AASHTO/NSBA Steel Bridge Collaboration G13.1 Guidelines for Steel Girder Bridge Analysis

North Carolina Steel Bridge Workshop

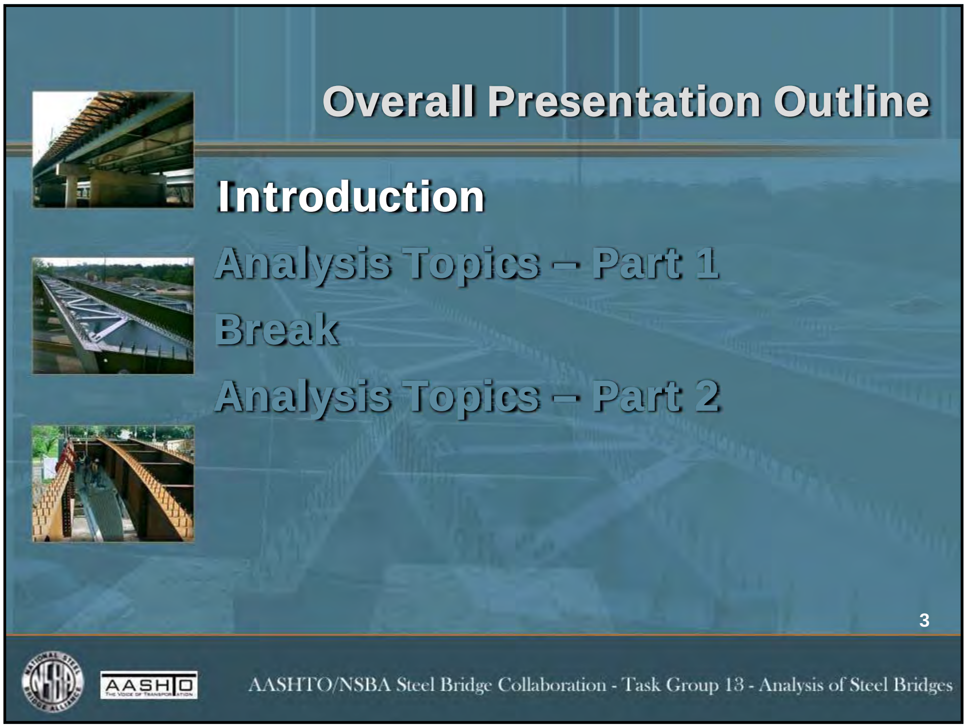
Sponsored by the NCDOT and the NSBA

September 14, 2011

Raleigh, NC

Overall Presentation Outline

- Introduction
- Analysis Topics – Part 1
- Break
- Analysis Topics – Part 2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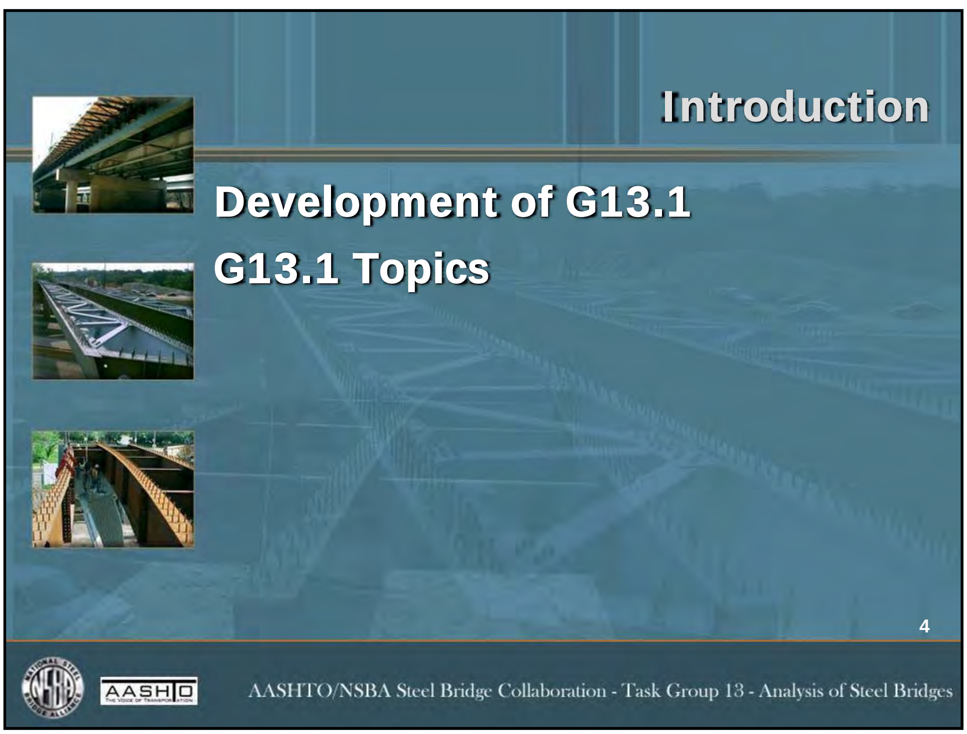
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Development of G13.1
G13.1 Topics
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Development of G13.1

G13.1 Topics

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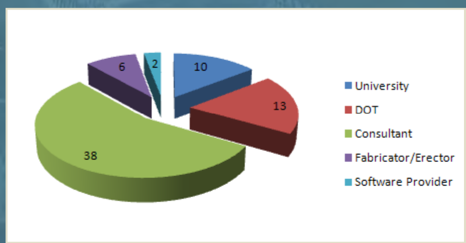
Development of G13.1

- Written by AASHTO/NSBA Task Group 13
  - A committee interested in steel bridge analysis issues
  - 69 members
  - A broad cross-section of the industry



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Development of G13.1

- Mission Statement

  "Develop and maintain consensus recommendations on the applicability, advantages, and disadvantages of analysis techniques for various types of steel girder bridges"

Development of G13.1

- Which means…
  - Gather input from owners, designers, and industry
  - Develop consensus recommendations / understanding of steel girder analysis issues
  - Publish a guideline document on analysis of steel bridges



Development of G13.1

- Timeline of TG13's efforts

Activity	Date
Initial Meeting of TG 13	May 9, 2007
Survey of Current Practice	Summer 2007
Prepared Outline of G13.1	Winter 2007/2008
Assigned Authors for G13.1	June 2008
Reviewed Draft of G13.1	November 2009
Collaboration Ballot of G13.1	April 2010
Initial AASHTO T-14 Review of G13.1	August 2010
AASHTO SCOBS Approval of G13.1	May 2011
Publication of G13.1	August 2011

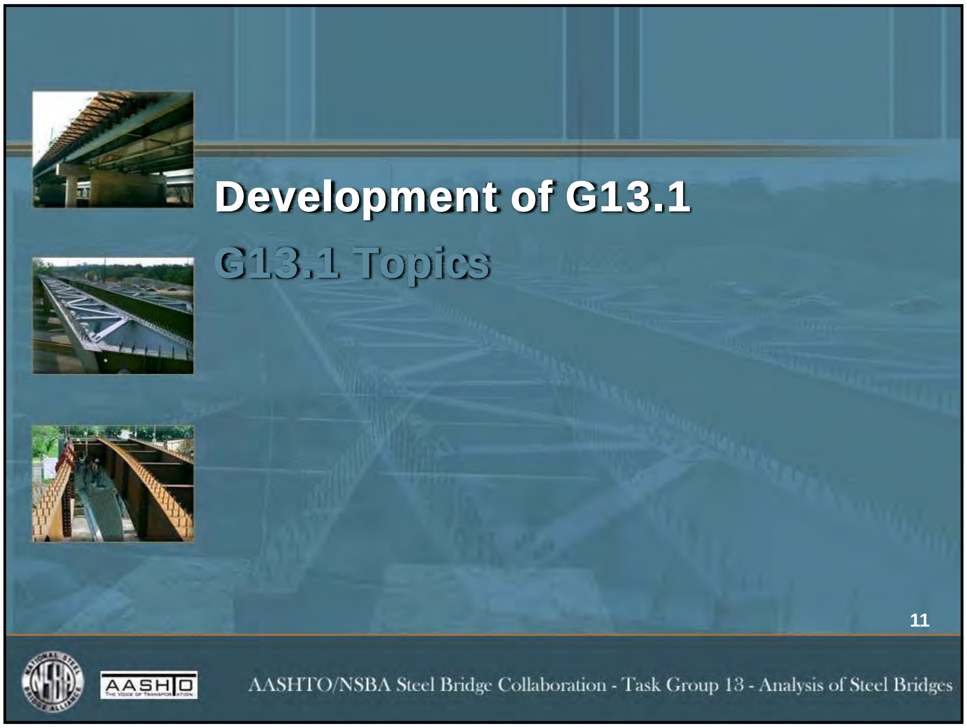
From initial meeting to publication: > 4 years



Development of G13.1

- Formal development of consensus

Review	Comments Addressed
October 2009 Review by TG13	411
March 2010 Review by TG13	193
April 2010 Review by Industry	35
October 2010 Review by T-14	5
February 2011 Review by T-14	18
May 2011 Review by AASHTO Editor	95
Total Comments Addressed	**757**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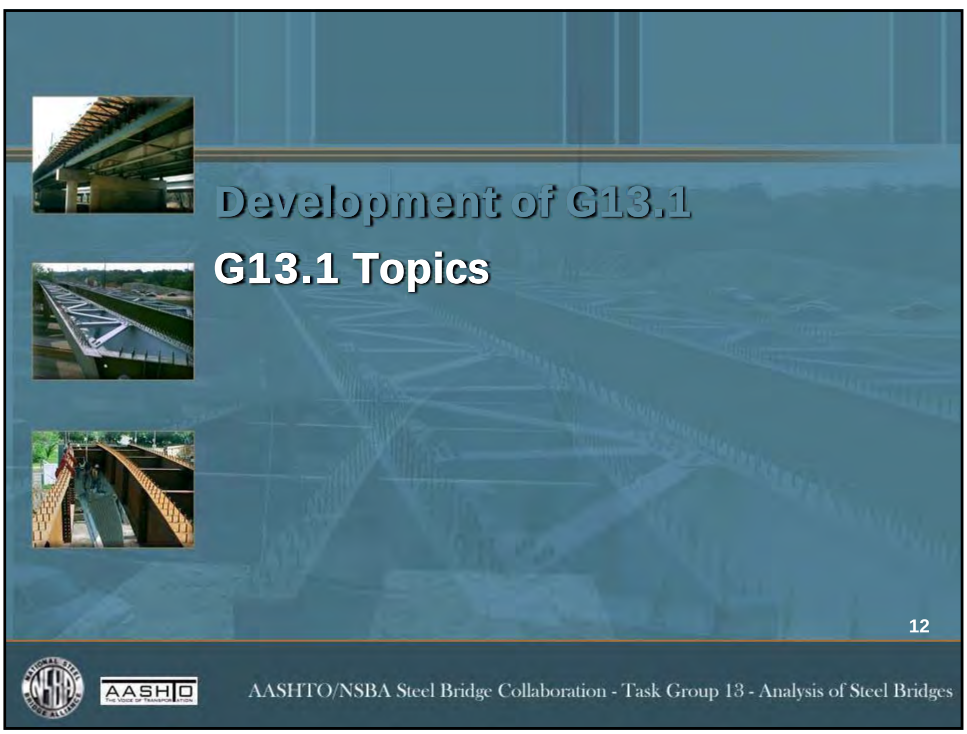
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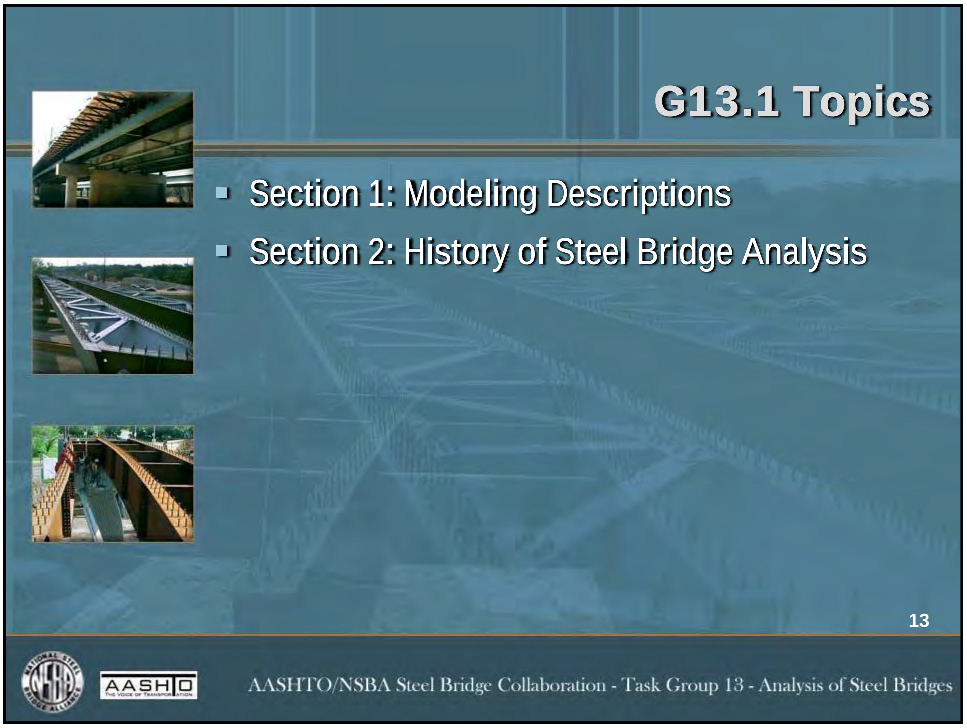
G13.1 Topics
Section 1: Modeling Descriptions
Section 2: History of Steel Bridge Analysis
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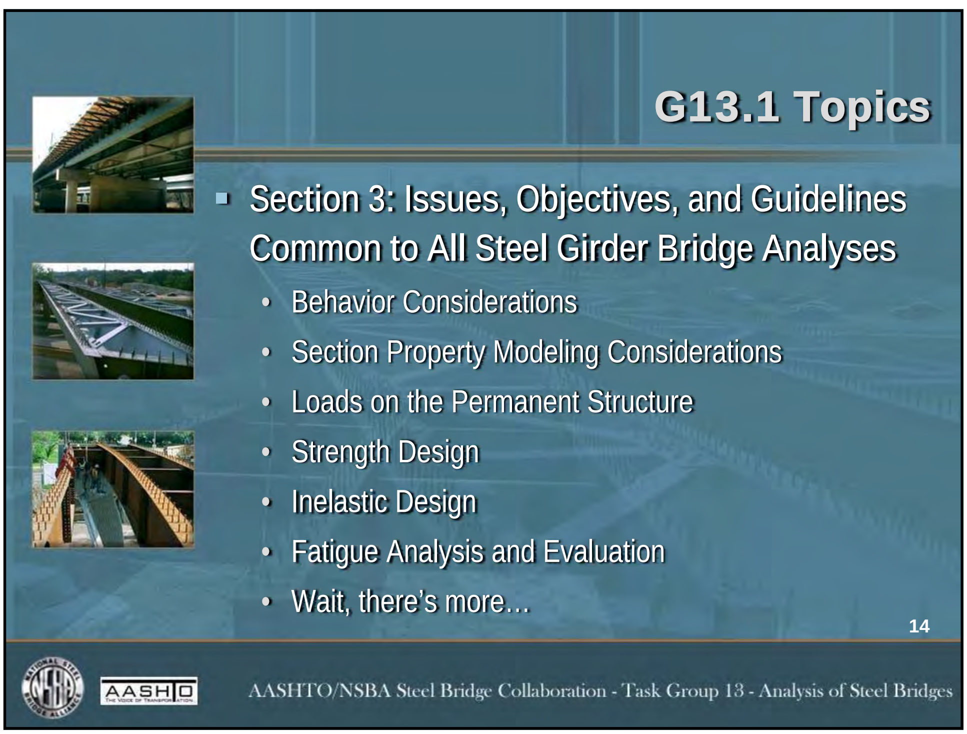
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Section 3: Issues, Objectives, and Guidelines Common to All Steel Girder Bridge Analyses
Behavior Considerations
Section Property Modeling Considerations
Loads on the Permanent Structure
Strength Design
Inelastic Design
Fatigue Analysis and Evaluation
Wait, there's more…
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G13.1 Topics

- Section 3: Issues, Objectives, and Guidelines Common to All Steel Girder Bridge Analyses
  - Superstructure Live Load Reactions for Substructure Design
  - Constructability – Analysis Issues
  - Prediction of Deflections
  - Detailing of Cross Frames and Girders for the Intended Erected Position
  - Wait, there's still more…

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G13.1 Topics

- Section 3: Issues, Objectives, and Guidelines Common to All Steel Girder Bridge Analyses
  - Cross Frame Modeling (2D vs. 3D)
  - Deck Modeling
  - Bearings, Substructures, and Boundary Conditions for Models
  - Roadway/Structure Geometry Coordination
  - Second-Order Effects
  - Wait, there's yet more…

