The Problems with Skew

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HDR

Western Bridge Engineers' Seminar

- Introduction
- Behavior Considerations
- Analysis Considerations
- Detailing Considerations
- Reducing Severity of Skew
- Current Research
- Summary

Introduction

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Introduction

- "PRINCIPLE XIII –The Building of a Skew-Bridge Should Always Be Avoided when it is Practicable." *J.A.L. Waddell, Bridge Engineering, 1916*
- Why?

Introduction

- Skew complicates design, detailing, fabrication, and construction of bridges
- But, skewed bridges are becoming more and more common
- So, what should we do?

Introduction

- Understand the behavior of skewed bridges
- Analyze skewed bridges properly
- Detail skewed bridges properly
- Minimize skew when possible
- Minimize effects of skew

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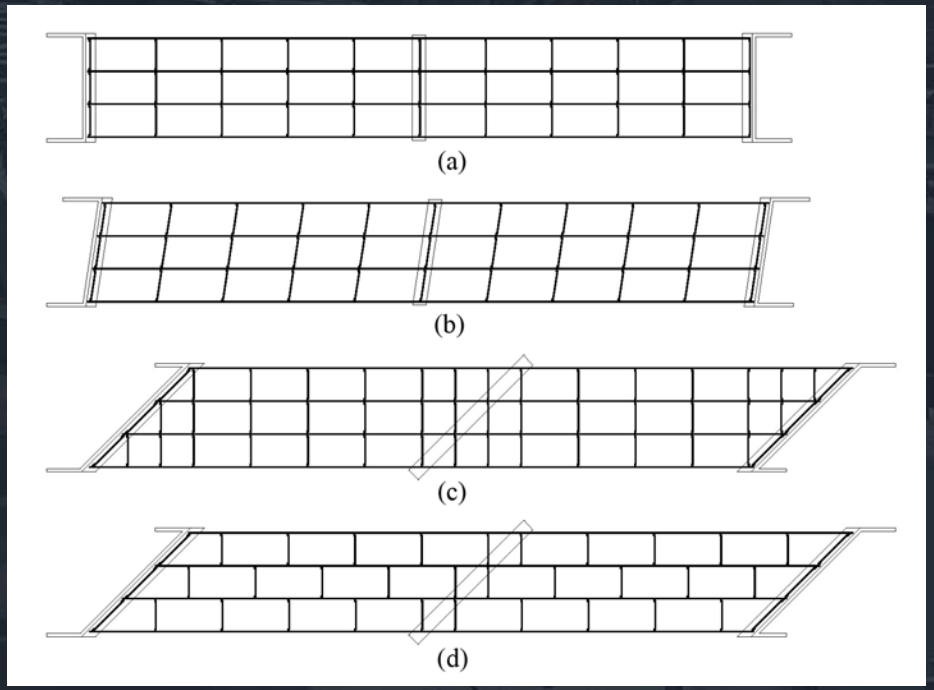
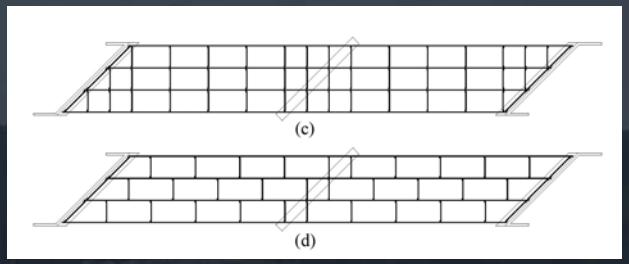
Behavior Considerations

