Girder Stability in Erection & Demolition

2015 Western Bridge Engineers Seminar

Reno, Nevada

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Problem

- It is unacceptable for bridges to collapse at any time
- Such events (and near misses) are too common during erection and/or demolition
- The majority of engineering effort in projects is being placed in design rather than construction
- There is a general lack of criteria and guidance
- Stability is a complicated issue

Cantilever Arm Under Construction

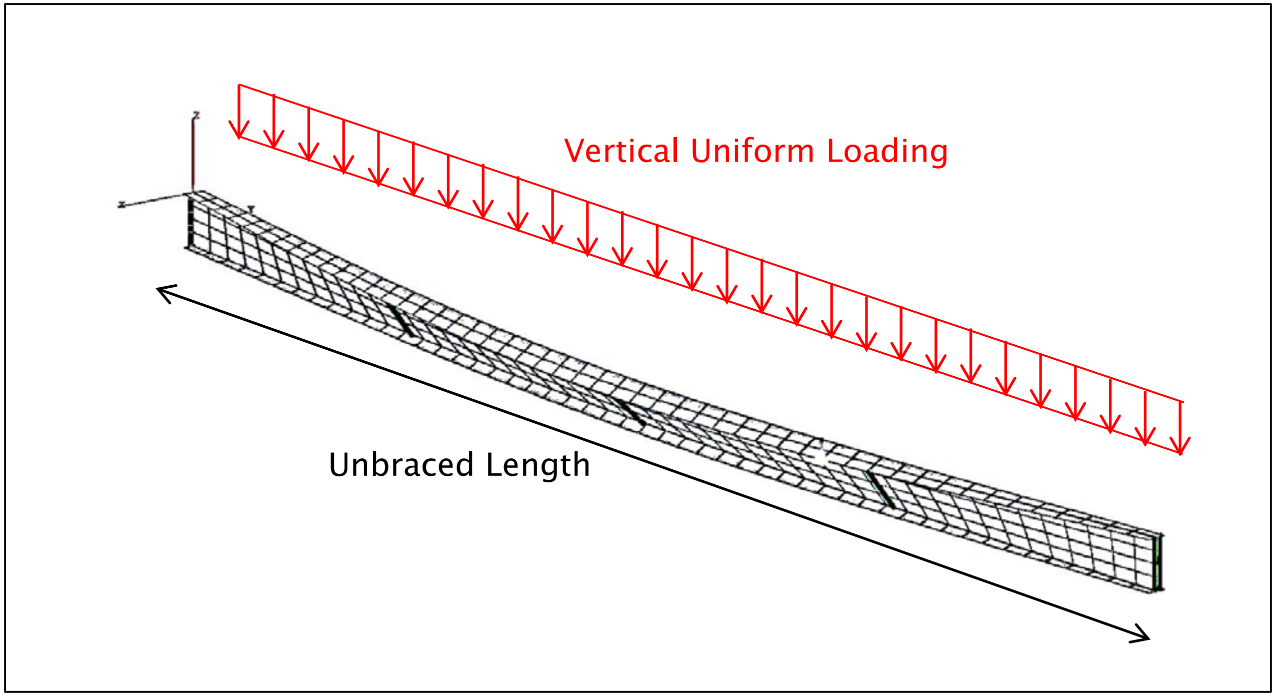
Collapsed Bridge


ORIGINAL JOE'S
BONNETT


kokosing

Girder Buckling Mode: Lateral-Torsional

- Tensile and compressive stresses produced by bending
- Result: lateral translation and twisting of cross-section
  - Compression flange buckles & laterally translates
  - Tension flange doesn't buckle so shape must twist



AASHTO Equation for Lateral Torsional Buckling

$$F_{cr} = \frac{C_b \pi E}{\left(\frac{L_b}{r_t}\right)^2} \sqrt{1 + 0.078 \frac{J}{S_{xc} h} \left(\frac{L_b}{r_t}\right)^2}$$

- 1st term under radical: Warping torsional stiffness
- 2nd term under radical: Saint-Venant torsional stiffness
- Applicable to doubly-symmetric and singly-symmetric shapes

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Temporary Lean-on Brace

Bracing

- Load distribution
  - Live load
  - Wind
- Girder stability
- Combined wind and stability

Torsional Bracing

- $M_{br} = \dfrac{0.005\ L_b\ L\ M_u^2}{n\ E\ I_{eff}\ C_b^2\ h_o}$ (Str)