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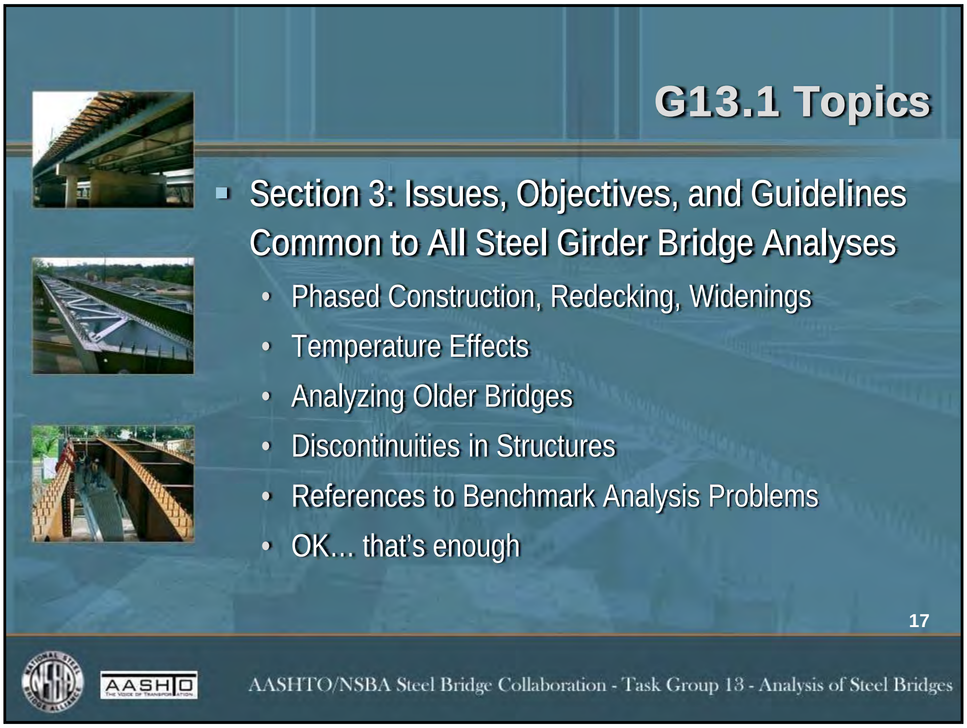
G13.1 Topics
Section 3: Issues, Objectives, and Guidelines Common to All Steel Girder Bridge Analyses
Phased Construction, Redecking, Widenings
Temperature Effects
Analyzing Older Bridges
Discontinuities in Structures
References to Benchmark Analysis Problems
OK… that's enough
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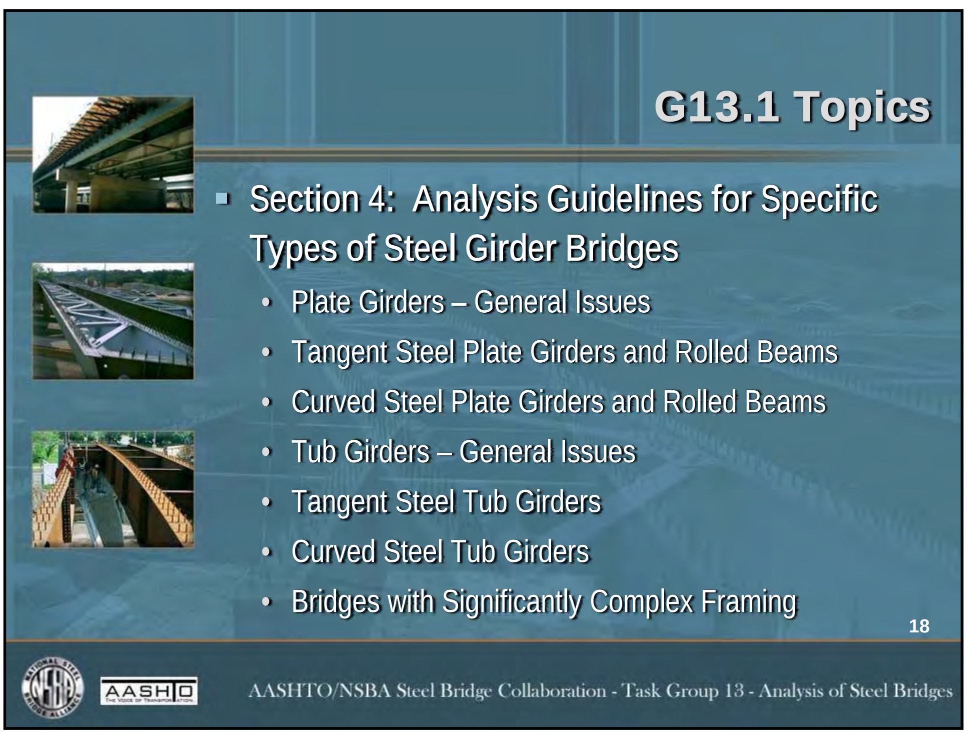
G13.1 Topics
Section 4: Analysis Guidelines for Specific Types of Steel Girder Bridges
Plate Girders – General Issues
Tangent Steel Plate Girders and Rolled Beams
Curved Steel Plate Girders and Rolled Beams
Tub Girders – General Issues
Tangent Steel Tub Girders
Curved Steel Tub Girders
Bridges with Significantly Complex Framing
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G13.1 Topics

- References
- Glossary
- Survey of Current Practice

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G13.1 Topics

- "Lively Discussion Items"
  - "Recommendations" vs. "Understanding"
  - Level of analysis (line girder / 2D, grid / 3D)
  - Effects of deck placement sequence
  - Phased construction analysis
  - Substructures (integral, straddle bents, etc.)
  - Detailing of cross frames and girders for intended erected position

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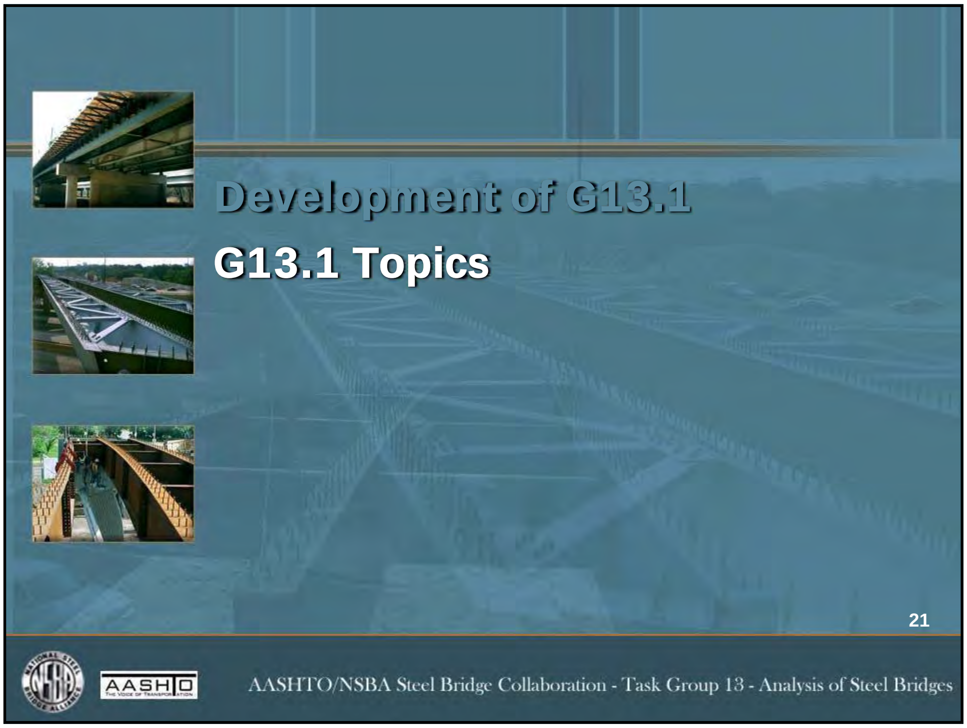
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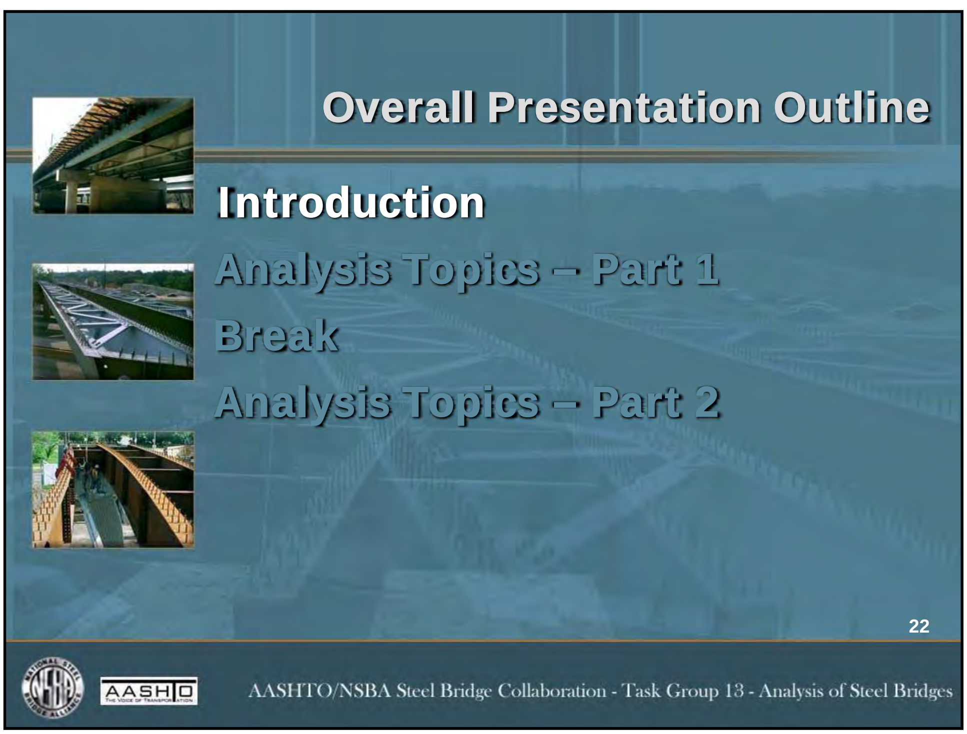
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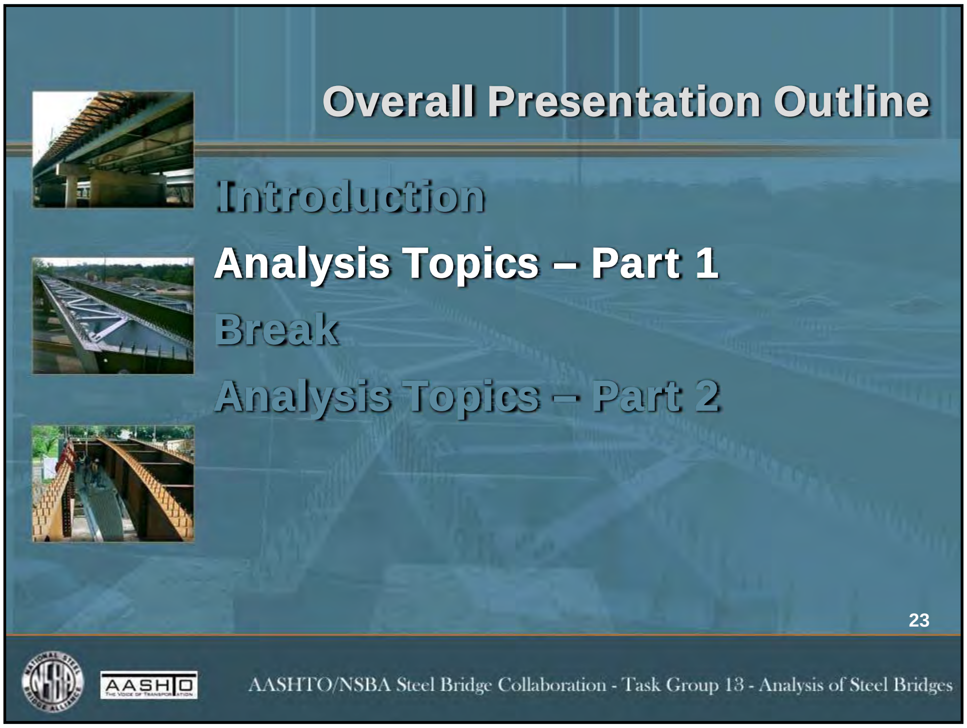
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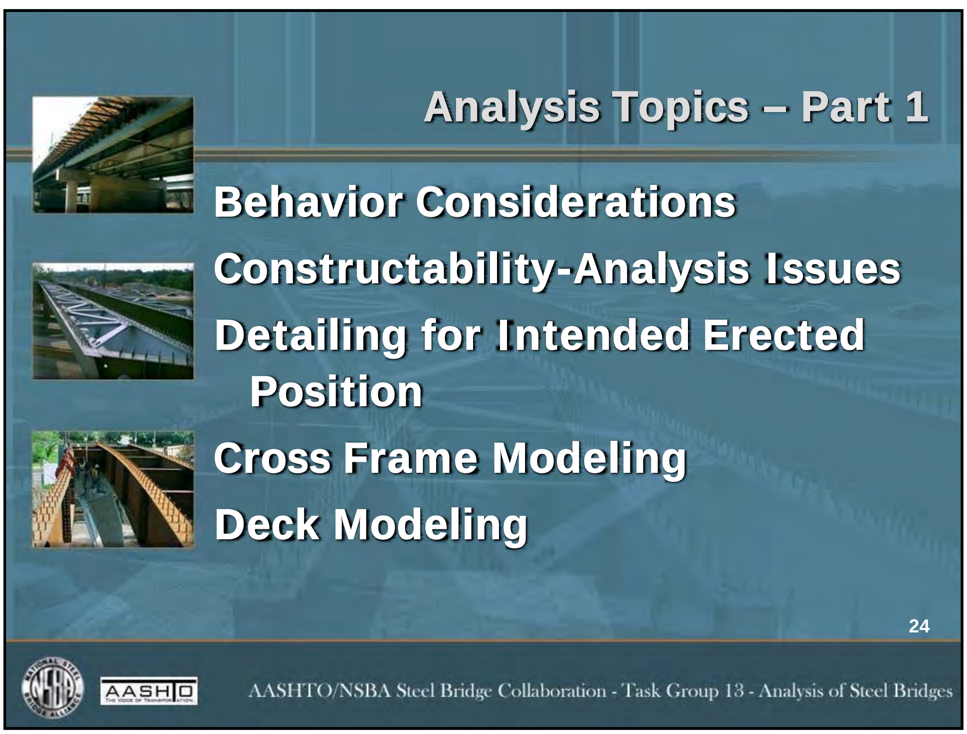
Analysis Topics – Part 1
Behavior Considerations
Constructability-Analysis Issues
Detailing for Intended Erected Position
Cross Frame Modeling
Deck Modeling
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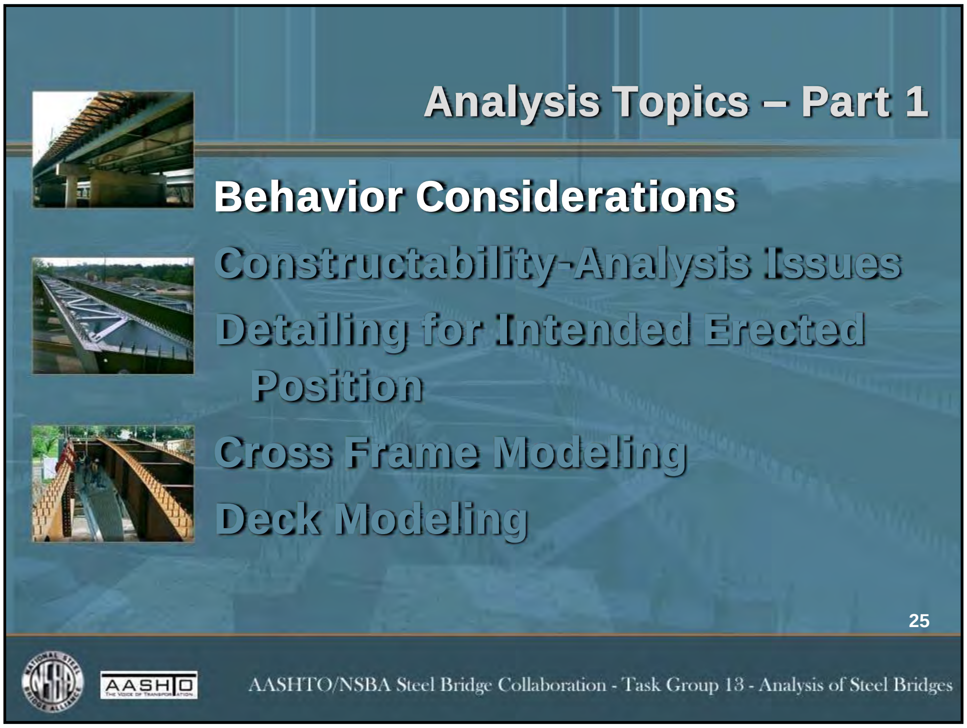
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Behavior Considerations
Overview
The Basics
Effects of Curvature
Torsion – Stresses
Torsion – Rotations
Load Shifting
Effects of Skew
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Behavior Considerations