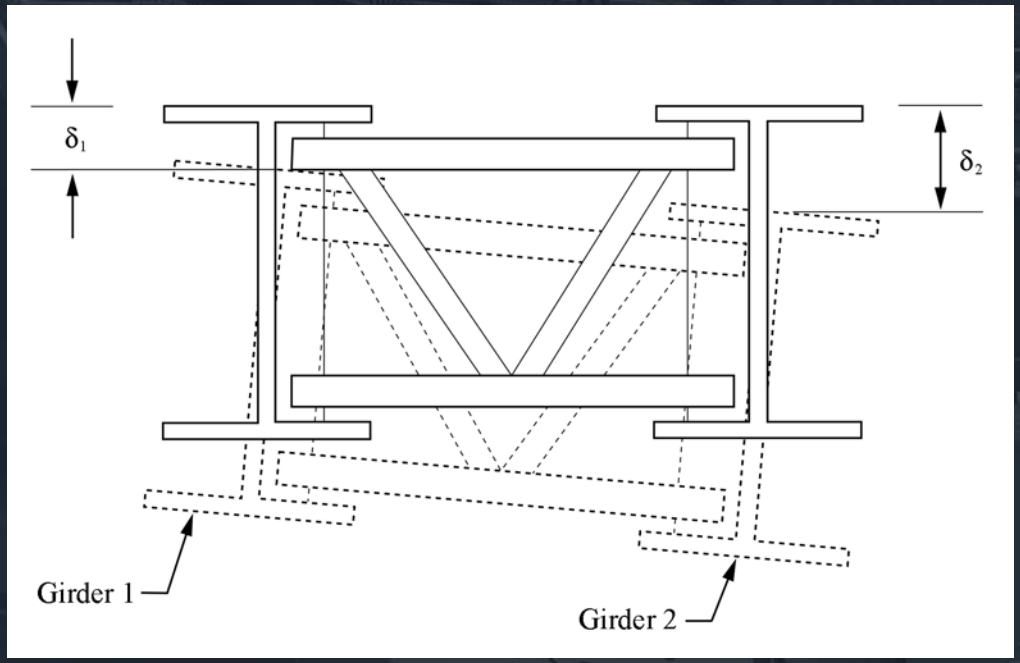
- The effects of skew on steel I-girder bridges depend on the severity of skew and type of framing



Behavior Considerations

- Non-skewed diaphragms
  - Diaphragm loads
  - Flange lateral bending