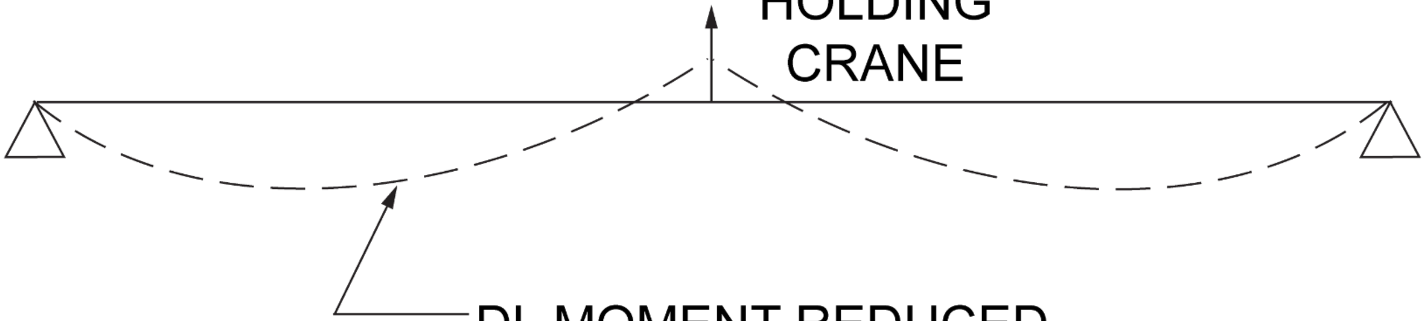
- $\beta_t = \dfrac{2.4\ L\ M_u^2}{n\ E\ I_{eff}\ C_b^2}$ (Stif)

Holding Crane

Holding Crane Effect

DL MOMENT

$C_b = 1$

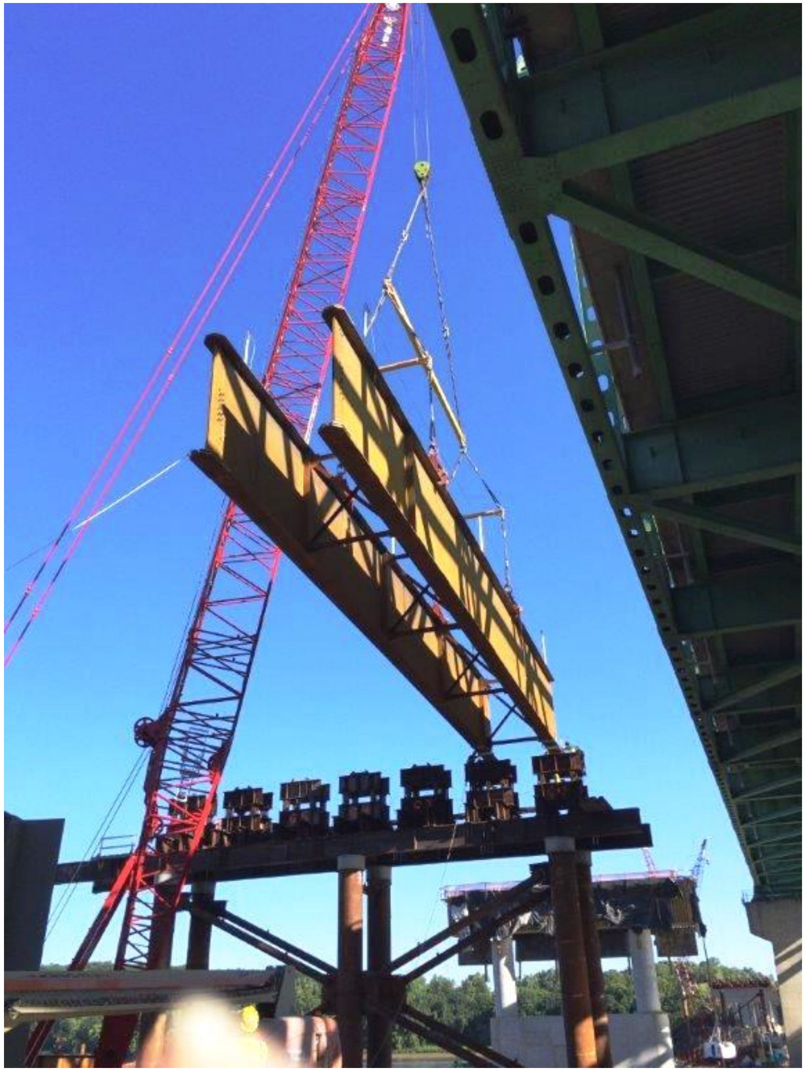


HOLDING CRANE

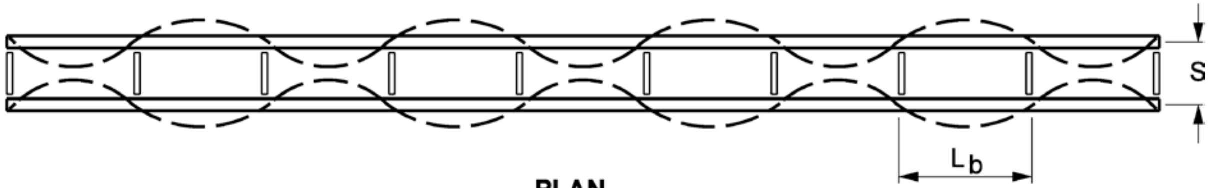
DL MOMENT REDUCED

$C_b > 1$ NOT A LATERAL BRACE!