- The Basics
  - Shear
  - Moment
  - Primary Bending Deflection
  - Primary Bending Rotation

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Behavior Considerations

- Effects of Curvature
  - Torsion – Stresses
  - Torsion – Rotations
  - Load Shifting
  - Discussed in the context of "effects of curvature," but skewed bridges experience much of the same behavior

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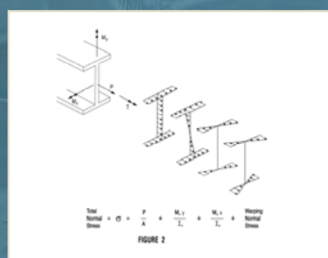
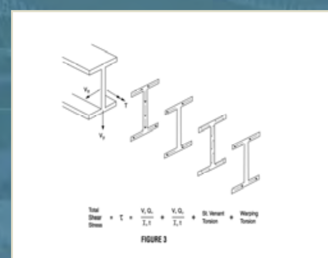
Behavior Considerations

- Torsion – Stresses, I-Girders
  - St. Venant Torsion
  - Warping Torsion





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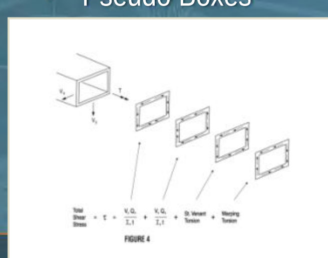
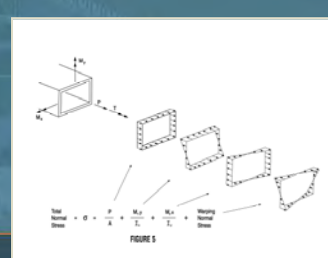
Behavior Considerations

- Torsion – Stresses, Tub Girders
  - St. Venant Torsion
  - Warping Torsion
  - Shear Flow increases web and flange shear
  - “Pseudo Boxes”





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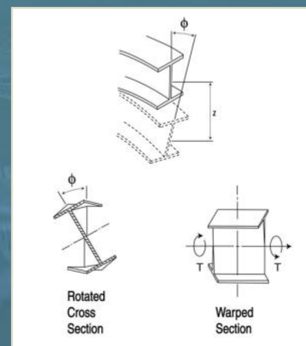
Behavior Considerations

- Torsion – Deformations
  - Twisting
  - Warping
  - These deformations can potentially affect fit-up during construction



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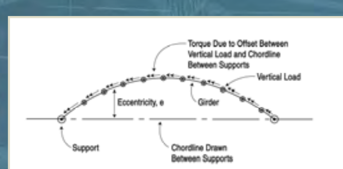
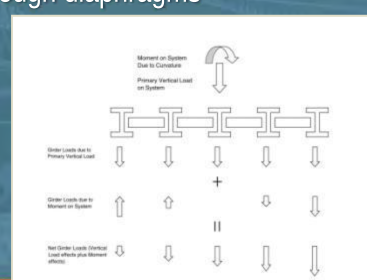
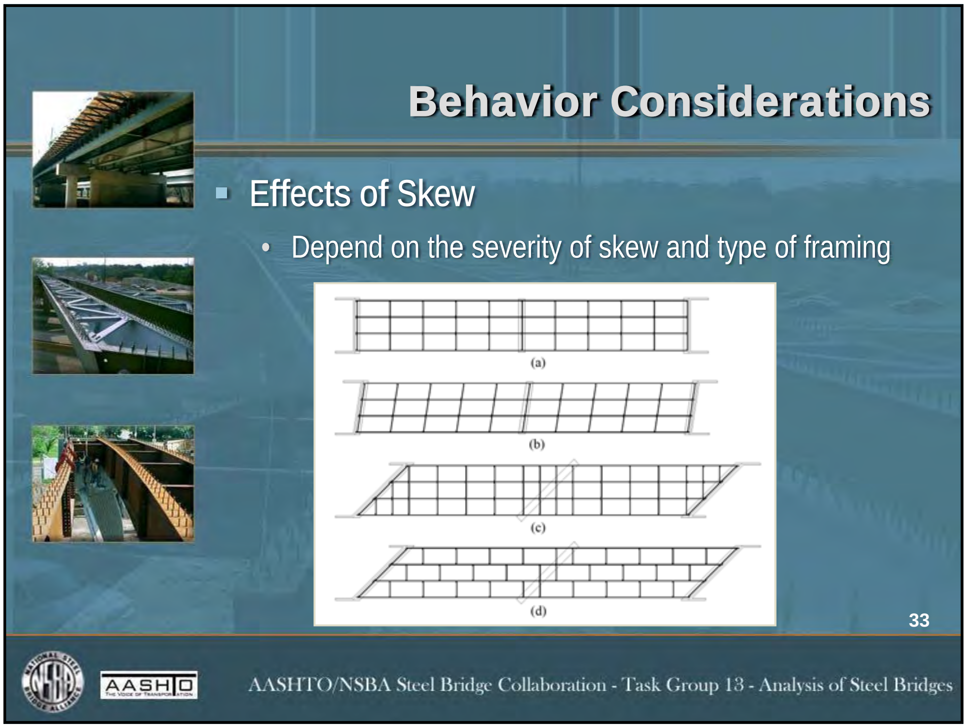
Behavior Considerations

- Load Shifting
  - Center of Gravity is offset from line between supports
  - Girders on outside of curve carry more load
  - Load is transferred through diaphragms






Behavior Considerations
Effects of Skew
Depend on the severity of skew and type of framing
(a)
(b)
(c)
(d)
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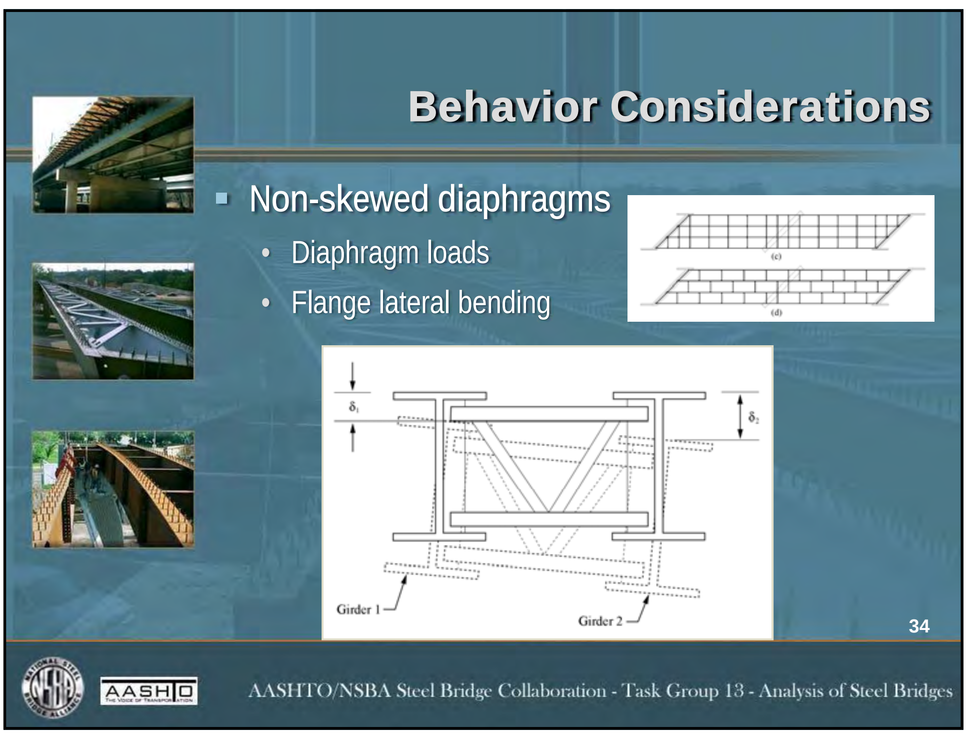
Behavior Considerations
Non-skewed diaphragms
Diaphragm loads
Flange lateral bending
(c)
(d)
Girder 1
Girder 2
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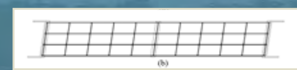
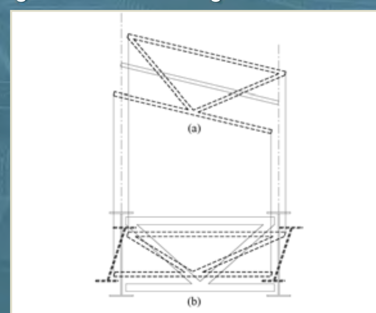
Behavior Considerations

- Skewed diaphragms
  - Diaphragm loads
  - Flange lateral bending





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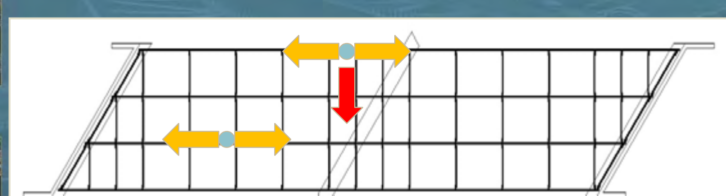
Behavior Considerations

- "Nuisance stiffness" effects
  - Development of transverse load paths



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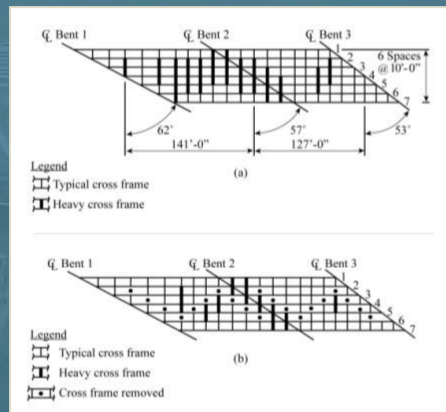
Behavior Considerations

- "Nuisance stiffness" effects



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Analysis Topics – Part 1

Behavior Considerations

Constructability-Analysis Issues

Detailing for Intended Erected Position

Cross Frame Modeling

Deck Modeling

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Analysis Topics – Part 1

Behavior Considerations

Constructability-Analysis Issues

Detailing for Intended Erected Position

Cross Frame Modeling

Deck Modeling

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Constructability-Analysis Issues

- Erection of Steel Framing
  - General Guidance
    - NCDOT "Constructability Guidelines for Steel Plate Girder Bridges"
    - NCDOT Working Drawing Review (WDR) guidelines
    - AASHTO/NSBA S10.1 *Steel Bridge Erection Guide Specifications*
    - NCHRP 12-79 Task 9 Report
  - Minimum items to consider in erection submittals
  - Use of appropriate analysis methods

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Constructability-Analysis Issues

- Investigation of Steel Erection Sequence
  - Stability throughout the erection sequence
  - Constructed geometry throughout erection sequence

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Constructability-Analysis Issues

- Investigation of Steel Erection Sequence
  - Critical Scenarios
    - Stability of girders during lifting
    - Single girder with minimal bracing
    - Minimal bracing in stages with few girders
    - Significant cantilever lengths
    - Significant curvature and/or skew – fit-up issues
    - Instability of incomplete framing under wind load

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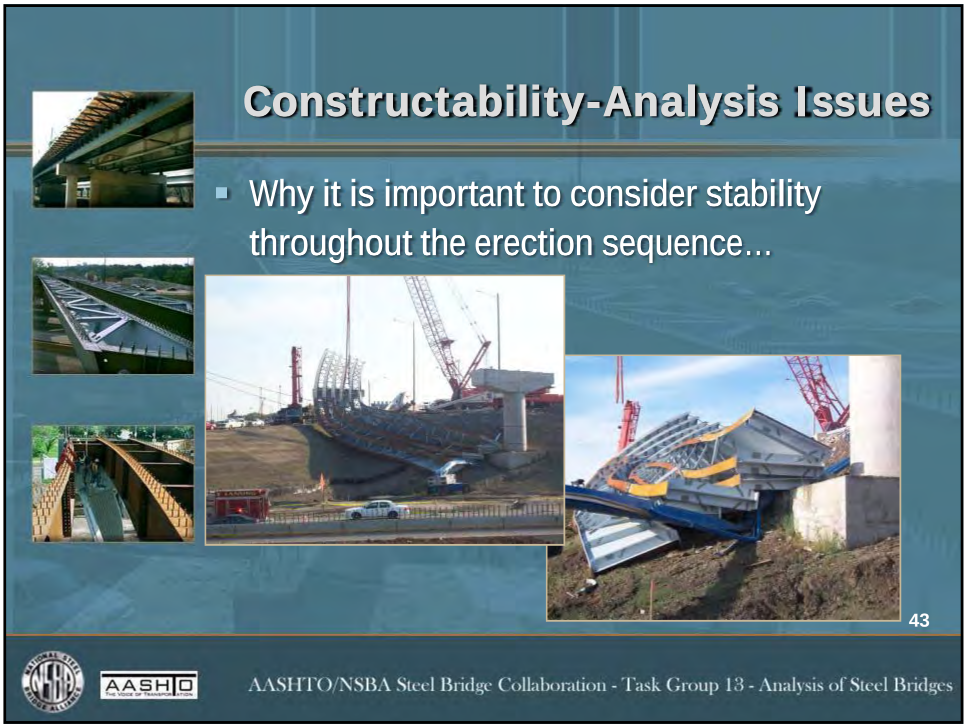
Constructability-Analysis Issues
Why it is important to consider stability throughout the erection sequence…
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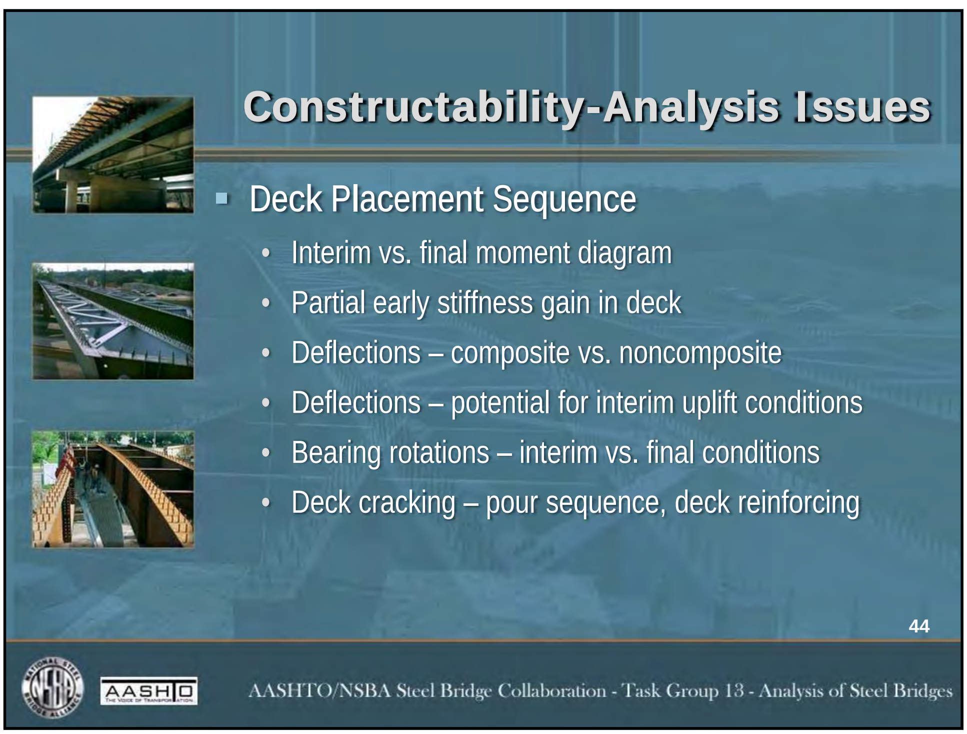
Constructability-Analysis Issues
Deck Placement Sequence
Interim vs. final moment diagram
Partial early stiffness gain in deck
Deflections – composite vs. noncomposite
Deflections – potential for interim uplift conditions
Bearing rotations – interim vs. final conditions
Deck cracking – pour sequence, deck reinforcing
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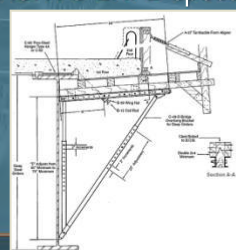
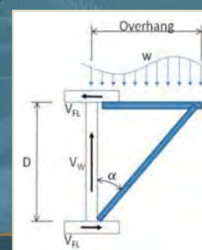
Constructability-Analysis Issues

- Overhang Analysis & Effect on Girders
  - Overhang width vs. girder spacing (1/4 to 1/3 S)
  - Traditional widths = typical overhang bracket systems
  - Effect of overhang loads on girders (addressed in AASHTO LRFD specs)





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Constructability-Analysis Issues

- Loads During Construction
  - Girder and deck dead load
  - Wind load on steel frame without deck
  - Live load – construction (workers, equipment, screed)
  - Live load – rehab or demolition (workers, equipment)
  - Miscellaneous loads (stockpiled materials)

