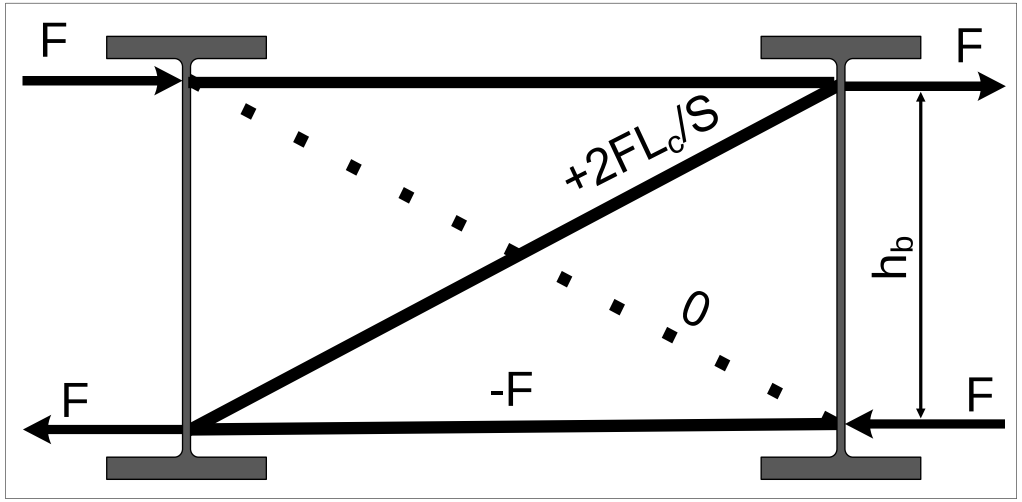


Tension-Only Diagonal System



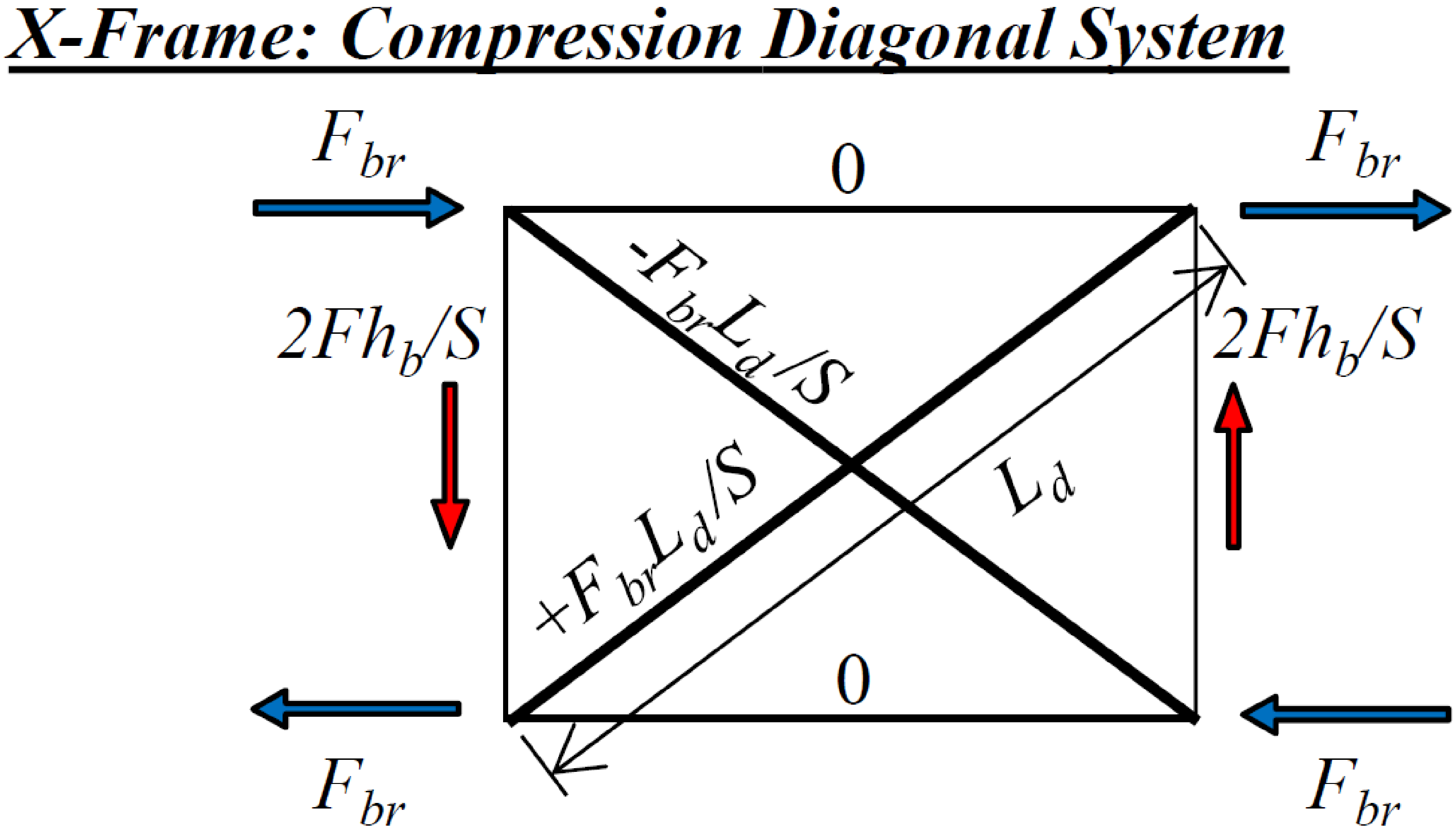
Tension-Only Diagonal System

$$\beta_b = \frac{ES^2h_b^2}{\frac{2L_c^3}{A_c} + \frac{S^3}{A_h}}$$



E = Modulus of elasticity (ksi)
L_c = Length of diagonal (in)
h_b = Height of brace system (in)
A_c = Area of diagonal member(s) (in)
A_h = Area of horizontal member(s) (in)
S = Spacing of girders (in)