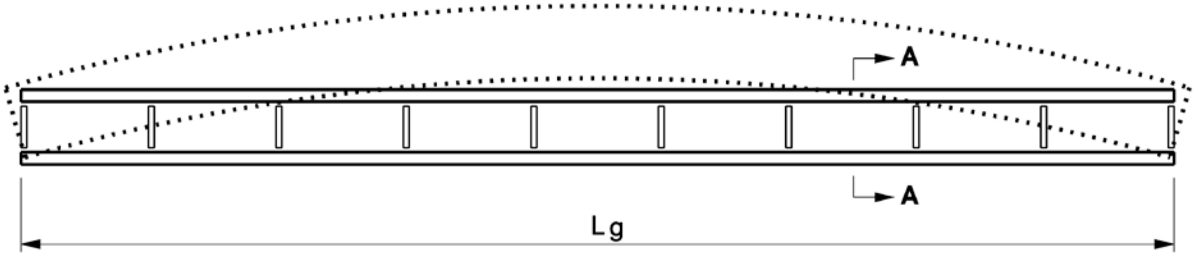
Setting Girder Pairs



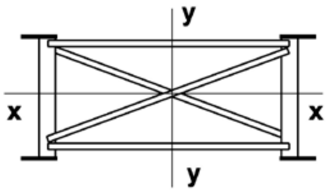
System Buckling of Girders



PLAN
(a) Individual girder buckling



PLAN
(b) Global system buckling



SECTION A-A
(c) System cross section

System Buckling

- $M_b = \frac{\pi^2 SE}{L_g^2} \sqrt{I_x I_y}$ (2 girders, symmetric)
- S = girder spacing
- $\Phi M_b > 1.5 M_o$
- Non-symmetric; 3- and 4-girder equations available

Eigenvalue (a.k.a. critical load) Buckling Analysis

- Evaluate global and potentially local stability
- Analysis program can solve for…
  - Buckling mode shape (eigenvector)
  - Buckling mode value (eigenvalue)
- Analysis provides elastic buckling capacity
  - Material inelasticity is not considered, but…
  - Stresses during construction in elastic range anyway
- Most commercial software tools can do eigenvalue buckling
- Straight bridges

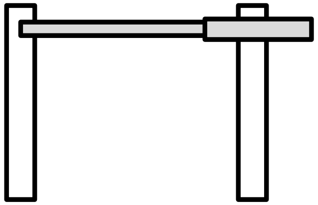
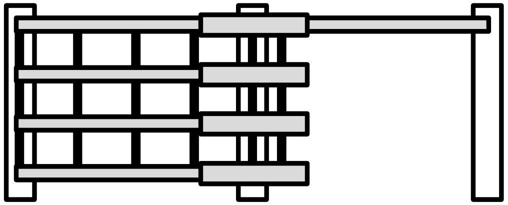
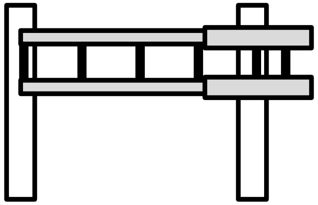
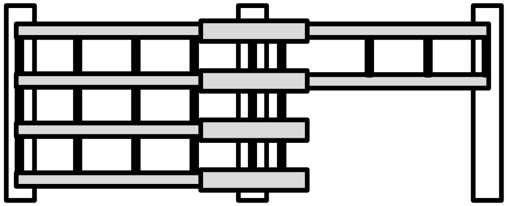
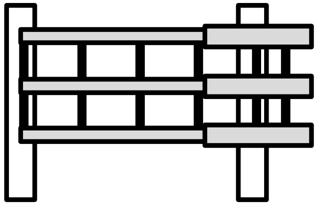
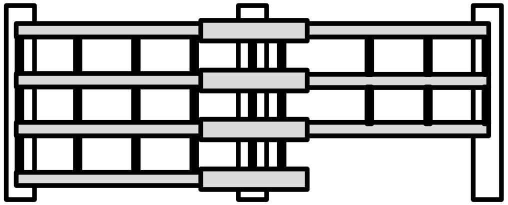
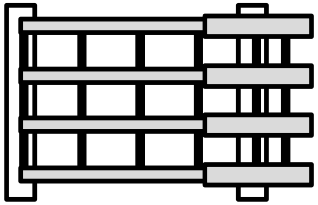
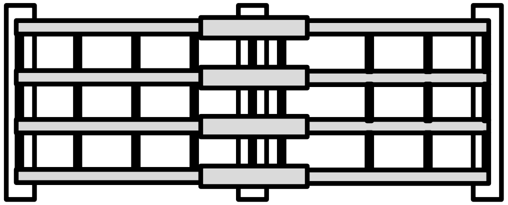
Eigenvalues

- Eigenvalue λ: factor applied to reference load
- This determines critical buckling load
- $P_{cr} = \lambda P_{ref}$
  - P_{cr} = corresponding buckling load (k)
  - λ = eigenvalue
  - P_{ref} = magnitude of applied force (k)
- Target, $P_{cr} \geq 1.75 \times$ selfweight