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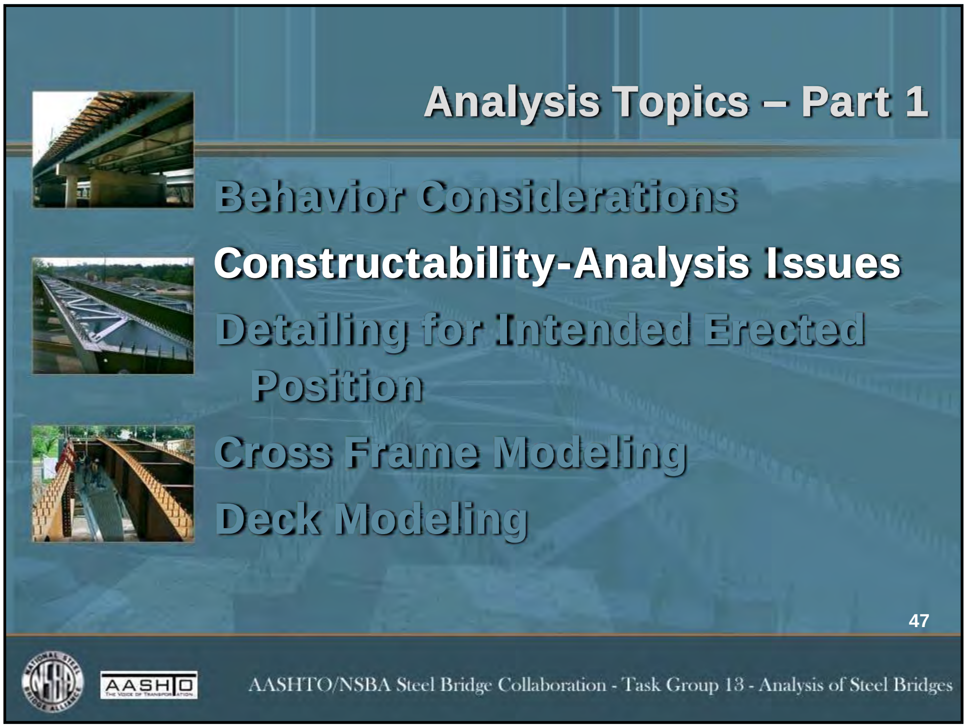

Analysis Topics – Part 1
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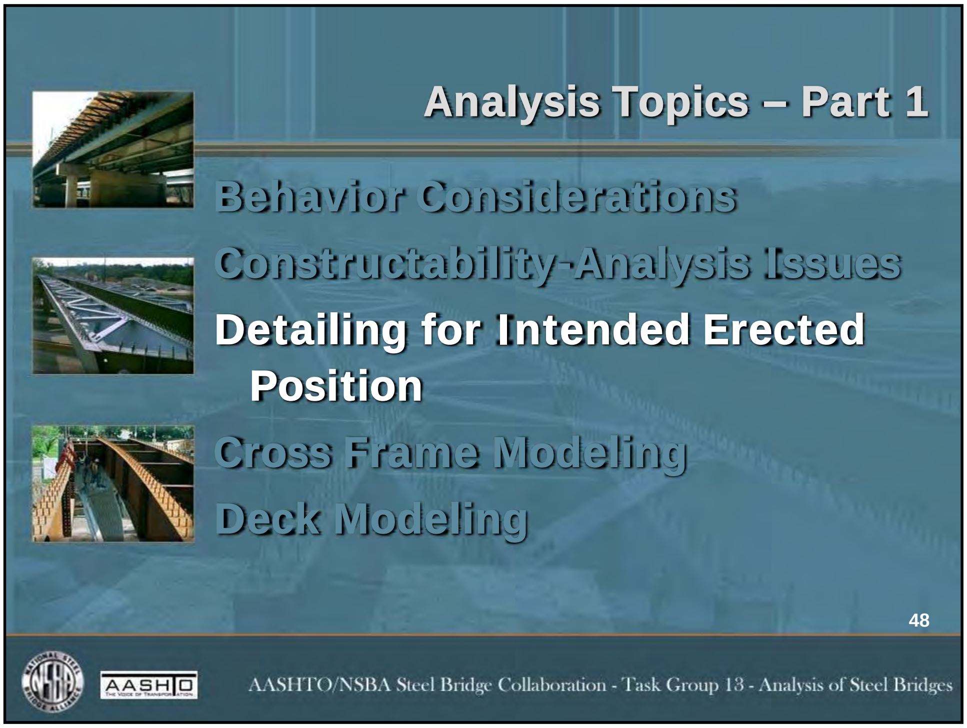

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Detailing for Intended Erected Position

- Two possible positions
  - Girder webs vertical (webs plumb)
  - Girder webs not vertical (out-of-plumb)
- Three stages of loading
  - No Load
  - Steel Dead Load
  - Total Dead Load

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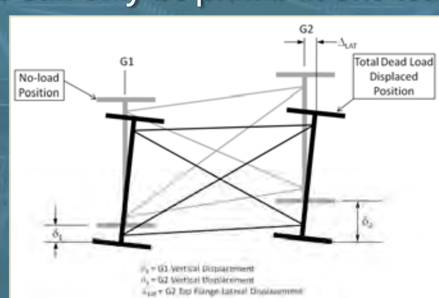
Detailing for Intended Erected Position

- Girders rotate (twist) in curved and/or skewed bridges
- Webs can only be plumb in one loading stage



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Detailing for Intended Erected Position

- Three common detailing methods
- No Load Fit (NLF)
  - Webs plumb under no load conditions
  - No force-fitting required
- Steel Dead Load Fit (SDLF)
- Total Dead Load Fit (TDLF)
  - Webs plumb under steel DL or total DL
  - Force-fit cross frames/girders under no load conditions

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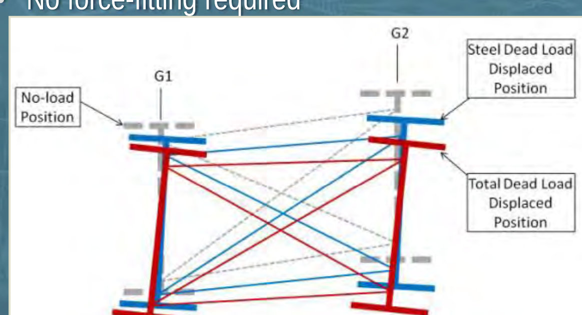
Detailing for Intended Erected Position

- No Load Fit (NLF)
  - Webs plumb under no load conditions
  - No force-fitting required



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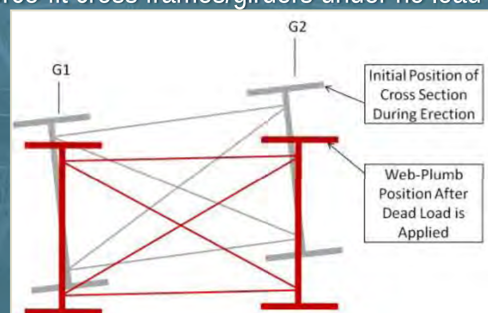
Detailing for Intended Erected Position

- Steel or Total Dead Load Fit (SDLF or TDLF)
  - Webs plumb under steel DL or total DL
  - Force-fit cross frames/girders under no load conditions



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Detailing for Intended Erected Position

- Considerations
  - Detailing
    - Cross frame geometry is different for NLF vs. SDLF vs. TDLF
  - Fit-up
    - Plans must clearly specify detailing method or there may be fit-up issues during construction
  - Forces
    - NLF = Forces in final condition from traditional analysis
    - SDFL, TDLF = Technically a “lack of fit” analysis is required
  - See NCHRP 12-79 Task 8 Report for more guidance

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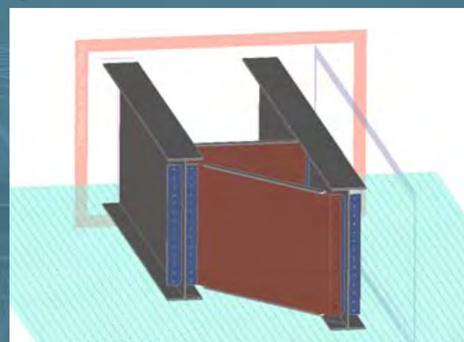
Detailing for Intended Erected Position

- Example



Girders straight, girder webs vertical
(final position, isometric view)

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Detailing for Intended Erected Position

- Example

Cambered position
Back view showing girders rotated up from horizontal plane
Diaphragms not aligned (designed to fit in final position)

Diaphragm holes do not align with web stiffener holes when girders are cambered

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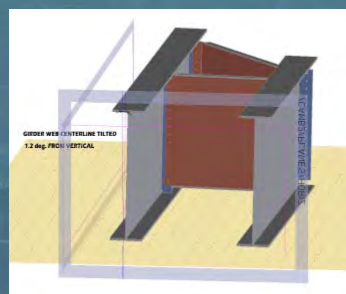
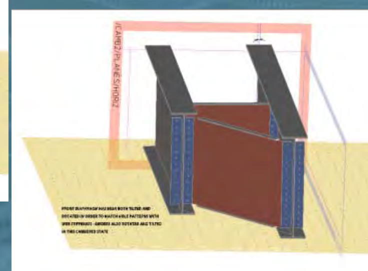
Detailing for Intended Erected Position

- Example



Girder web centerline tilted 1.2 deg from vertical

Front diaphragm has been both tilted and rotated in order to match hole patterns with web stiffeners. Girders also rotated and tilted in this cambered state



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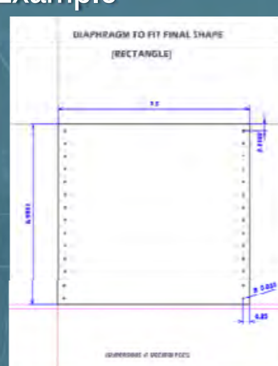
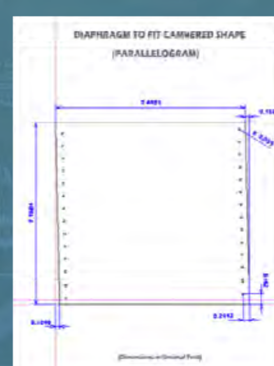
Detailing for Intended Erected Position

- Example



Diaphragm fit to final shape
(Total Dead Load Fit)
Rectangle



Diaphragm fit to cambered shape
(No Load Fit)
Parallelogram

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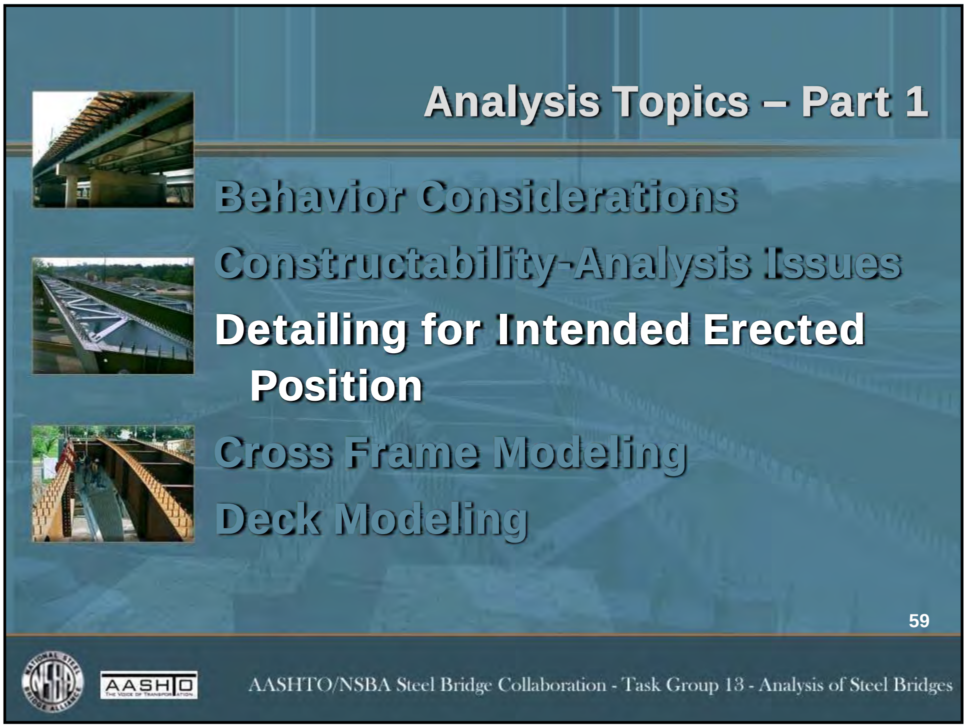
Analysis Topics – Part 1
Behavior Considerations
Constructability-Analysis Issues
Detailing for Intended Erected Position
Cross Frame Modeling
Deck Modeling
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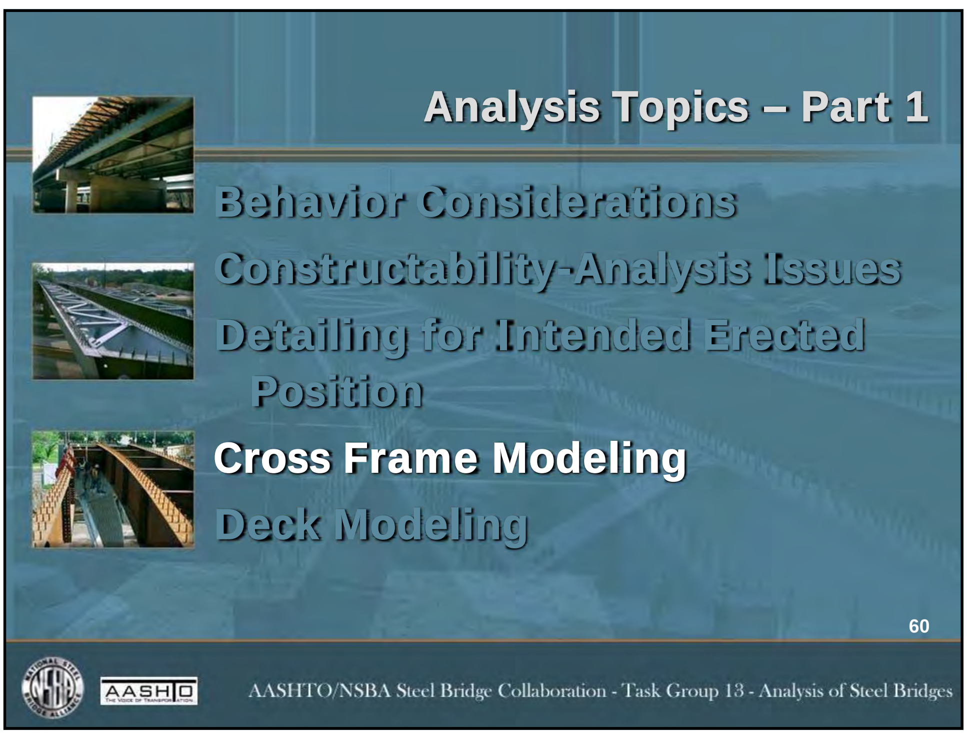
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Deck Modeling
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Cross Frame Modeling

- 3D vs. 2D modeling
- Modeling cross frames in 3D analyses
  - Refined analysis of stiffness and response
  - Direct analysis results for all members
- Modeling cross frames in 2D analyses
  - Approximations of stiffness and response
  - Must convert simplified results into member forces

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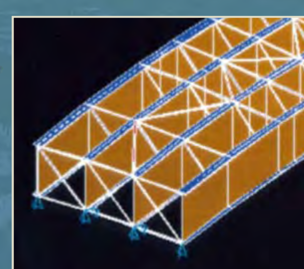
Cross Frame Modeling

- 3D modeling
  - Flanges: beam or plate elements
  - Webs: plate elements
  - Diaphragms, bracing: truss or plate elements
  - Deck: solid or plate elements



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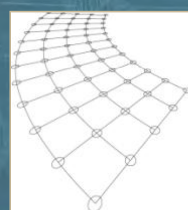
Cross Frame Modeling

- 2D ("Grid" or "Grillage") modeling
  - Girders modeled as line elements
  - Diaphragms modeled as line elements
  - Deck modeled in strips as line elements
  - Plate and eccentric beam models



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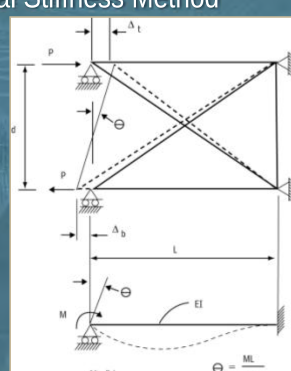
Cross Frame Modeling

- 2D Modeling of Cross Frames
  - Flexural Stiffness Method



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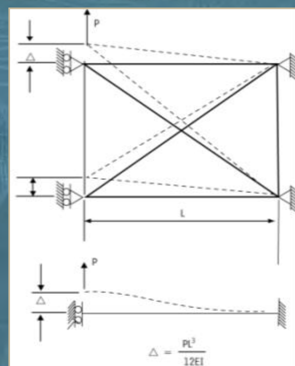
Cross Frame Modeling