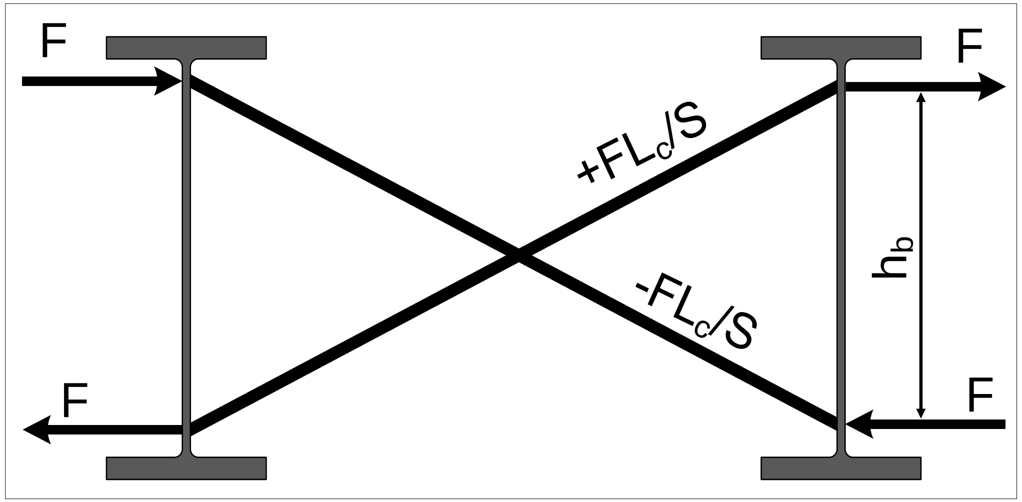
Compression Diagonal System



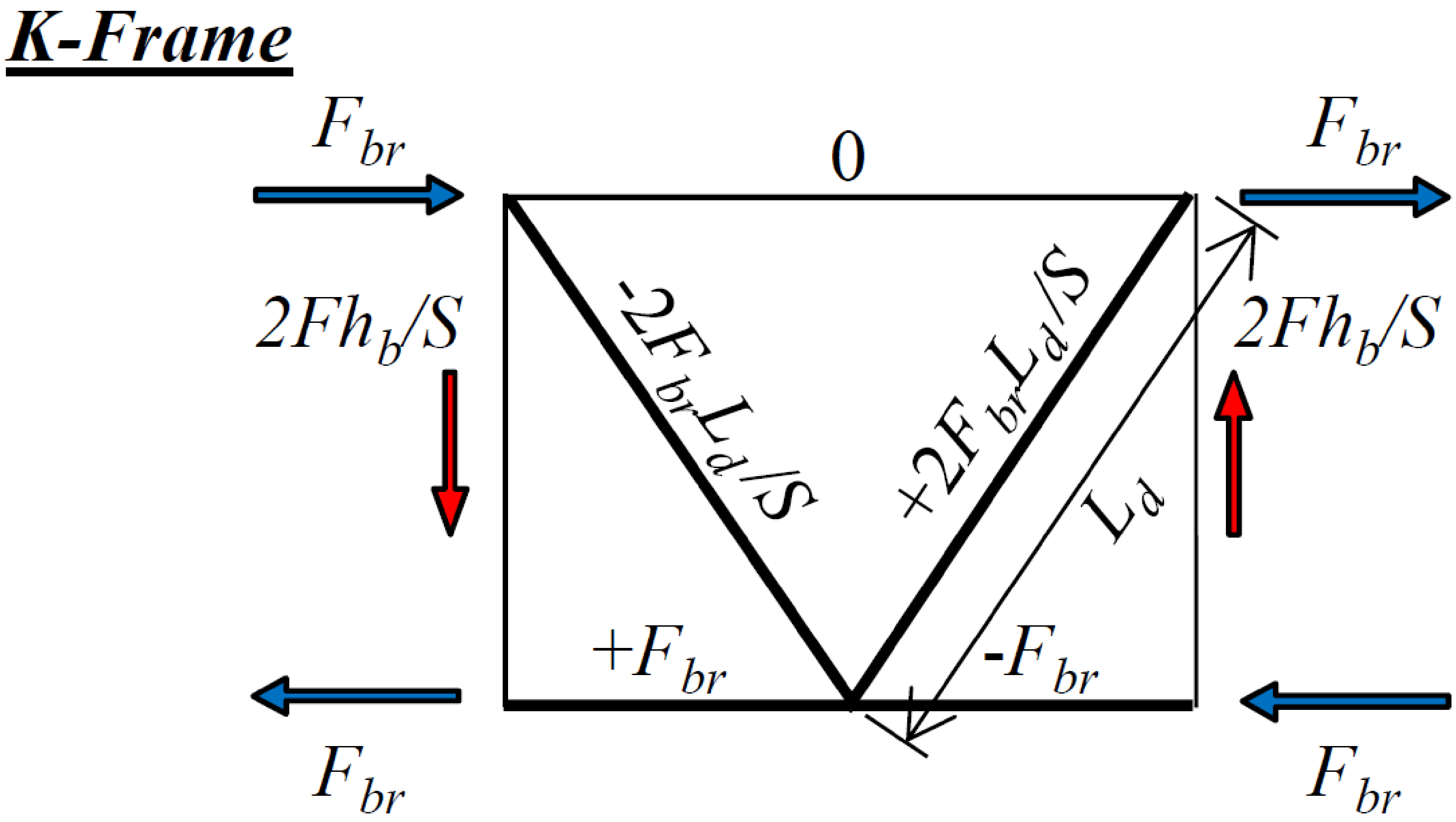
Compression Diagonal System

$$\beta_b = \frac{A_c E S^2 h_b^2}{L_c^3}$$

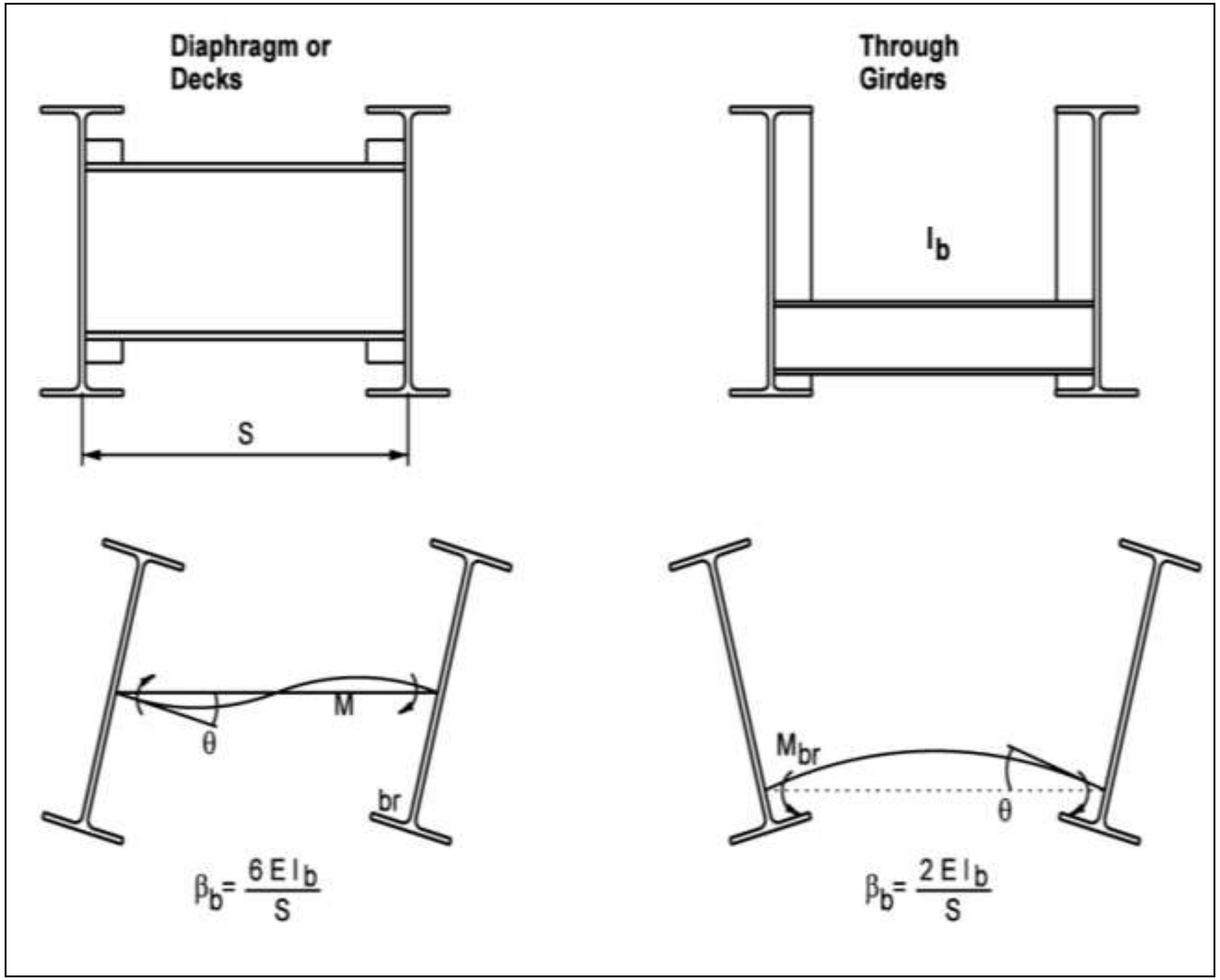
E = Modulus of elasticity (ksi)
L_c = Length of diagonal (in)
A_c = Area of diagonal member(s) (in)
h_b = Height of brace system (in)
S = Spacing of girders (in)



K-Brace System



Diaphragm/Deck or Through Girders



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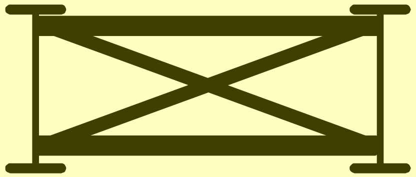
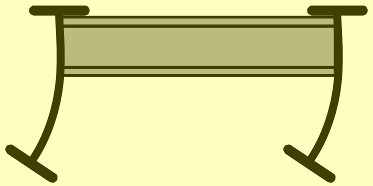
Component of Provided Stiffness - Cross-sectional Distortion, βsec

- Cross-Sectional Distortion: depending on the region of the web outside of the depth of the brace, cross-sectional distortion can be significant.