Critical Erection Stages

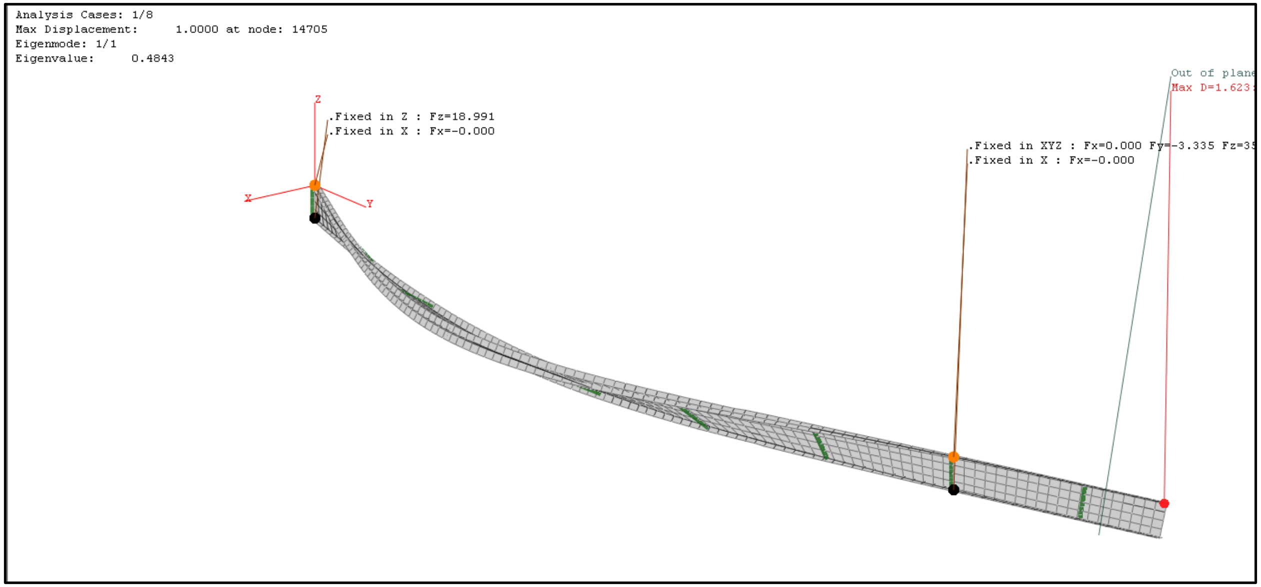
Contractor’s preferred erection method

- Complete 1st splice on ground
- Erect Span 1 with cantilever portion

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

Critical Erection Stages

- Eigenvalue analysis of Case 1 (Span 1)
  - Girder 1 erected with no intermediate bracing
    - Eigenvalue on unfactored selfweight = 0.48 < 1
    - Buckled shape shown; girder clearly inadequate (LTB)



```
Analysis Cases: 1/8
Max Displacement:     1.0000 at node: 14705
Eigenmode: 1/1
Eigenvalue:     0.4843
```

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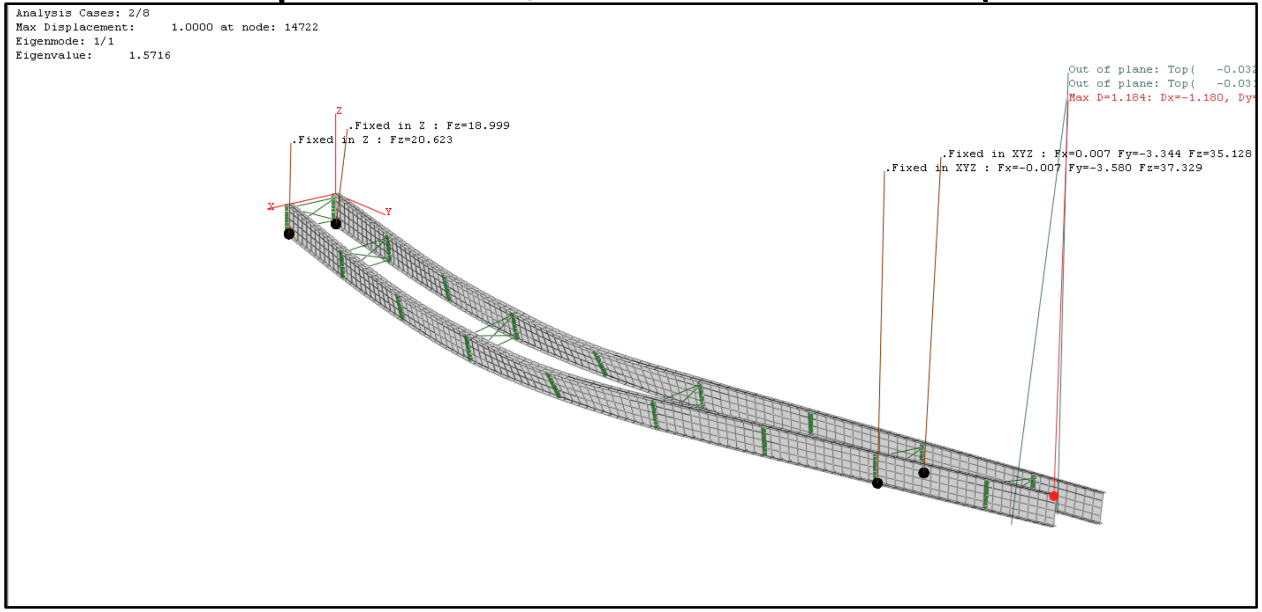
Critical Erection Stages

- Eigenvalue analysis of Case 2 (Span 1)
  - Girders 1 & 2 erected with 50% cross-frames
    - Eigenvalue on unfactored selfweight = 1.57
    - Buckled shape shown; case borderline (1.25<λ<1.75)



```
Analysis Cases: 2/8
Max Displacement:     1.0000 at node: 14722
Eigenmode: 1/1
Eigenvalue:      1.5716
```