- 2D Modeling of Cross Frames
  - Shear Stiffness Method



Analysis Topics – Part 1

Behavior Considerations

Constructability-Analysis Issues

Detailing for Intended Erected Position

Cross Frame Modeling

Deck Modeling

Analysis Topics – Part 1

- Behavior Considerations
- Constructability-Analysis Issues
- Detailing for Intended Erected Position
- Cross Frame Modeling
- **Deck Modeling**

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Deck Modeling

- Composite vs. Noncomposite
- If no shear connectors are provided…
  - Typically deck considered noncomposite for all loads
  - There may be some bond between deck and girder
  - When bond stress is exceeded, change to noncomposite behavior is sudden

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Deck Modeling

- Composite vs. Noncomposite
- If shear connectors are provided…
- Positive moment region
  - Deck considered full composite once cured
  - In special cases – may see partial early stiffness gain
  - Transient loads act on short term composite section
    - Modular ratio = n
  - Permanent loads act on long term composite section
    - Modular ratio = 3n

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Deck Modeling

- Composite vs. Noncomposite
- If shear connectors are provided…
- Negative moment region
  - Without shear connectors in negative moment region
    - No composite action
    - Deck concrete and longitudinal reinforcing considered totally ineffective
  - With shear connectors in negative moment region
    - Deck longitudinal reinforcing acts as part of composite section

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Deck Modeling



- Effective Width
- Simplified analyses (line girder, 2D Grid)
  - Historically limited to 12 times deck thickness, ¼ of span length, or girder spacing
  - Currently full width considered fully effective
  - Longitudinal direction – deck modeled in strips
  - Transverse direction – deck neglected in line girder
  - Transverse direction – deck effectively modeled in strips, particularly at cross frame locations

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Deck Modeling



- Effective Width
- Refined analyses (2D P&EB, 3D)
  - Deck is explicitly modeled in the analysis using plate, shell, or brick elements
  - Longitudinal and transverse effects captured directly

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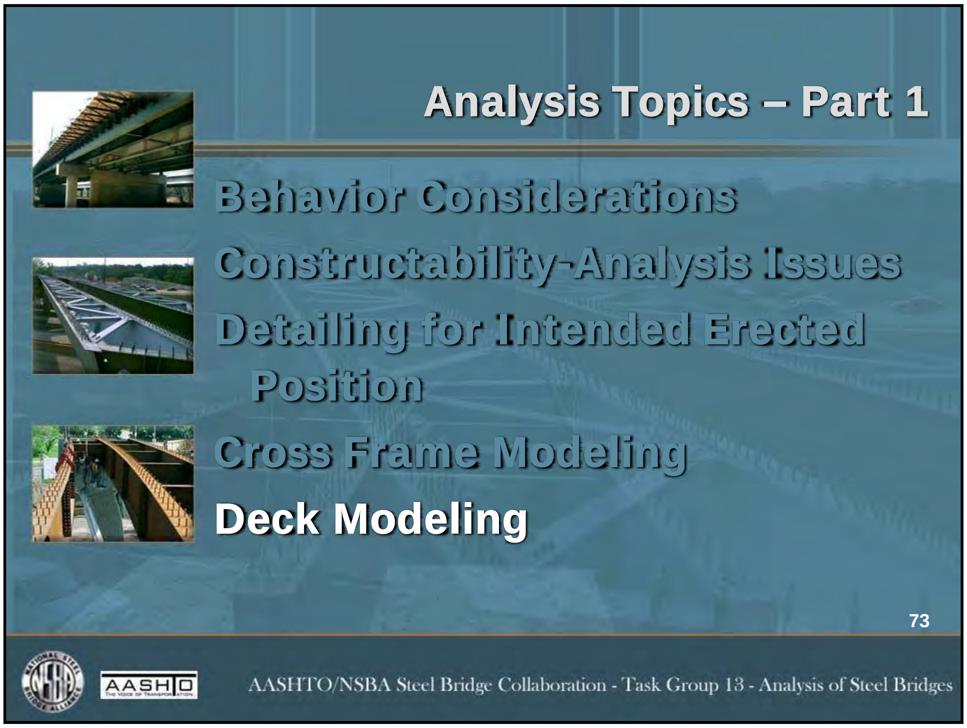
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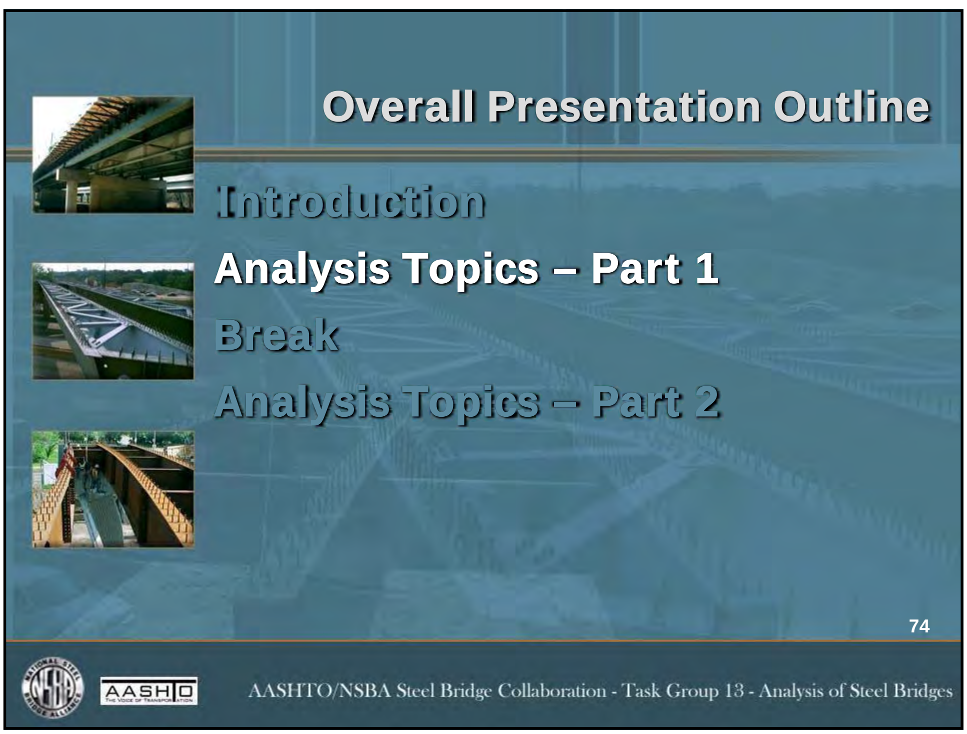
AASHTO/NSBA Steel Bridge Collaboration - Task Group 13 - Analysis of Steel Bridges


Overall Presentation Outline
Introduction
Analysis Topics – Part 1
Break
Analysis Topics – Part 2
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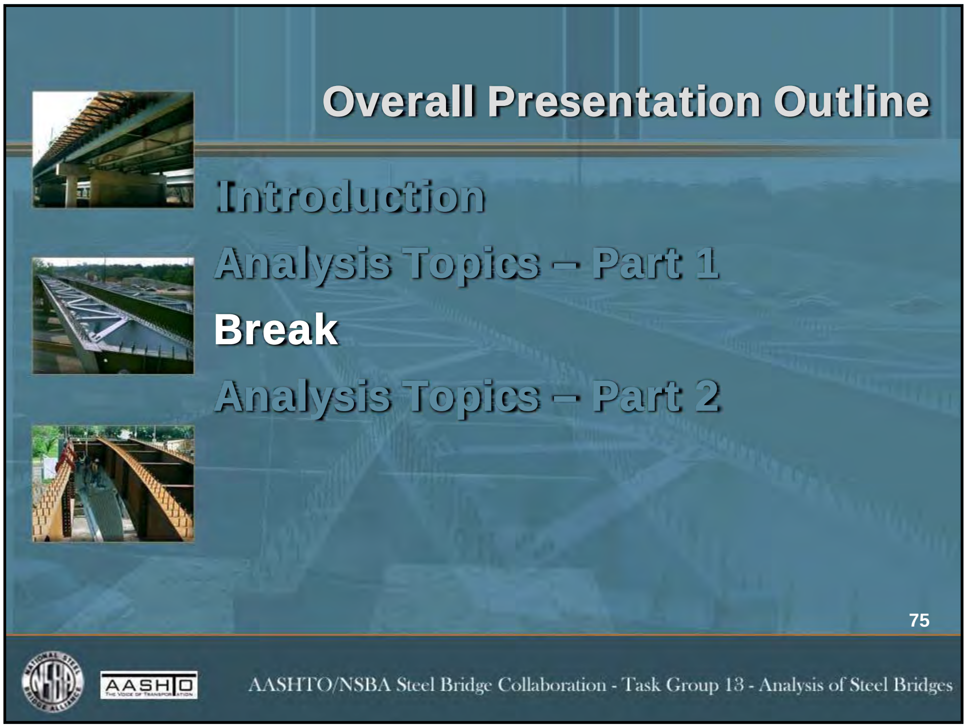
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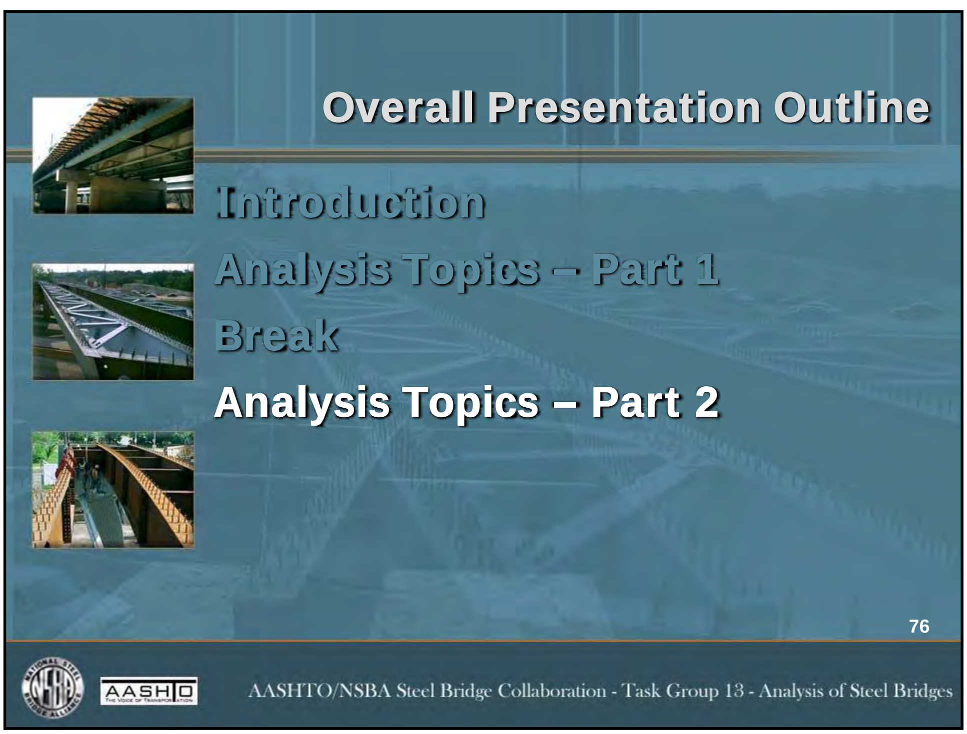
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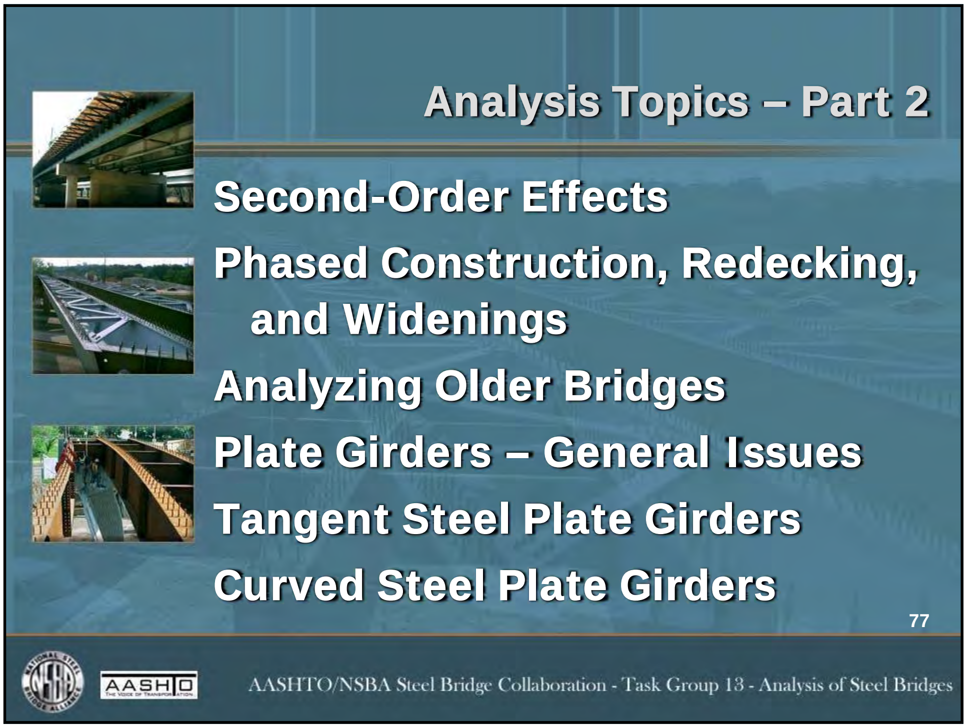
Analysis Topics – Part 2
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Phased Construction, Redecking, and Widenings
Analyzing Older Bridges
Plate Girders – General Issues
Tangent Steel Plate Girders
Curved Steel Plate Girders
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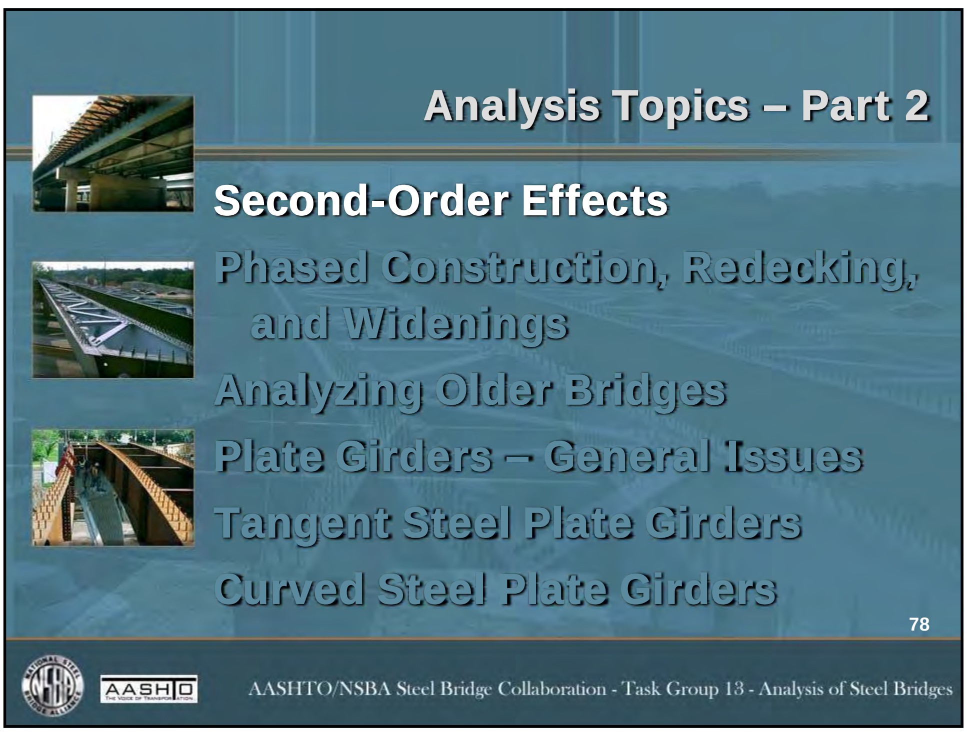
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Second-Order Effects

- What is a “second-order” analysis?
  - Any analysis which considers the deflected position of the structure in satisfying equilibrium
  - AASHTO LRFD Section 4 also uses the terms “large deflection theory” and “stability analysis”
  - AASHTO LRFD Sections 4 and 6 also use the term “geometric nonlinear analysis”

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Second-Order Effects

- Generally two types of second-order analyses
- Buckling analysis
  - Eigenvalues (buckling load levels)
  - Eigenvectors (buckling modes)
  - “K-factors” are derived from eigenvalue buckling analyses
- P-delta analysis (P-Δ, P-δ)
  - Effects of load times relative displacement are considered incrementally via “iterative analysis”

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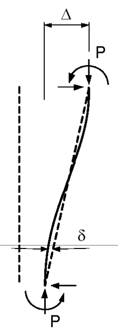
Second-Order Effects