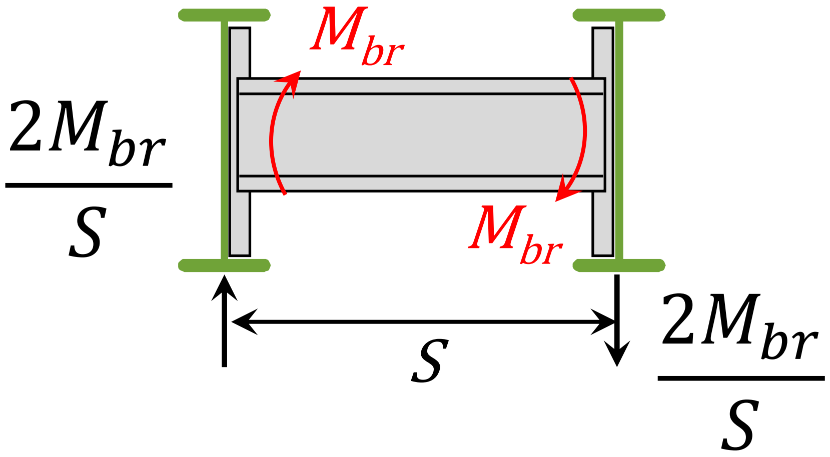


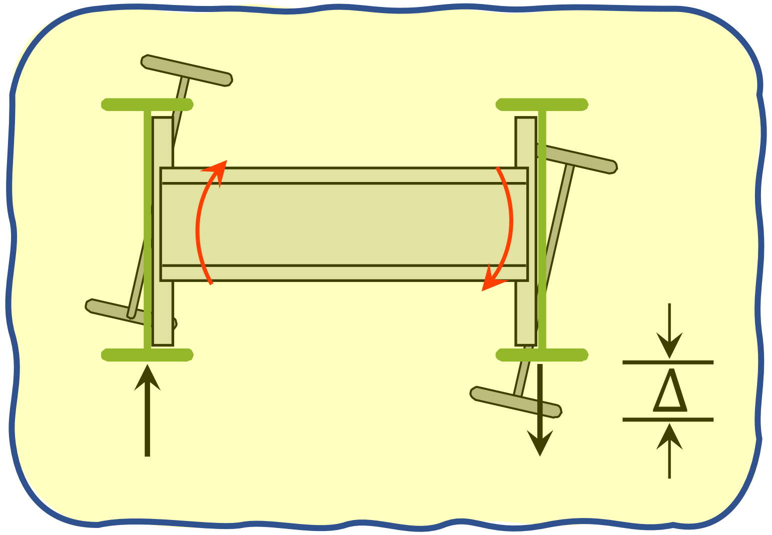
low distortion



Significant distortion

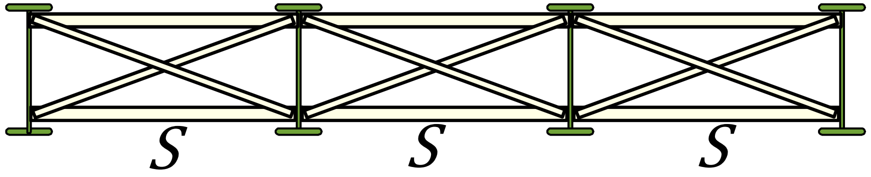
Component of Provided Stiffness – In-plane Girder Stiffeners, β_g





In-plane girder stiffness, (β_g)

β_g is a function of the stiffness of the individual girders as well as the number of girders across the width of the bridge:



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

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

I_x= in-plane moment of inertia of girders

n_g= number of girders across the width of the bridge that are interconnected by the braces.

REMINDER – Torsional Stability Bracing Requirements

Stiffness requirement

$$(\beta_T)_{act} \geq (\beta_T)_{req}$$

- As with column bracing, the ideal stiffness is not sufficient. A greater value, 2x the ideal stiffness, is the basis of the AISC design provisions.

$$(\beta_T)_{req} = \frac{2.4LM_u^2}{\phi_{br} n C_b^2 E I_{yeff}}$$

AASHTO LRFD Upcoming 10th Edition Bracing Design Provisions

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AASHTO Provisions

- 6.7.4.2 Diaphragm/Cross-frames
  - Rolled beams - at least 0.5 x member depth
  - Plate girder – at least 0.75 x member depth
  - Curved bridge cross-frames - contain diagonals and top and bottom chords.
- AASHTO strength / stiffness bracing provisions
  - Except slenderness ratios…there are none!

Until you came here today !!!

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Hot off the Presses !!!