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Critical Erection Stages

- Contractor’s erection method (continued)
- Erect Span 2 with air splice
- Erect remaining cross-frames
  - 50% of intermediate cross-frames installed originally
- Evaluate each case’s stability with UT Bridge
- Eigenvalue analysis using unfactored self-weight

Case	Eigenvalue
1	0.48
2	1.57
3	1.84
4	1.96
5	1.32
6	2.36
7	3.15
8	3.55

Setting Girder with Bracing Attached

I-394 Erection

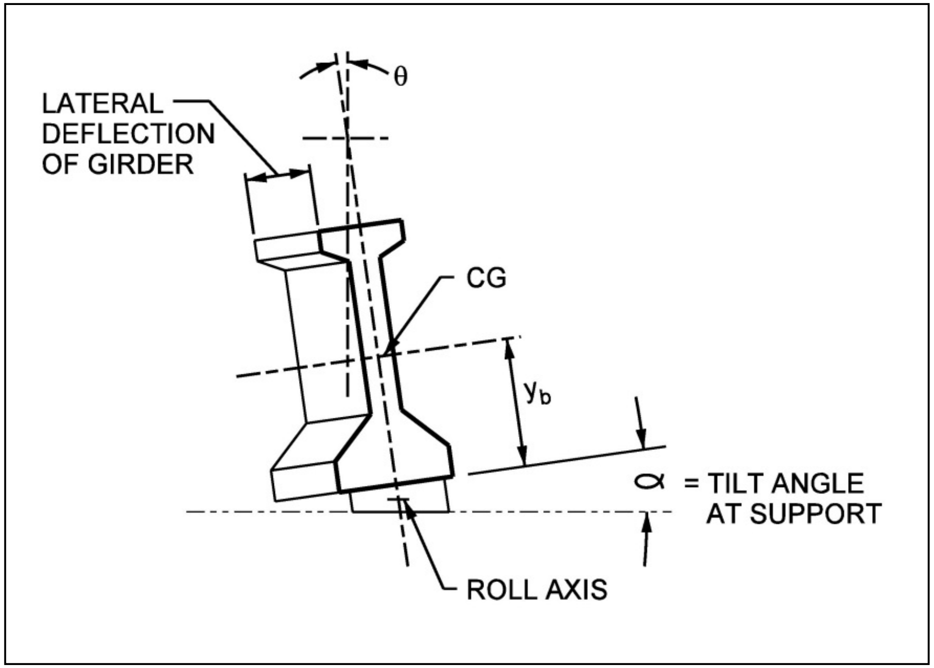
Collapsed Girders

Bent Diagonal Brace for shoring fascia

09:36

Roll Stability of Concrete Girders

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



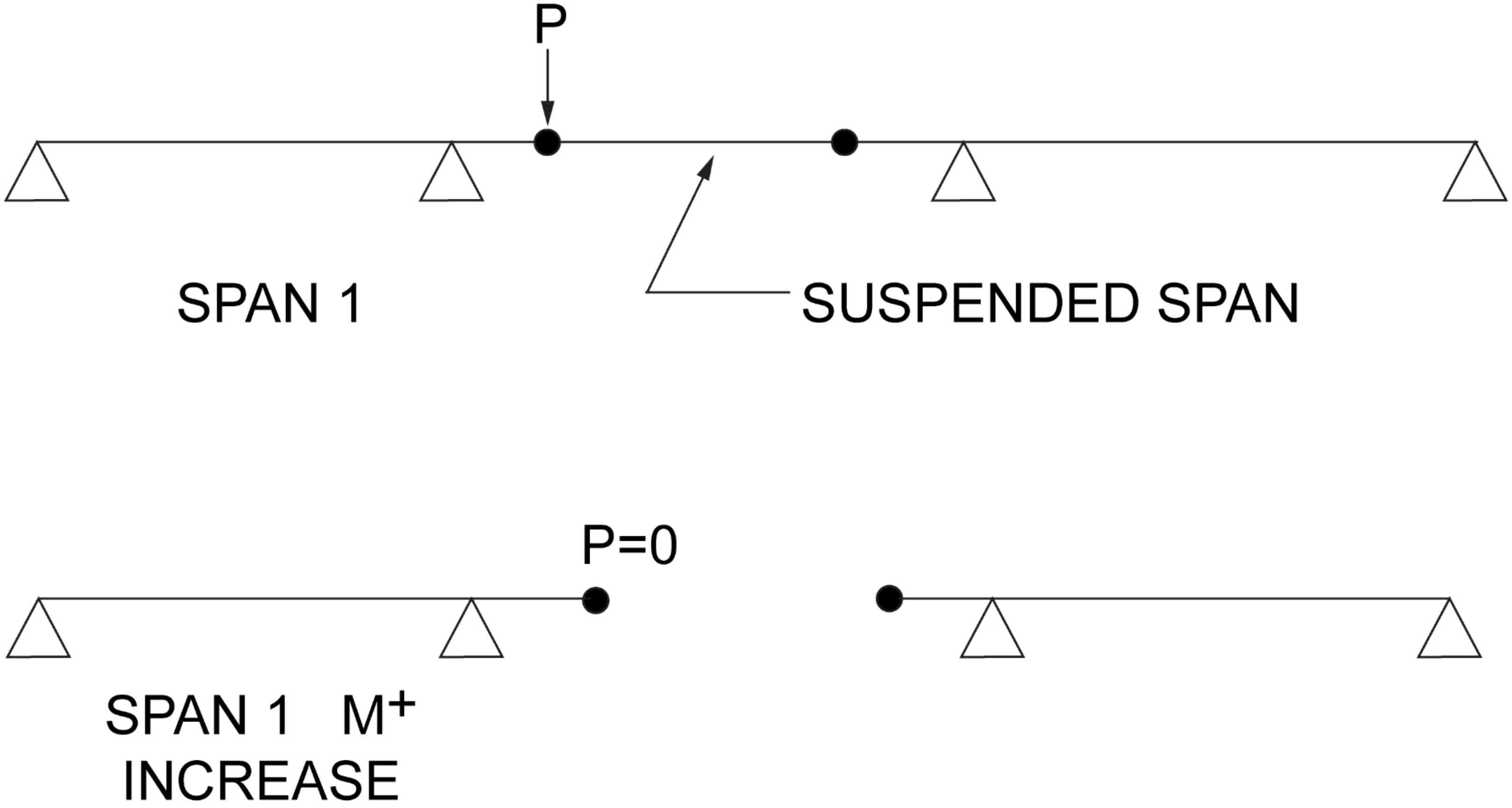
Note: Figure adapted from Mast (1993)