- Column and beam-column analysis



$P\Delta$ = Additional moment (couple) due to the axial force acting through the relative transverse displacement of member (or segment) ends

$P\delta$ = Additional moment due to the axial force acting through the transverse displacement relative to the member (or segment) chord

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Second-Order Effects

- What about steel girders?
- Many contributors to flange lateral bending
  - Curvature
  - Overhang brackets
  - Skew
  - Wind
- Approximate moment amplifier in AASHTO LRFD 6.10.1.6 is simple and conservative
- Construction cases typically most critical

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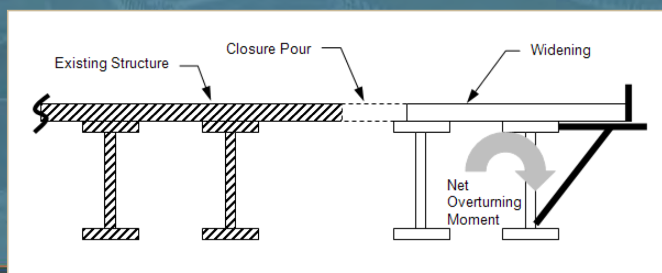
Second-Order Effects

- Global stability of narrow steel girder systems
  - Two-girder bridge (pedestrian bridges, etc.)
  - Intermediate stages during construction, widening
  - Refined computer analysis, or Yura method



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Analysis Topics – Part 2

Second-Order Effects

Phased Construction, Redecking, and Widenings

Analyzing Older Bridges

Plate Girders – General Issues

Tangent Steel Plate Girders

Curved Steel Plate Girders

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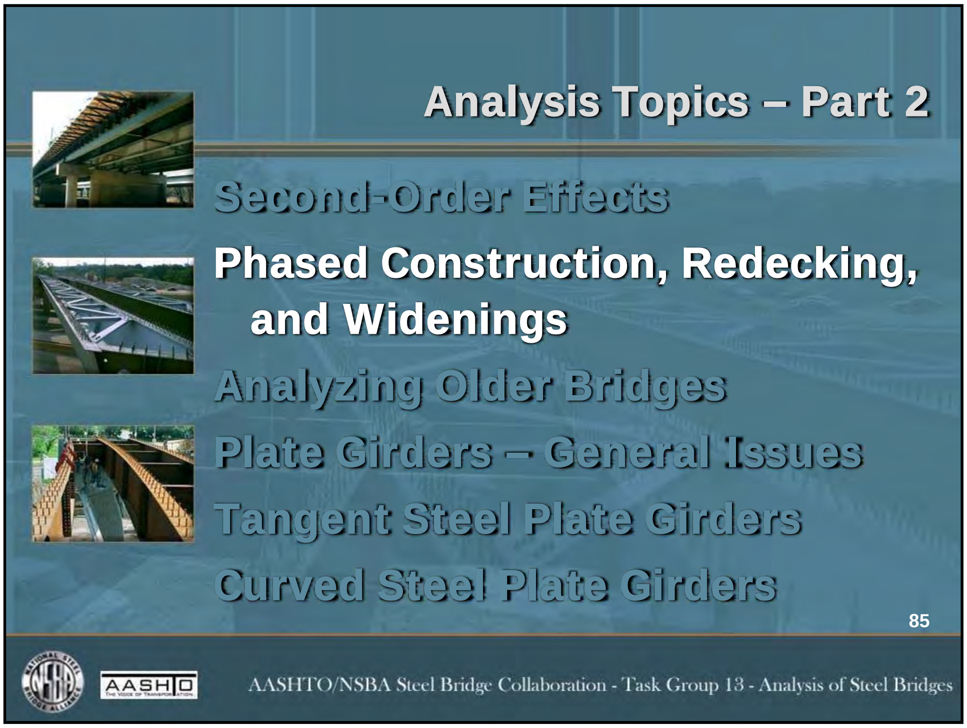
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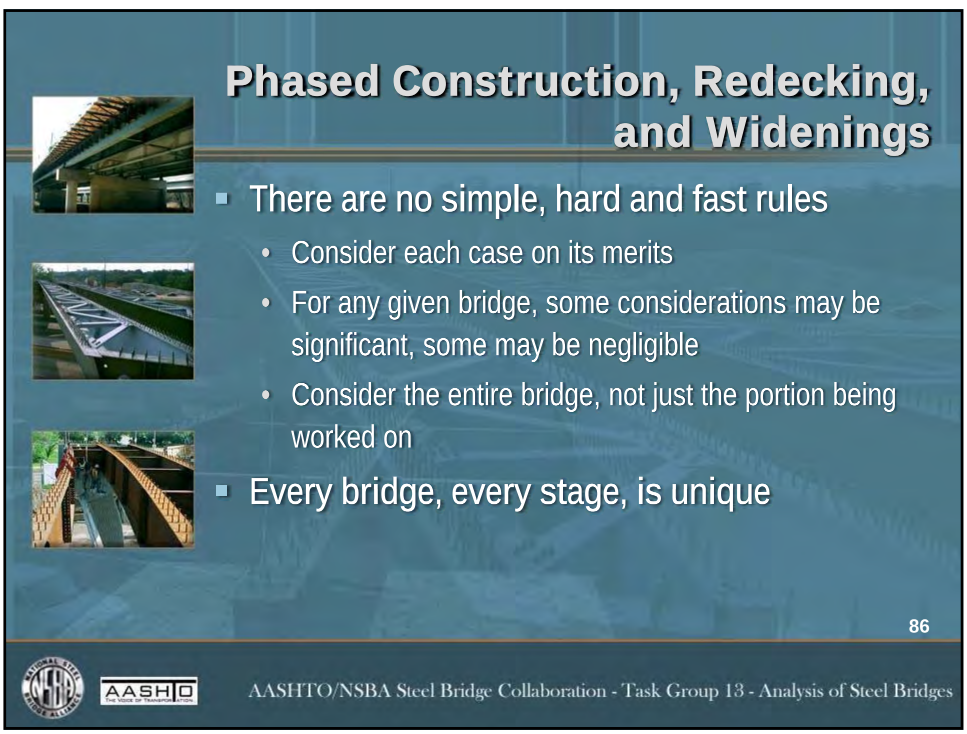
Phased Construction, Redecking, and Widenings
There are no simple, hard and fast rules
Consider each case on its merits
For any given bridge, some considerations may be significant, some may be negligible
Consider the entire bridge, not just the portion being worked on
Every bridge, every stage, is unique
86
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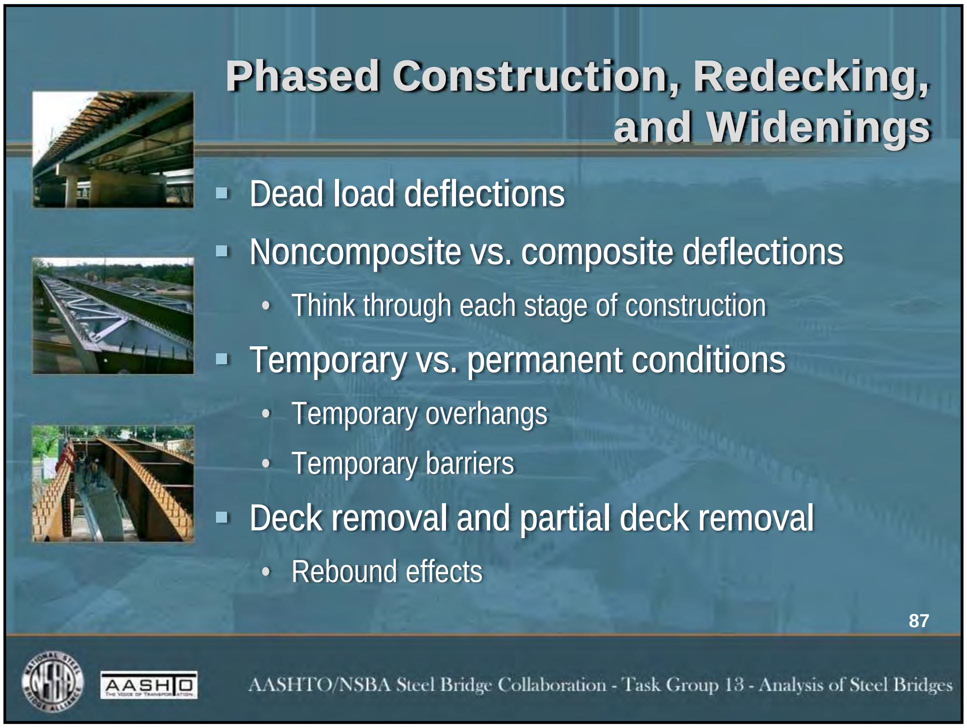
Phased Construction, Redecking, and Widenings
Dead load deflections
Noncomposite vs. composite deflections
Think through each stage of construction
Temporary vs. permanent conditions
Temporary overhangs
Temporary barriers
Deck removal and partial deck removal
Rebound effects
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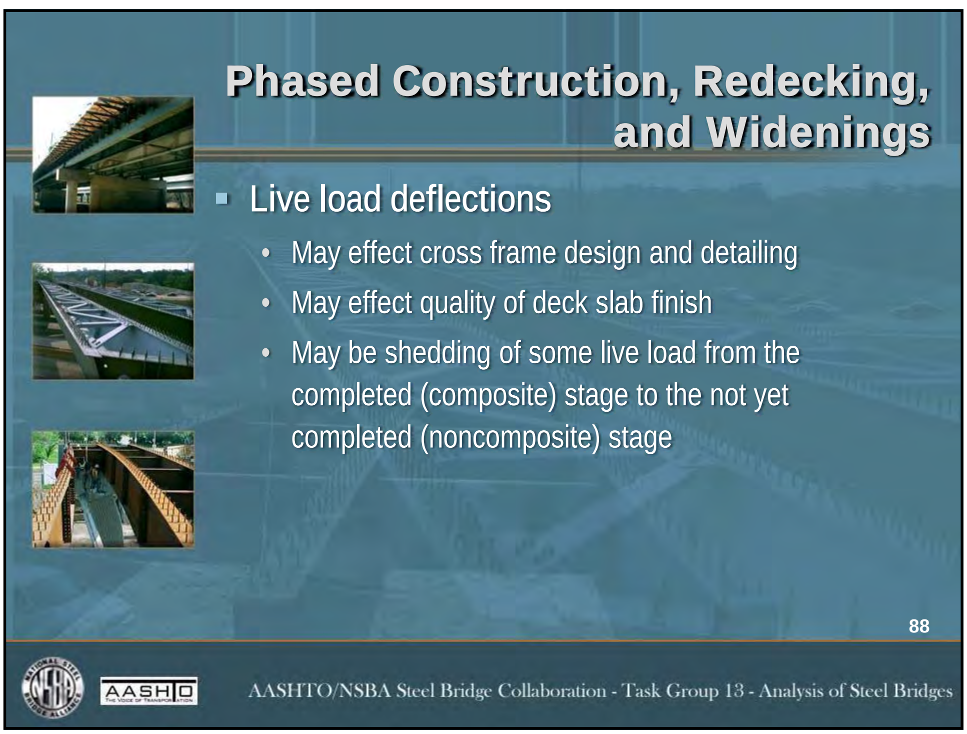
Phased Construction, Redecking, and Widenings
Live load deflections
May effect cross frame design and detailing
May effect quality of deck slab finish
May be shedding of some live load from the completed (composite) stage to the not yet completed (noncomposite) stage
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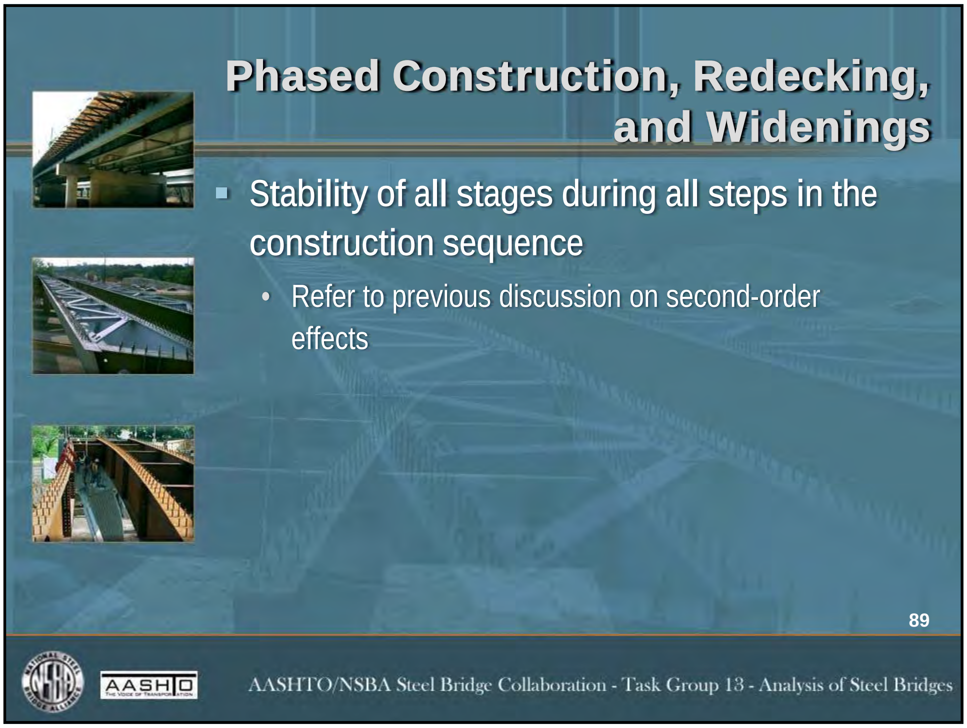
Phased Construction, Redecking, and Widenings
Stability of all stages during all steps in the construction sequence
Refer to previous discussion on second-order effects
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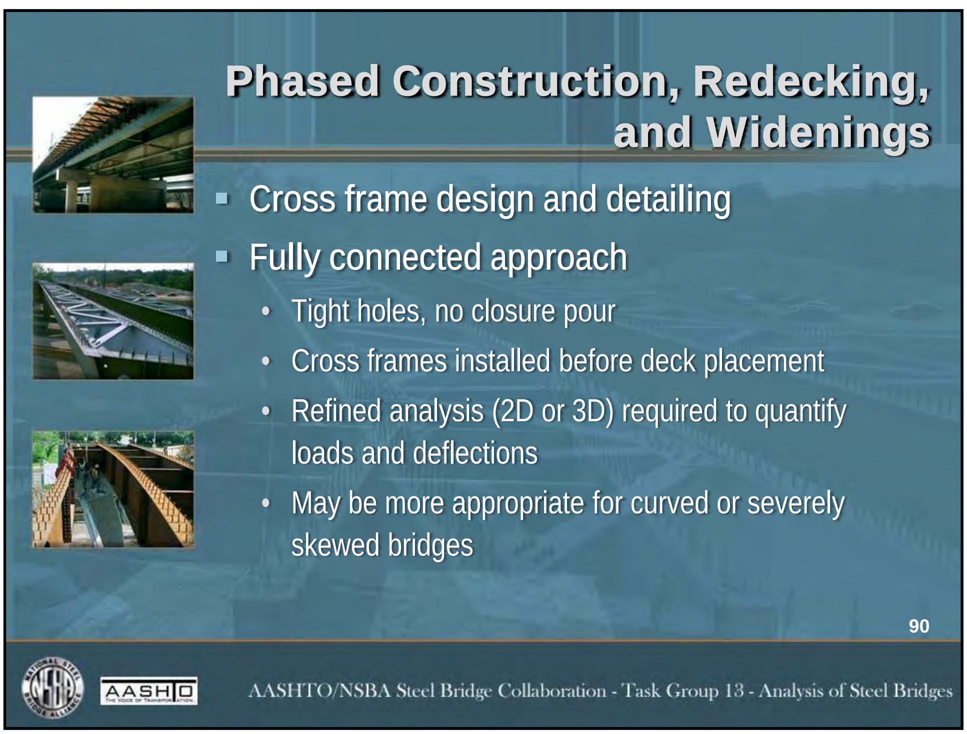
Phased Construction, Redecking, and Widenings
Cross frame design and detailing
Fully connected approach
Tight holes, no closure pour
Cross frames installed before deck placement
Refined analysis (2D or 3D) required to quantify loads and deflections
May be more appropriate for curved or severely skewed bridges
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Phased Construction, Redecking, and Widenings

- Cross frame design and detailing
- "Disconnected" approach
  - Slotted holes or cross frames installed after deck placement
  - Closure pour
  - Simplified analyses may be sufficient
  - May be more appropriate for straight, non-skewed bridges

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Analysis Topics – Part 2

Second-Order Effects

Phased Construction, Redecking, and Widenings

Analyzing Older Bridges

Plate Girders – General Issues

Tangent Steel Plate Girders

Curved Steel Plate Girders

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Analysis Topics – Part 2

- Second-Order Effects
- Phased Construction, Redecking, and Widenings
- **Analyzing Older Bridges**
- Plate Girders – General Issues
- Tangent Steel Plate Girders
- Curved Steel Plate Girders