- New requirements of AASHTO to be included in the 10th edition.
- Synopsis of those requirements is provided

6.7.4 Diaphragms and Cross Frames

- 6.7.4.2.1 … *Diaphragms or cross-frames for rolled-beam and plate-girder bridges* ***shall satisfy the stability bracing stiffness and strength requirements specified in Article 6.7.4.2.2****, as applicable.*

- 6.7.4.2.2 **Stability Bracing Requirements** (new article)

6.7.4.2.2 Stability Bracing Requirements

AASHTO Stiffness requirement

$$(\beta_T)_{act} \geq \frac{2.4L}{\phi_{sb} n E I_{yeff}} \left(\frac{M_u}{C_b}\right)^2$$

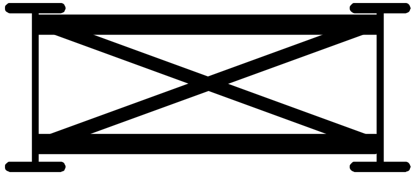
- AISC requirement

$$\beta_T = \frac{1}{\phi_{br}} \frac{2.4L}{nEI_{yeff}} \left(\frac{M_r^2}{C_b^2}\right)$$

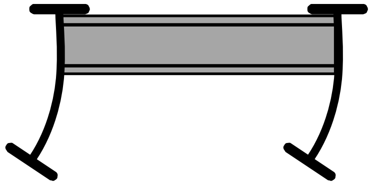
- In the AASHTO approach, if the bracing is not at least 0.8*member depth, the 2.4 becomes a 3.6

Cross-sectional Distortion (βsec)

- New AASHTO 6.7.4.2.2
  - For diaphragms or cross-frames whose depth is at least 0.8 times the depth of the beam or girder, $\beta sec = \infty$



low distortion



Significant distortion

  - Otherwise AASHTO (and AISC) provide methods to account for web distortion associated with partial depth diaphragms / crossframes

AASHTO Diaphragm Strength Provisions

- AASHTO (6.7.4.2.2-14)

$$M_{br} = \beta_T \theta_o = \left(\frac{2.4 L M_r^2}{n E I_{yeff} C_b^2} \right) \left(\frac{L_{br}}{500 h_o} \right)$$

- This is the same as AISC prior to 15th edition. AISC now uses 2% M_r as the required strength
- In the AASHTO equation, if the brace is not at least 80% of beam height, 2.4 becomes 3.6

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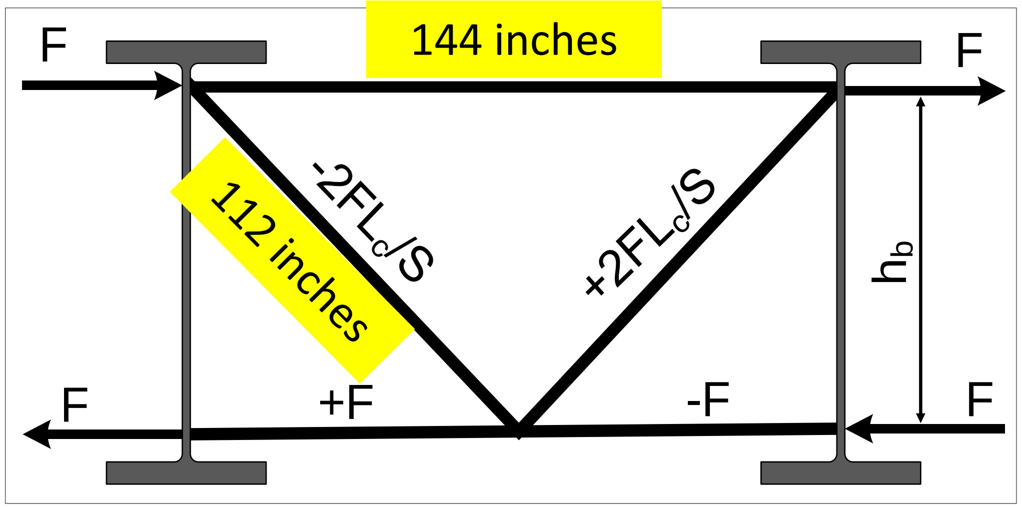
A Practical Example

- Scenario
  - Simple span – 200 ft
  - 4 beams @ 12 ft on center
  - Web depth 86 inches (about L/28 for the web alone)
  - Factored construction moment at midspan = 14,000 FK
  - S/D = 144 / 86 = 1.67 > 1.5 a K-frame is recommended.
  - Minimum size angle to meet kl/r = 6x6x3/8 for the top chord. Try this for all members
  - Crossframes at 25 ft on center
  - Cb = 1 for simplicity