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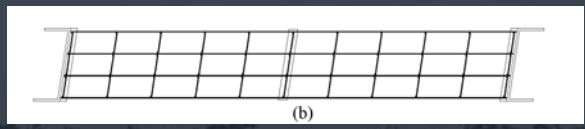
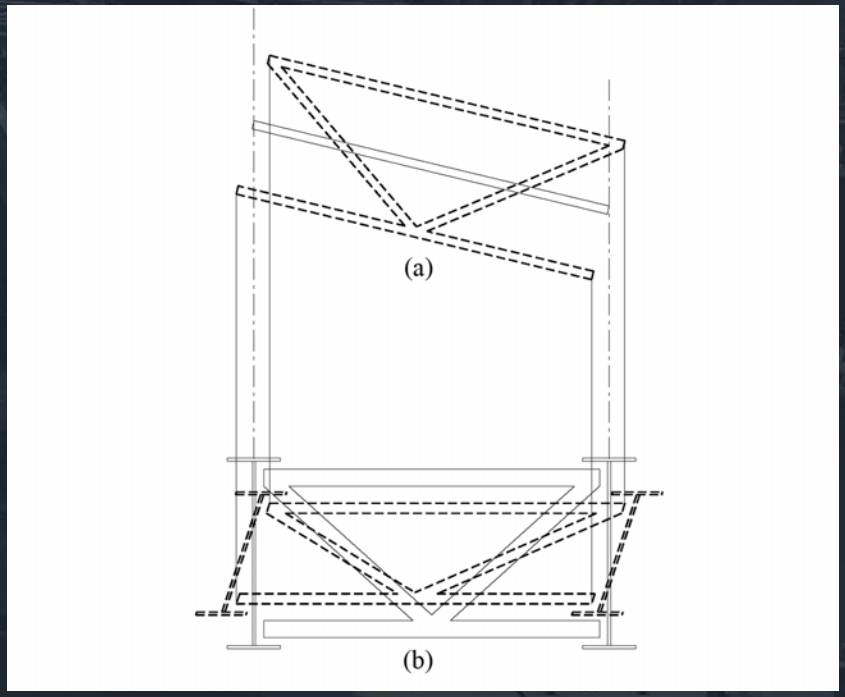
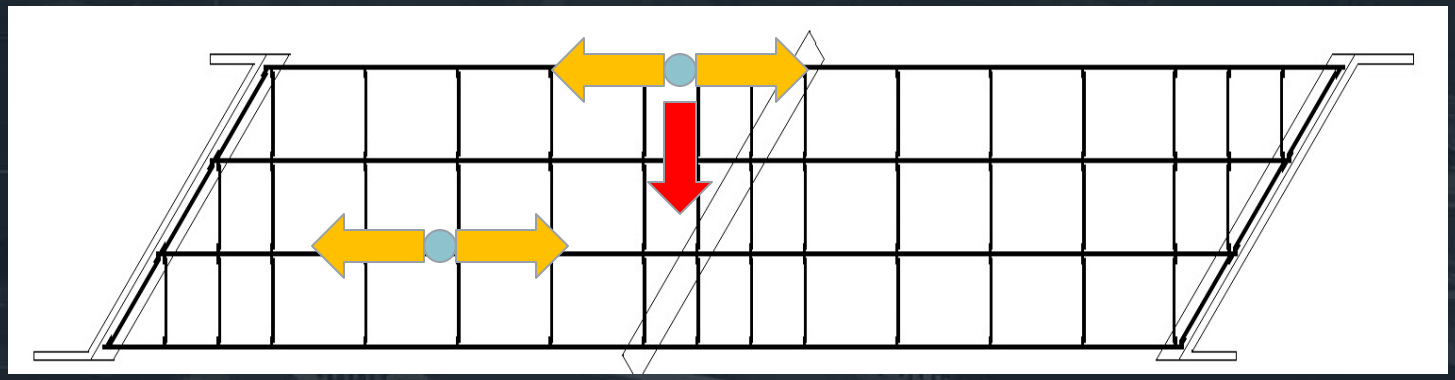
- Skewed diaphragms
  - Diaphragm loads
  - Flange lateral bending