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Analyzing Older Bridges

- Routine bridge inspections
  - “Hands on,” every two years
  - General documentation of condition and section loss

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Analyzing Older Bridges

- Special inspections
  - Focus on specific details with a history of problems
  - May be more frequent
- Damage inspections
  - Case by case depending on what happened

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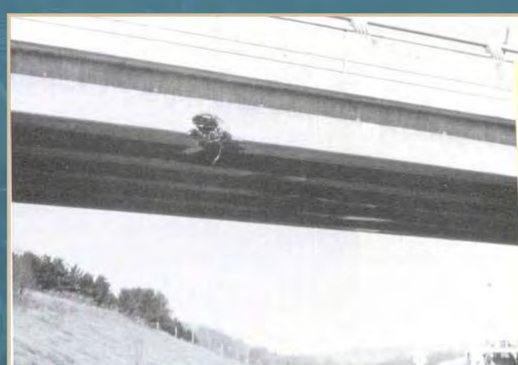
Analyzing Older Bridges

- Overheight Vehicle Damage



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Analyzing Older Bridges

- Overheight Vehicle Damage

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Analyzing Older Bridges

- Errant Vehicle Damage

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Analyzing Older Bridges

- Errant Vehicle Damage
  - I-70 Bridge Strike, Hays, KS

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Analyzing Older Bridges

- Errant Vehicle Damage
  - I-70 Bridge Strike, Hays, KS

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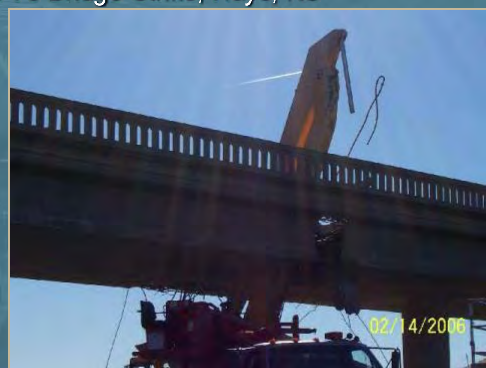
Analyzing Older Bridges

- Errant Vehicle Damage
  - I-70 Bridge Strike, Hays, KS



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Analyzing Older Bridges

- Errant Vehicle Damage
  - I-70 Bridge Strike, Hays, KS

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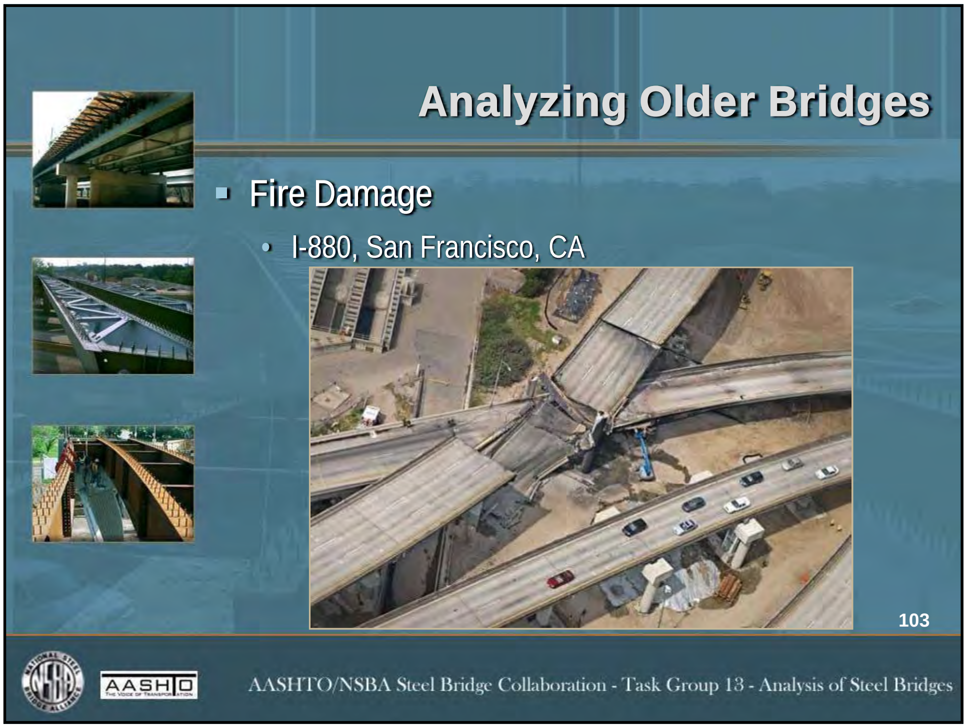
Analyzing Older Bridges
Fire Damage
I-880, San Francisco, CA
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Analyzing Older Bridges
Fire Damage
I-880, San Francisco, CA
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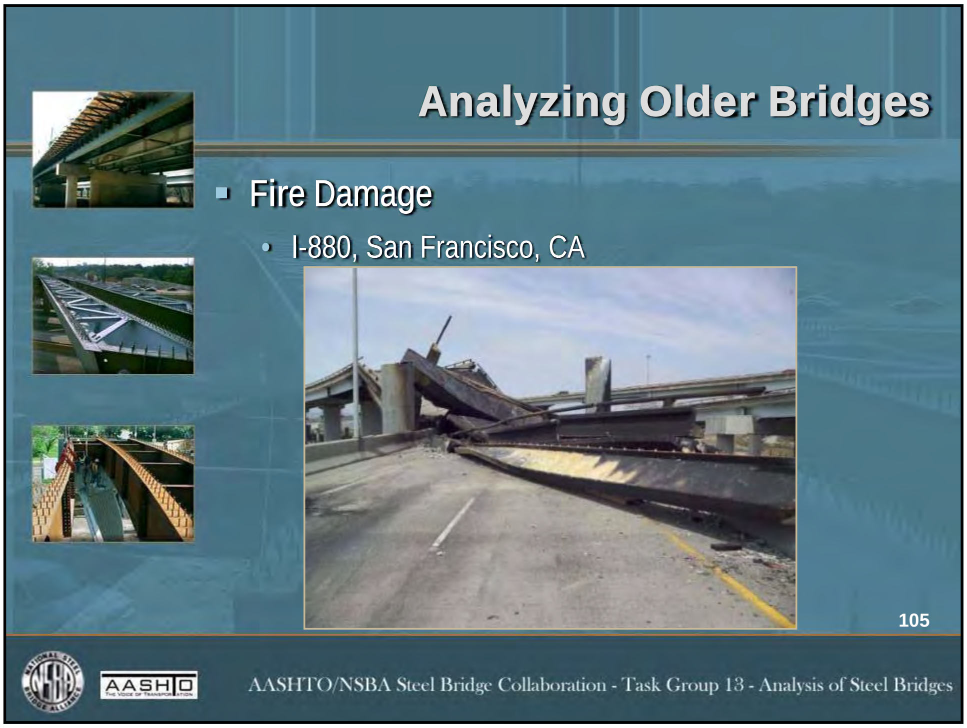
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Analyzing Older Bridges
Fire Damage
I-880, San Francisco, CA
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Analyzing Older Bridges

- Load rating
  - Routine ratings – simpler analysis methods
  - Refined analysis when appropriate
  - Consider condition of bridge, degradation of materials, section loss
  - Consider composite behavior appropriately – are there shear connectors?

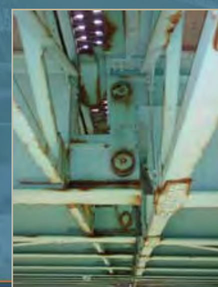


Analyzing Older Bridges

- Fatigue evaluations
  - Not typically part of routine evaluations, but may be appropriate in older steel bridges, especially if:
    - Details with a history of problems
    - Cracking has been observed
  - Load-induced fatigue
    - In-plane fatigue stresses due to repetitive loading
  - Distortion-induced fatigue
    - Out-of-plane stresses due to unrestrained connection details

Analyzing Older Bridges

- Bridges with hinges
  - Some details are fracture-critical
  - Consider appropriately in the analysis – does the hinge still function or is it seized/frozen?



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Analyzing Older Bridges

- Non-destructive load testing
  - Very complex structures
  - Structures with a history of problems
- Steps
  1. Instrument bridge
  2. Apply a limited number of known loadings
  3. Calibrate analysis model to measured responses
  4. Then perform analysis of other load cases

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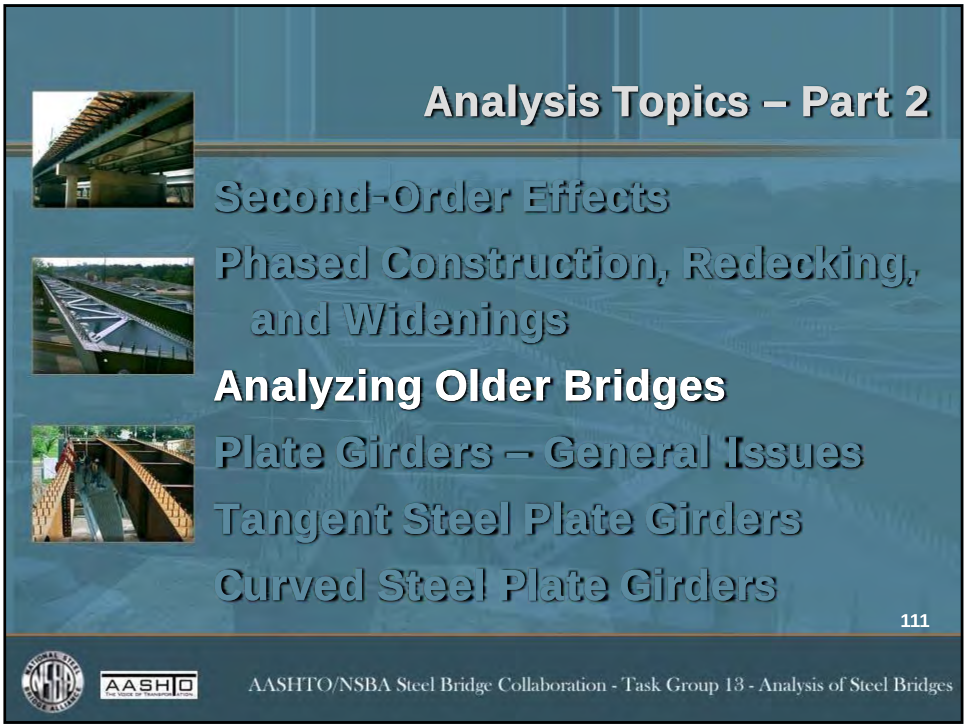
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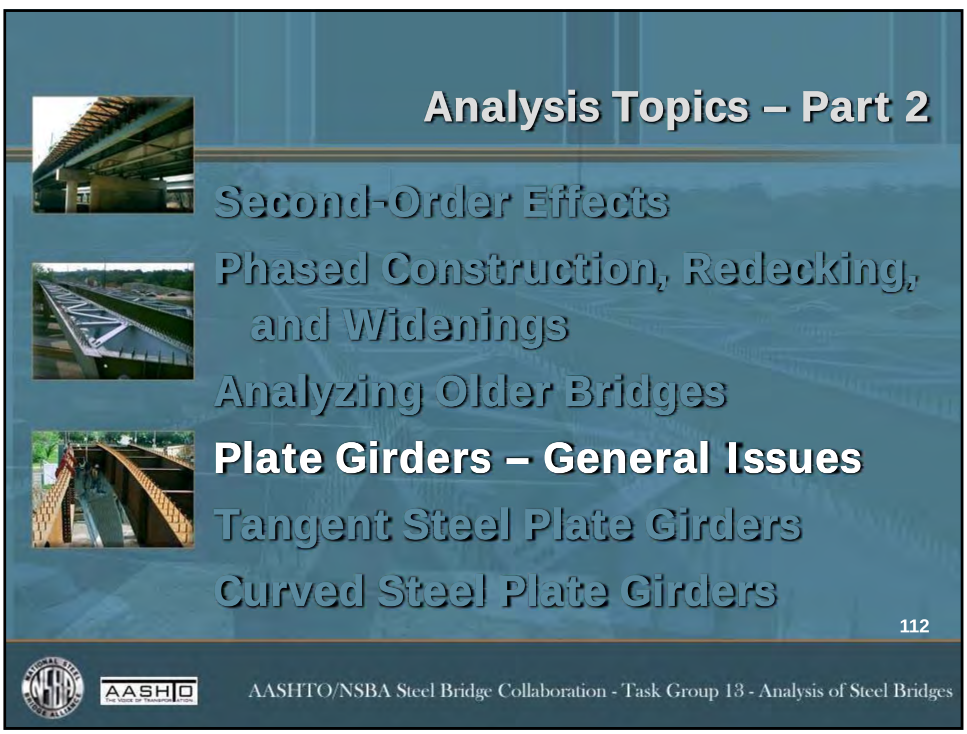
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Plate Girders – General Issues

- Cross frame modeling
- Lateral bracing
- Narrow systems – stability analysis
- Narrow systems – redundancy analysis
- Variable depth girders
- Width to span ratio

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Plate Girders – General Issues

- Cross frame modeling
- Lateral bracing
- Narrow systems – stability analysis
- Narrow systems – redundancy analysis
- Variable depth girders
- Width to span ratio

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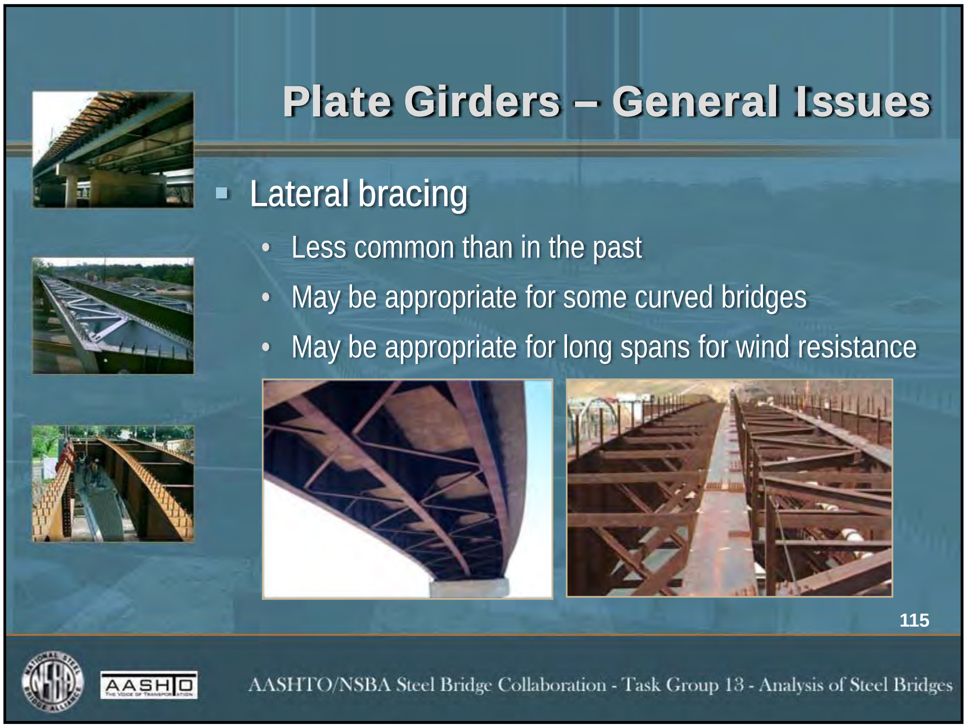
Plate Girders – General Issues
Lateral bracing
Less common than in the past
May be appropriate for some curved bridges
May be appropriate for long spans for wind resistance
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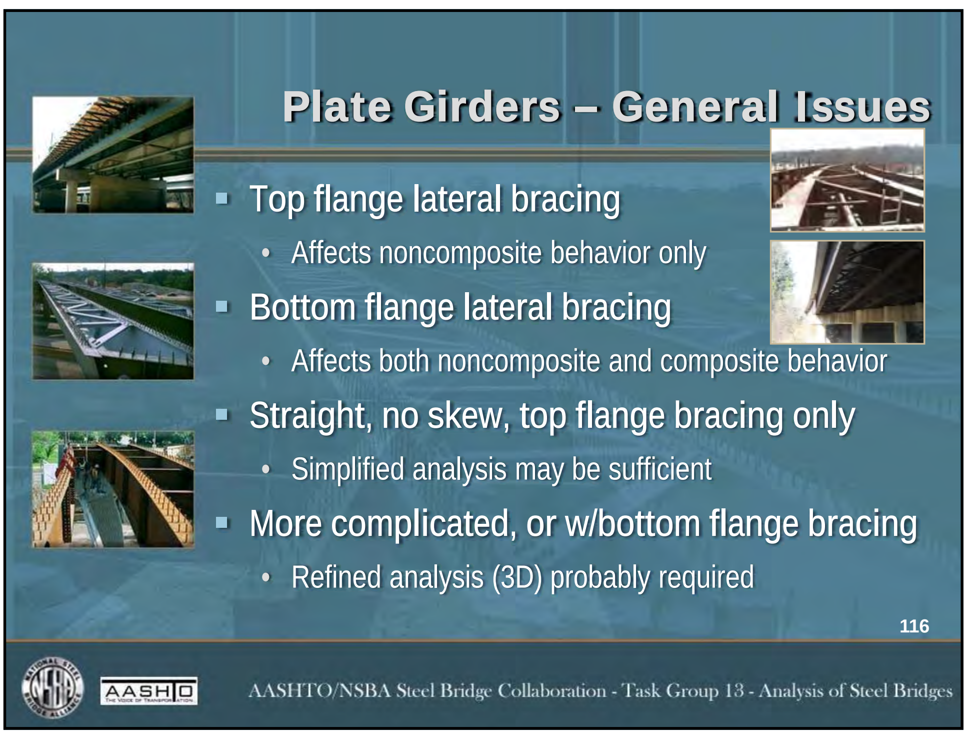
Plate Girders – General Issues
Top flange lateral bracing
Affects noncomposite behavior only
Bottom flange lateral bracing
Affects both noncomposite and composite behavior
Straight, no skew, top flange bracing only
Simplified analysis may be sufficient
More complicated, or w/bottom flange bracing
Refined analysis (3D) probably required
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Plate Girders – General Issues