K-Brace System

$$\beta_b = \frac{2ES^2h_b^2}{\frac{8L_c^3}{A_c} + \frac{S^3}{A_h}}$$

E = Modulus of elasticity (ksi)
L_c = Length of diagonal (in)
A_c = Area of diagonal member(s) (in)
A_h = Area of horizontal member(s) (in)
h_b = Height of brace system (in)
S = Spacing of girders (in)

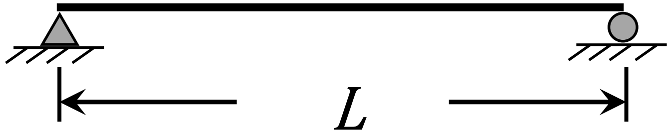


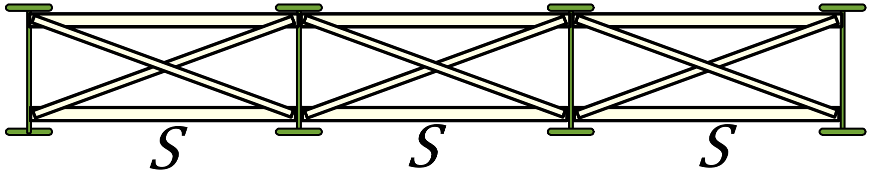
K-Brace System

$$\beta_b = \frac{2ES^2h_b^2}{\frac{8L_c^3}{A_c} + \frac{S^3}{A_h}} = \frac{2(29000)(144^2)(86^2)}{\frac{8(112^3)}{4.38} + \frac{144^3}{4.38}} = 2.74x10^6$$

In-plane girder stiffness (β_g)

β_g is a function of the stiffness of the individual girders as well as the number of girders across the width of the bridge:





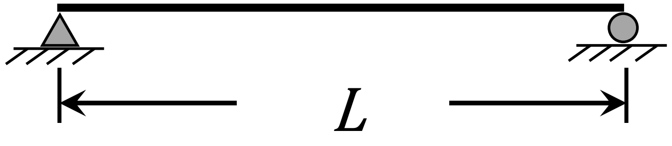
$$\beta_g = \frac{N_g S^2 E I_x}{L^3}$$

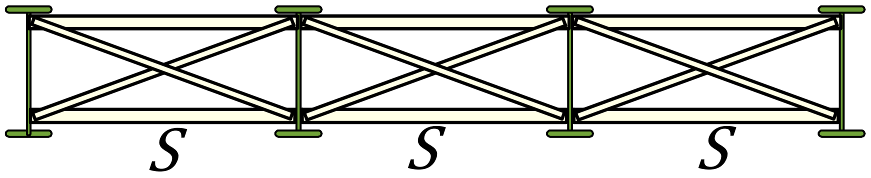
$$N_g = \frac{24\left(n_g - 1\right)^2}{n_g}$$

I_x= in-plane moment of inertia of girders

n_g= number of girders across the width of the bridge that are interconnected by the braces.

In-plane girder stiffness (β_g)





$$N_g = \frac{24\left(n_g - 1\right)^2}{n_g} = \frac{24(4-1)^2}{4} = 54$$

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

$$= \frac{(54)(144^2)(29000)(211{,}532)}{(2400^3)} = 4.97\text{x}10^5$$

Total Bracing Stiffness

$$(\beta_T)_{act} = \frac{1}{\left(\frac{1}{\beta_b} + \frac{1}{\beta_{sec}} + \frac{1}{\beta_g}\right)}$$

$$(\beta_T)_{act} = \frac{1}{\left(\frac{1}{2.74x10^6} + \frac{1}{\infty} + \frac{1}{4.97x10^5}\right)} = 4.21\text{x}10^5$$

6.7.4.2.2 Stability Bracing Requirements

Stiffness requirement

$$(\beta_T)_{act} \geq \frac{2.4L}{\phi_{sb} n E I_{yeff}} \left(\frac{M_u}{C_b} \right)^2$$

$$\beta_T = \frac{2.4(2400)(14{,}000*12)^2}{0.8(7)(1)(29000)(3449)} = 2.90x10^5 \leq 4.21x10^5$$

Design is satisfactory even with minimum kl/r angles

If it didn’t work, solutions include:

- Increase the size of the angles
- Add a line of crossframes
- Switch to an X Frame
- Increase Ixx to increase the in-plane girder stiffness