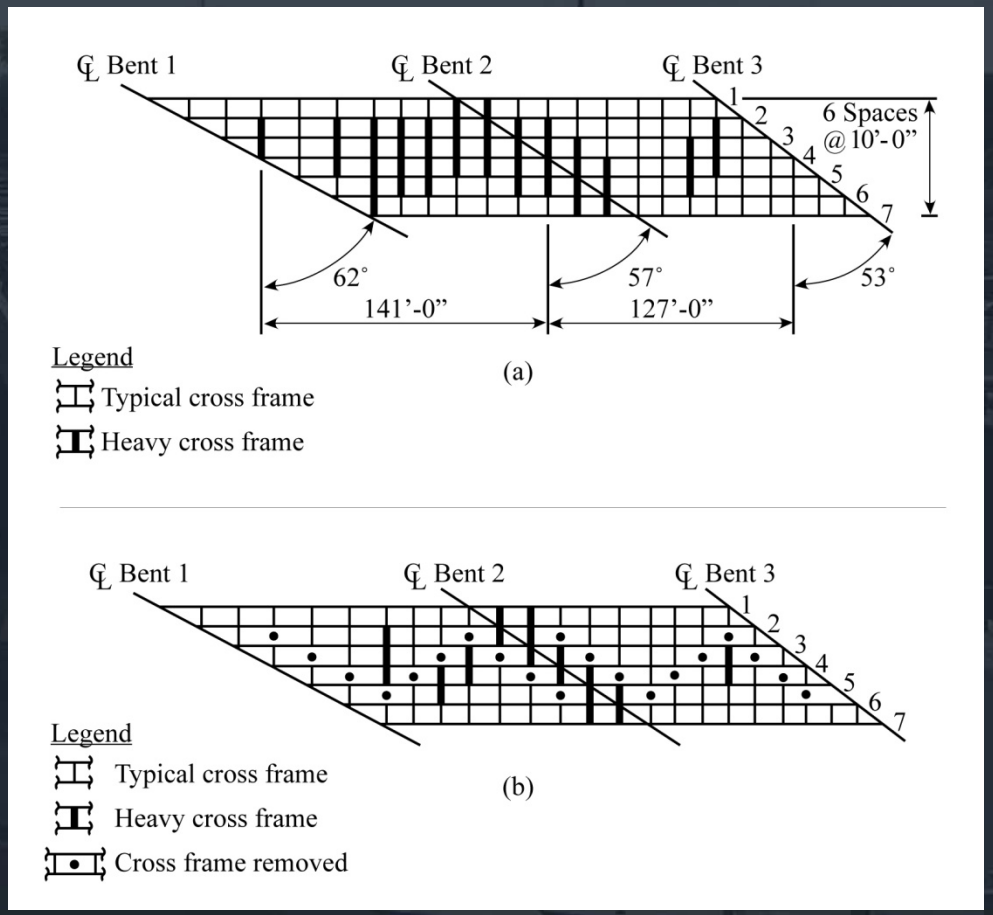
Behavior Considerations

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



Behavior Considerations

- "Nuisance stiffness" effects



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Analysis Considerations

- Approximate Analysis Methods
  - Line Girder
  - Line Girder + Adjustments
- Very quick and simple
- Does not directly address system behavior
- Good for minor skew
- Good for preliminary design / checking more complex analyses

Analysis Considerations

- 2D “Grid” Analysis Methods
  - Traditional 2D “Grid” Analysis
  - Plate & Eccentric Beam Analysis
- Relatively quick and simple
- Begins to address system behavior
- Generally cannot model warping stiffness
- Limits to modeling of diaphragms

Analysis Considerations

- 3D Finite Element Analysis Methods
- Fairly complicated and involved
- Very refined modeling of system behavior
- Modeling of girder warping stiffness
- Detailed modeling of diaphragms

Analysis Considerations

- Approximate? 2D? 3D? Which is best?
  - Depends on the nature of your bridge
  - Choose appropriate level of analysis for your bridge

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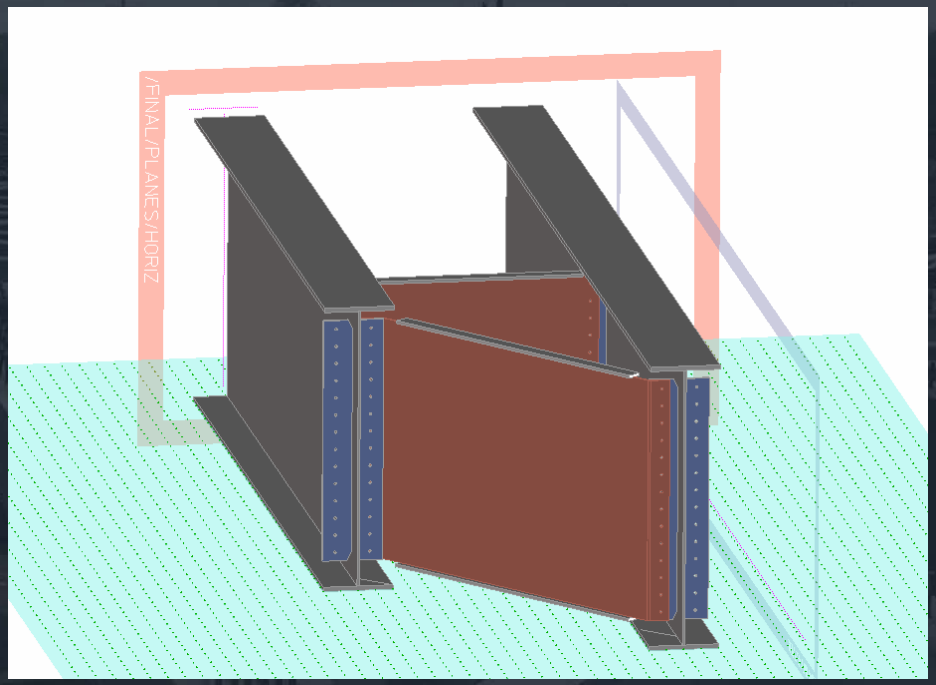
Detailing Considerations

- Diaphragm Fit Detailing
  - No Load Fit
  - Steel Dead Load Fit
  - Total Dead Load Fit
- Pros and cons for each
- Understand the implications