- Narrow systems – redundancy analysis
  - Two-girder ("twin-girder") bridges = nonredundant
  - For I-girder bridges, sophisticated analysis may demonstrate redundancy, but reliable load paths are tricky to provide and analysis is very difficult
  - Tub girder bridges are a different story…

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Plate Girders – General Issues

- Variable depth girders
- Analysis model
  - Stiffness must be modeled correctly or else moment, shear, and dead load deflection predictions will be erroneous
- Detailed stress analysis
  - Refined (3D) analysis
  - Hand analysis per AASHTO LRFD and Blodgett

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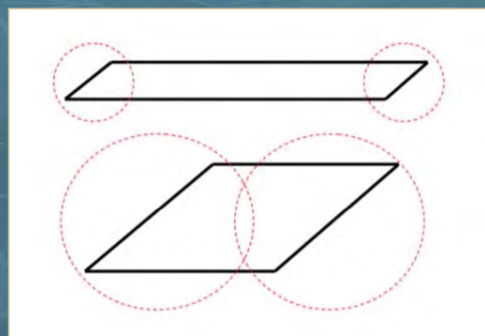
Plate Girders – General Issues

- Width to span ratio
  - Influence on secondary effects



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Analysis Topics – Part 2

Second-Order Effects

Phased Construction, Redecking, and Widenings

Analyzing Older Bridges

Plate Girders – General Issues

Tangent Steel Plate Girders

Curved Steel Plate Girders

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Analysis Topics – Part 2

- Second-Order Effects
- Phased Construction, Redecking, and Widenings
- Analyzing Older Bridges
- Plate Girders – General Issues
- **Tangent Steel Plate Girders**
- Curved Steel Plate Girders

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Tangent Steel Plate Girders

- No skew or limited skew
  - Simplified analysis (line girder)
  - NCDOT / NCSU factors for DL deflections
- Severe skew
  - Refer to previous discussions
  - Consider refined analysis

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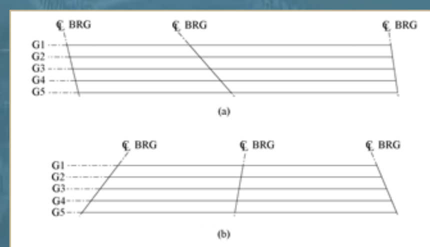
Tangent Steel Plate Girders

- Multiple different skews
  - Refined analysis may be appropriate
  - Consider girder twisting, cross frame forces
  - Watch out for uplift



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Tangent Steel Plate Girders

- Through-girder bridges
  - Simplified analysis (1D or 2D) generally sufficient
  - Check top flange stability
  - Design floor beam – girder connection carefully

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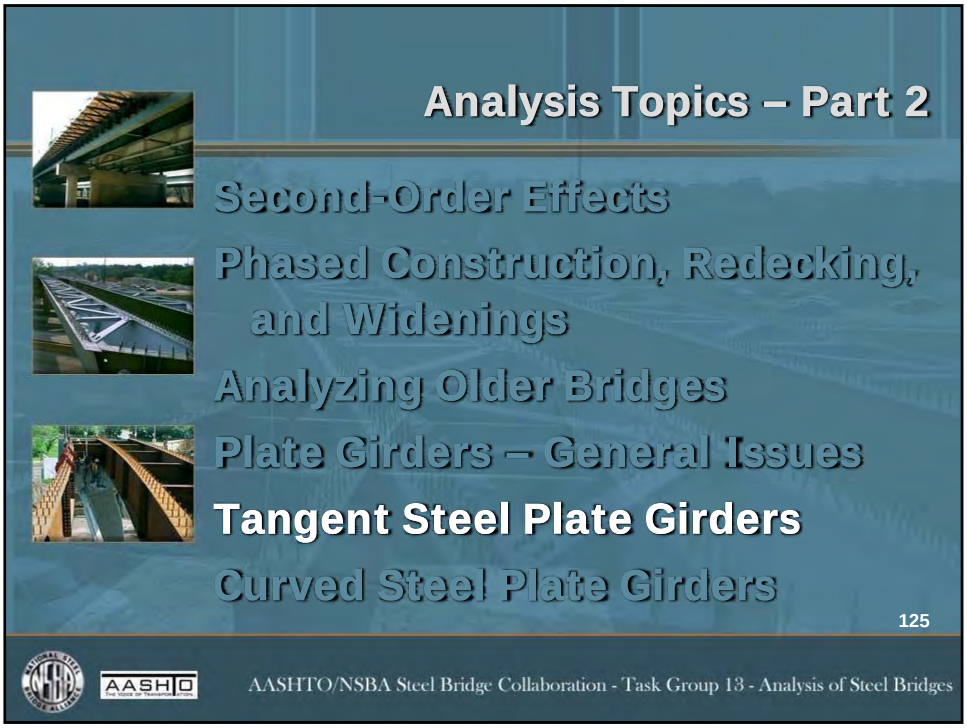
Analysis Topics – Part 2
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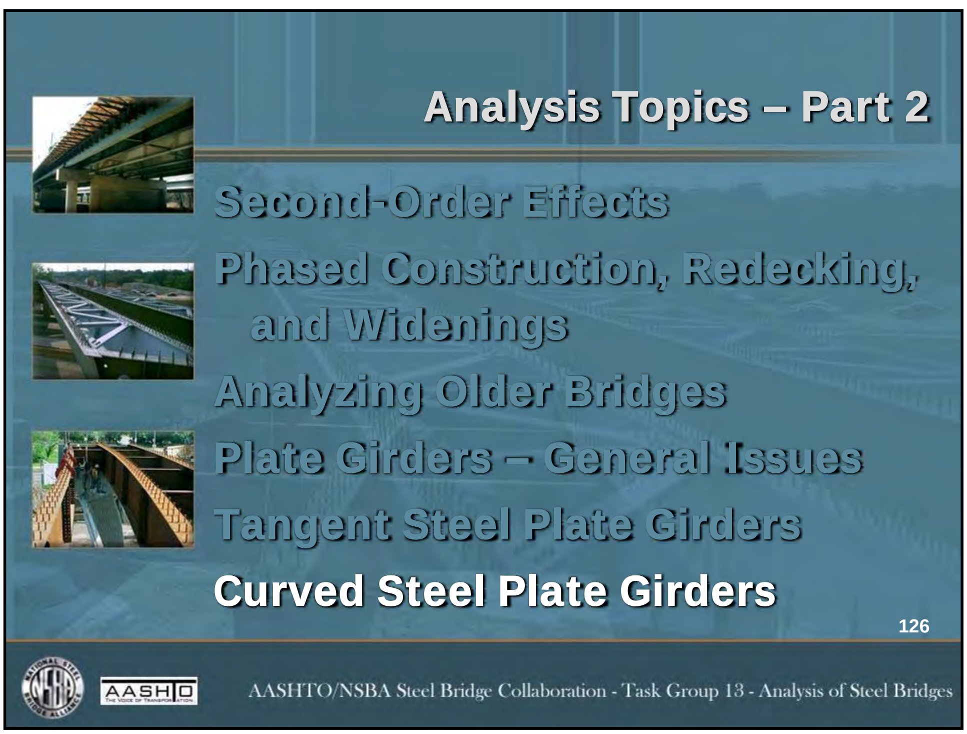
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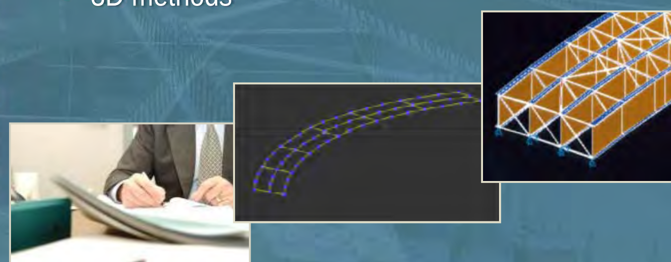
Curved Steel Plate Girders

- Three levels of analysis
  - 1D Approximate methods (Line Girder+factors, V-load)
  - 2D ("Grid" or "Grillage") methods
  - 3D methods



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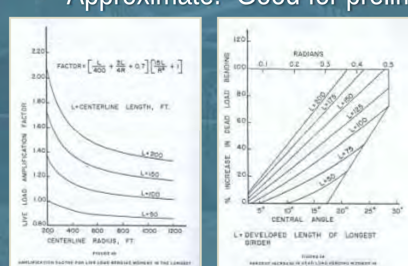
Curved Steel Plate Girders

- Line Girder+Factors
  - Any line girder analysis tool can be used
  - Factors from FHWA "Curved Girder Workshop"
  - Approximate! Good for prelim. design, sanity checking



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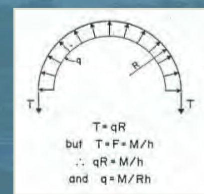
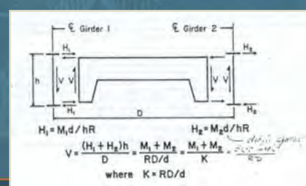
Curved Steel Plate Girders

- V-Load Method
  - Hand method, statics-based
  - "V-Loads" are the shears in diaphragms
  - Good for preliminary design or sanity checking more complex analyses





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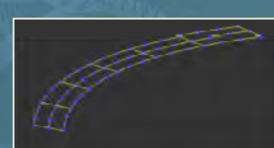
Curved Steel Plate Girders

- 2D "Grid" Analysis
  - Girders modeled as line elements
  - Diaphragms modeled as line elements
  - Deck modeled in strips as line elements
  - Plate and eccentric beam models



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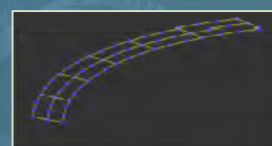
Curved Steel Plate Girders



- Grid Analysis Computer Tools
  - MDX
  - DESCUS I & II
  - General FEM programs
  - Others

MDX SOFTWARE CURVED & STRAIGHT STEEL BRIDGE DESIGN & RATING



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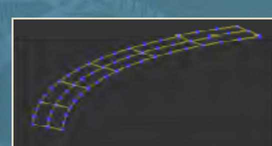
Curved Steel Plate Girders



- Advantages of Grid Analysis
  - Simple modeling
  - Efficient (level of modeling effort)
  - Some find it easier to understand
  - Computer tools readily available



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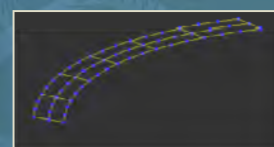
Curved Steel Plate Girders

- Disadvantages of Grid Analysis
  - Diaphragm modeling
  - Deck modeling
  - Load Distribution
  - In sum: Is a grid analysis sufficient for your bridge?



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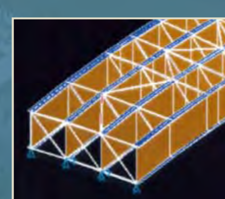
Curved Steel Plate Girders

- 3D Analysis
  - Flanges: beam or plate elements
  - Webs: plate elements
  - Diaphragms, bracing: truss or plate elements
  - Deck: solid or plate elements



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Curved Steel Plate Girders

- 3D Analysis Computer Tools
  - BSDI 3D System (limited LRFD capabilities)
  - General FEM programs
  - Others

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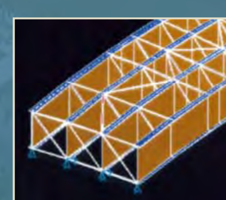
Curved Steel Plate Girders

- Advantages of 3D Analysis
  - All pieces and parts modeled - rigorous
  - Direct analysis results for all pieces and parts
  - Greater refinement
  - Greater accuracy (?)



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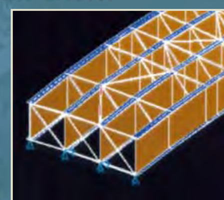
Curved Steel Plate Girders

- Disadvantages of 3D Analysis
  - Greater modeling effort
  - More complicated model
  - Results less "intuitive"
  - In sum: Is the refinement worth the effort?



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Curved Steel Plate Girders

- Modeling considerations
  - Boundary conditions – modeling bearings
  - Modeling substructure stiffness
  - Modeling connectivity between deck and girders
  - Modeling offsets
    - Girders to deck
    - Cross frame members to flanges
  - Modeling live loads

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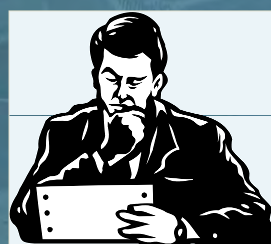
Curved Steel Plate Girders

- Which is best? *1D? 2D? 3D?*
  - "It depends"
  - Understand the behavior of your structure
  - Choose the right level of analysis



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Analysis Topics – Part 2

Second-Order Effects

Phased Construction, Redecking, and Widenings

Analyzing Older Bridges

Plate Girders – General Issues

Tangent Steel Plate Girders

Curved Steel Plate Girders

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Overall Presentation Outline

Introduction

Analysis Topics – Part 1

Break

Analysis Topics – Part 2

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Wrap-up

- Topics covered
  - Behavior Considerations
  - Constructability-Analysis Issues
  - Detailing for Intended Erected Position
  - Cross Frame Modeling
  - Deck Modeling
  - Second-Order Effects
  - Phased Construction, Redecking, and Widenings
  - Analyzing Older Bridges
  - Plate Girders – General Issues
  - Tangent Steel Plate Girders
  - Curved Steel Plate Girders

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Wrap-up

- Not satisfied? Want more?
  - Read G13.1
- Want even more?
  - Read the references mentioned in G13.1
- What else can you do?
  - Talk to senior engineers

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Wrap-up

- Always remember…
  - Each bridge is unique
  - Think about the anticipated behavior of the structure
  - Consider how the bridge will be constructed
  - Choose an appropriate analysis method

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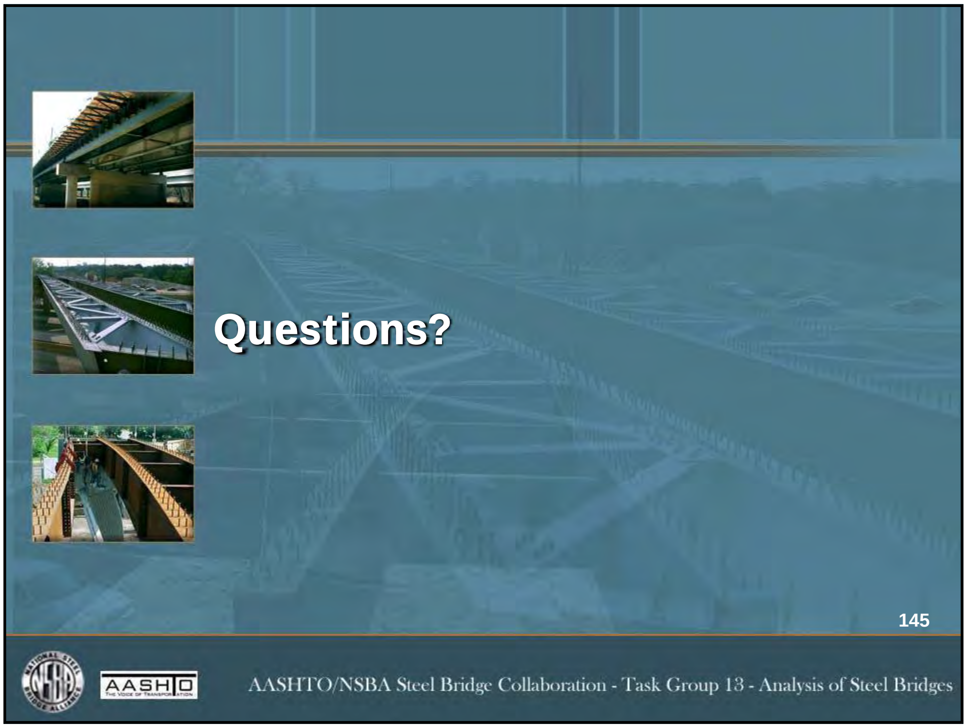
Questions?
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