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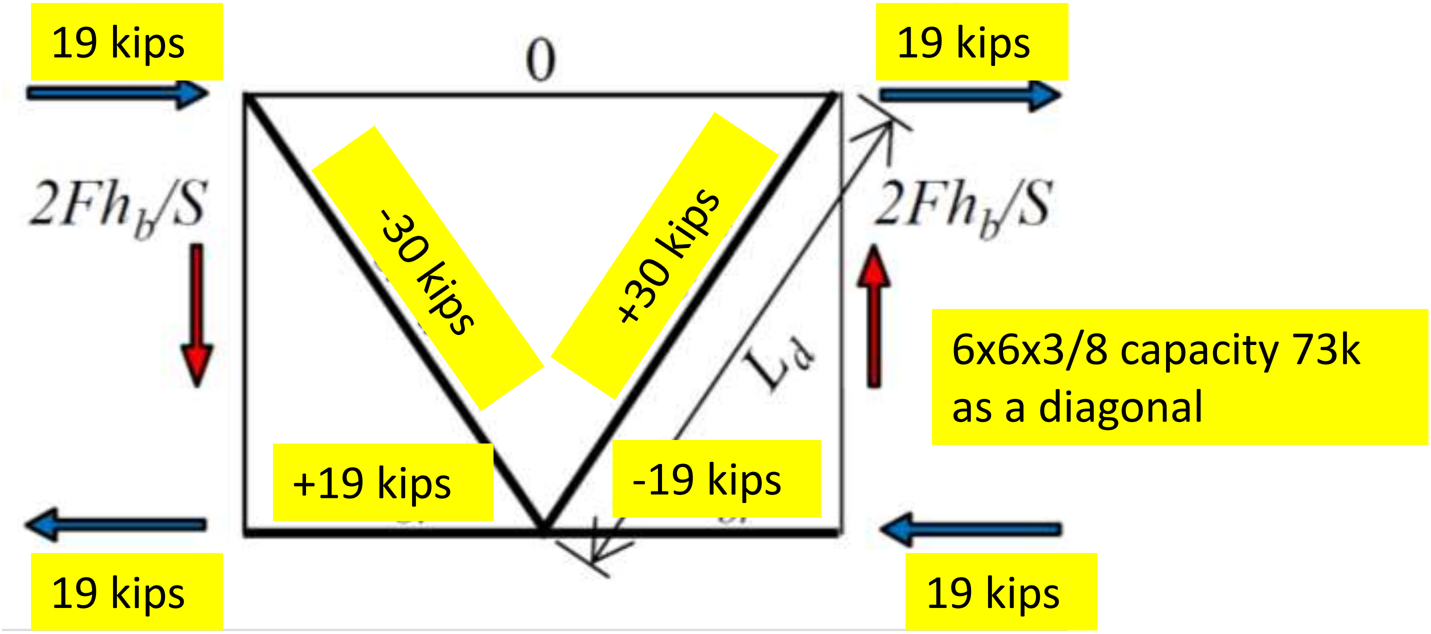
AASHTO / AISC Provisions

$$M_{br} = M_{br} = \beta_T \theta_o = \left(\frac{2.4LM_r^2}{nEI_{yeff}C_b^2}\right)\left(\frac{L_{br}}{500h_o}\right) = 135\ ft * kips$$

$$F_{br} = \frac{135 * ft - kips}{86 - in} = 19\ kips$$



6x6x3/8 capacity 73k as a diagonal

Summary – Good News

- AASHTO now has REQUIREMENTS (in the 10th edition) requiring that flexural members be braced with members of sufficient stiffness and strength
- Stiffness is required to control distortion (twist) in girders.
- Restraint of twist requires a strength design check of the bracing system
- **Calculations <u>on selected bridges</u> show that typical crossframes, designed for kl/r requirements meet or come close to meeting the stiffness and strength requirements.**

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Summary - Warnings

- Where are these provisions likely to cause problems?
  - Long spans, narrow cross section
  - Example, 300 ft span, 34 ft roadway, 4 or 5 beam cross-section
  - Example calcs show these GIRDERS satisfy AASHTO
  - The in-plane stiffness component of these bridges may be too low for bracing by diaphragms alone to be sufficient
  - These bridges may need a partial length lateral bracing system

Questions or Comments

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