Detailing Considerations

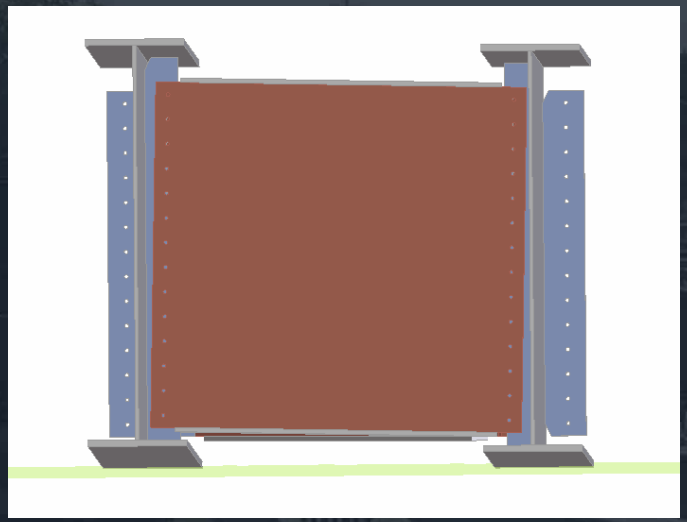
- Diaphragm Fit Detailing



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

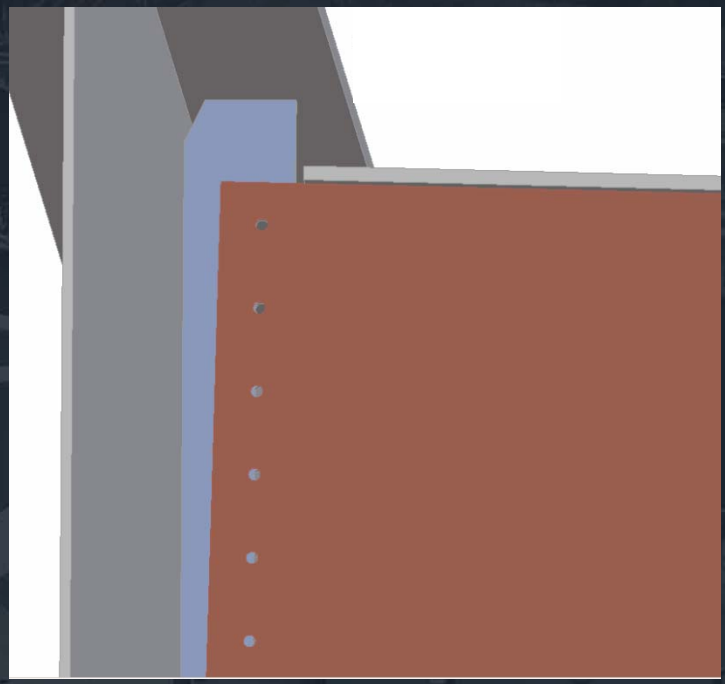
Detailing Considerations

- Diaphragm Fit Detailing



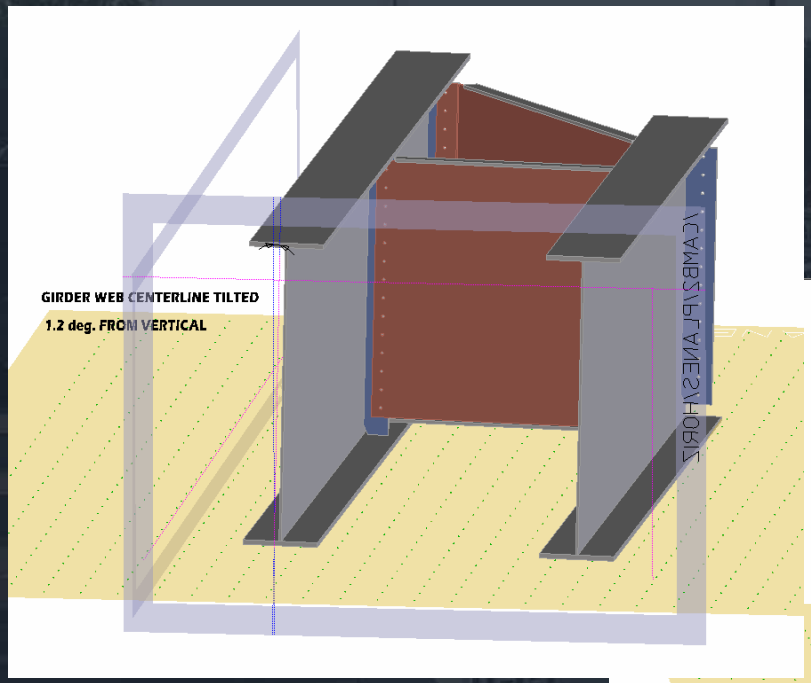
Cambered position
Back view showing girders rotated up from horizontal plane
Diaphragms not aligned
(designed to fit in final position)