Roll Stability of Concrete Girders

- Girder rollover stability can be influenced by:
  - Bearing slope and bearing type
  - Bearing skew relative to girder centerline
  - Girder imperfections (sweep)
- Rollover controls stability, not lateral-torsional buckling
  - PPC girders designed to not crack under selfweight
  - Relatively large I_y and J: no LTB

Concrete Girders X-Bracing

Demolition Load Changes



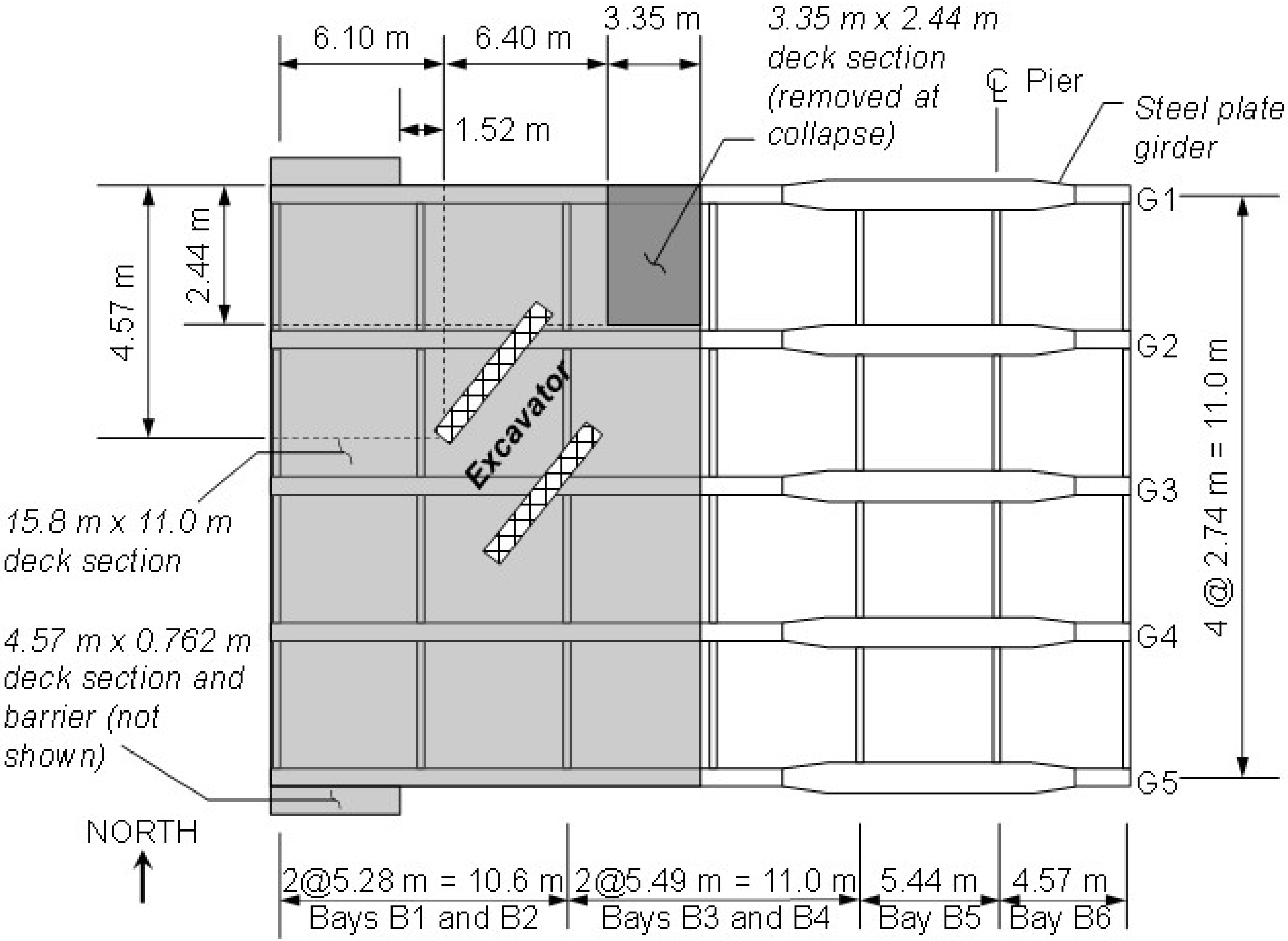
P

SPAN 1

SUSPENDED SPAN

P=0

SPAN 1 M^+
INCREASE



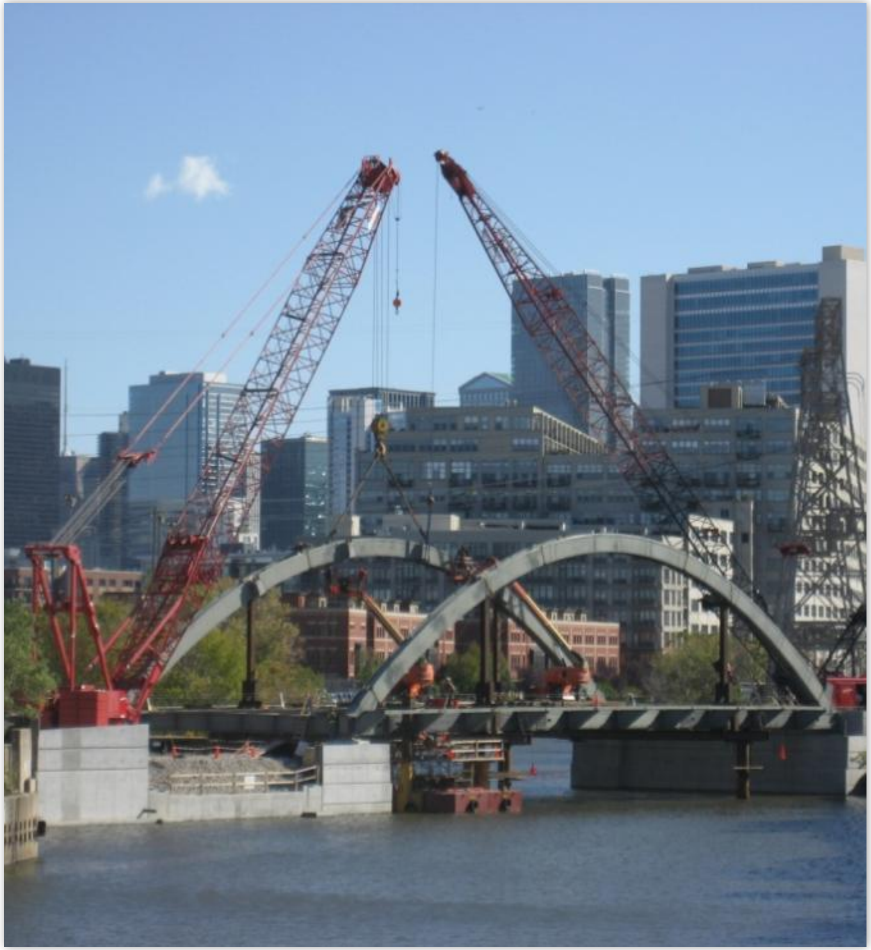
Courtesy of Dr. D. Jauregui

Bridge Demolition Failure

Courtesy of Dr. D. Jauregui

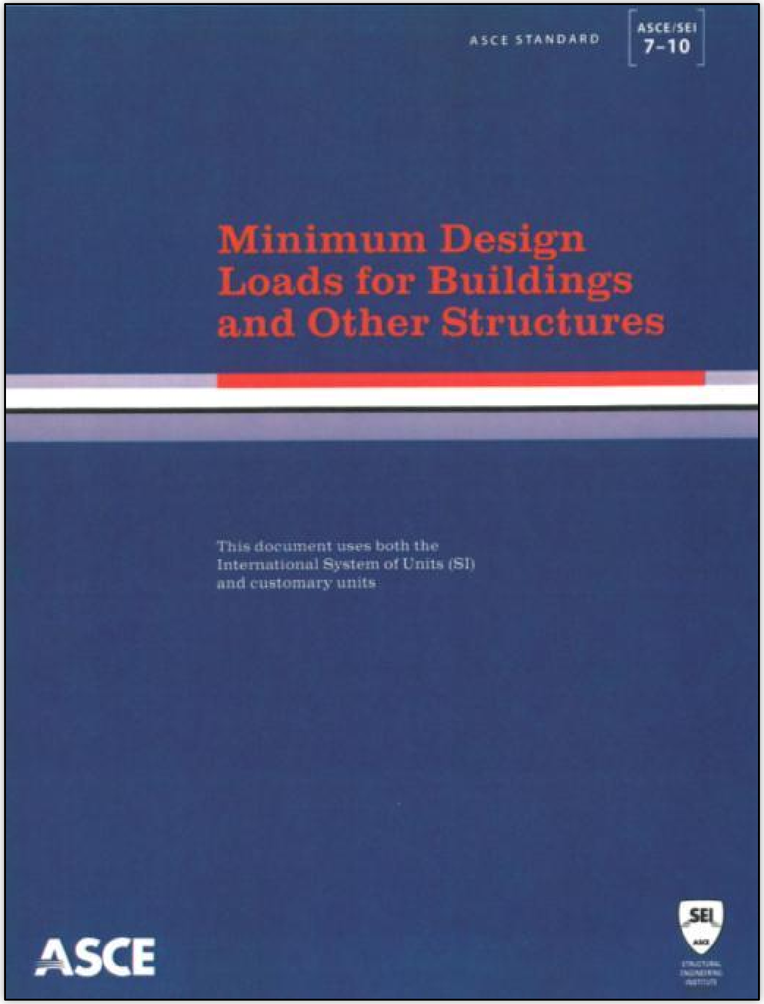
Engineering for Structural Stability in Bridge Construction

- FHWA has initiated effort to develop comprehensive manual and training course
- Product will attempt to provide
  - Summary of lessons learned
  - Understanding and analysis of global stability
  - Design criteria for erection
  - Guidance and best practices
  - Design examples



Wind Loads

- AASHTO
  - 300 PLF
- ASCE 7-10
  - $F = .00256\, k_z\, k_{zt}\, k_d\, G\, C_f\, A\, V^2$
  - Load factor in velocity
- ASCE 37 Reduction Factors



ASCE STANDARD

ASCE/SEI 7-10

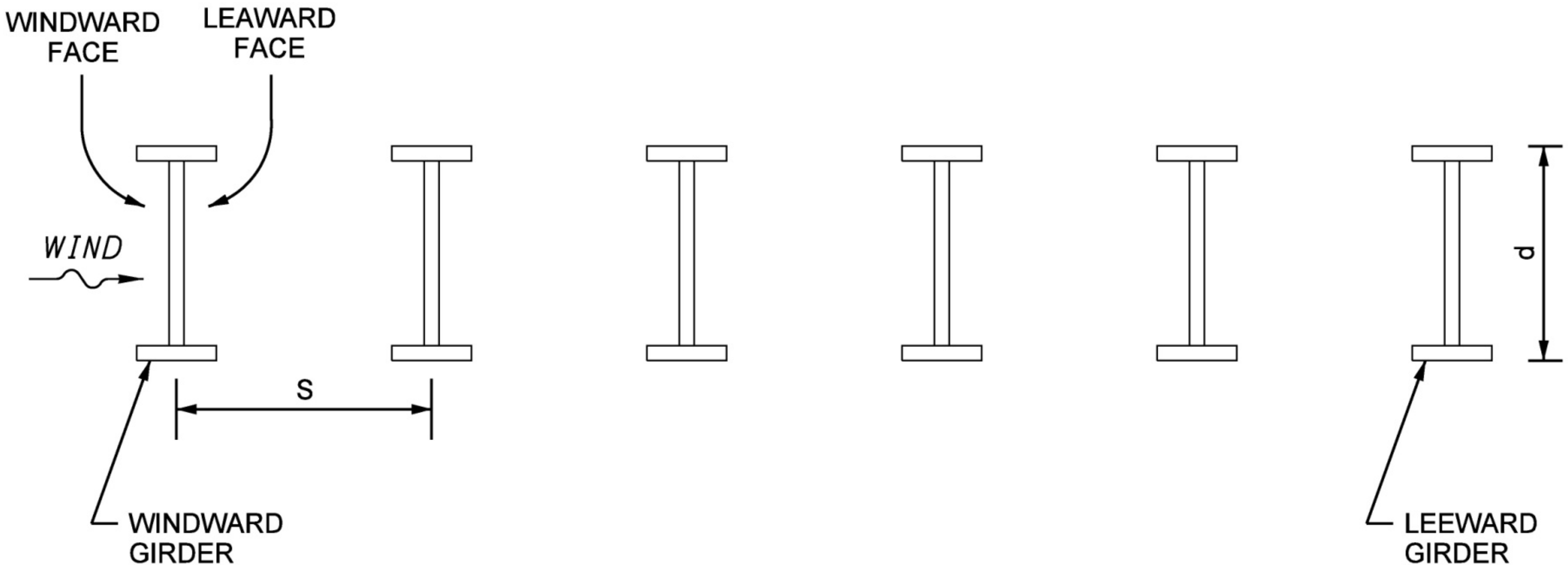
Minimum Design Loads for Buildings and Other Structures

This document uses both the International System of Units (SI) and customary units

ASCE

Wind Distribution—Open Structure

- C_f=2.2 (min)
- C_f=2(1 + 0.05 s/d) ≤ 4.0



Wind

- One day, design velocity = 20 mph
- Velocity modification factors (Vmod=FV)

Duration	Factor
0 – 6 weeks	0.65
6 weeks – 1 year	0.70
1 year – 2 years	0.8
2 years – 5 years	0.85

Load Factors

Load Combinations and Load Factors	DC	C_{DL}	C_{LL}, C_R	C_W
Strength I	1.25	1.25	1.75	—
Strength III	1.25	1.25	—	1.0
Strength V	1.25	1.5	—	1.0
Strength IV	1.40	1.40	1.50	—
Service	1.00	1.00	1.00	1.0

Questions