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



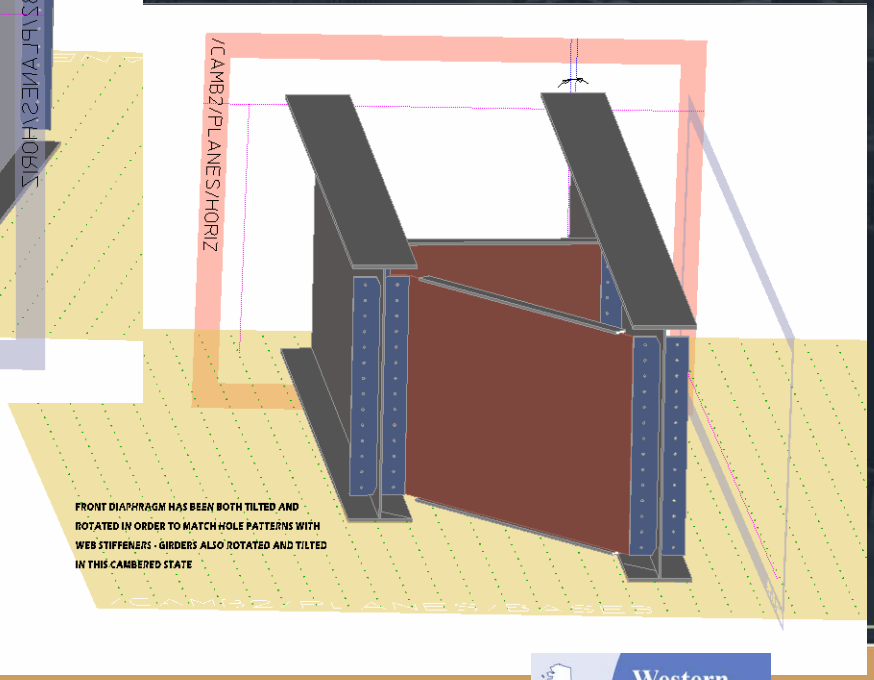
Detailing Considerations

- Diaphragm Fit Detailing



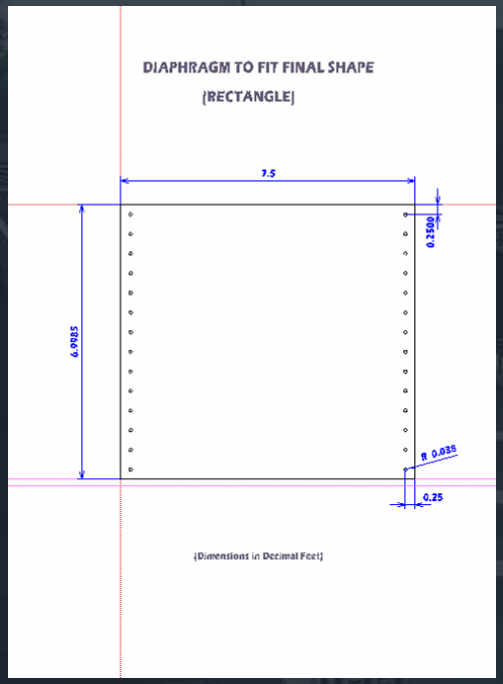
Girder web centerline tilted 1.2 deg from vertical

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

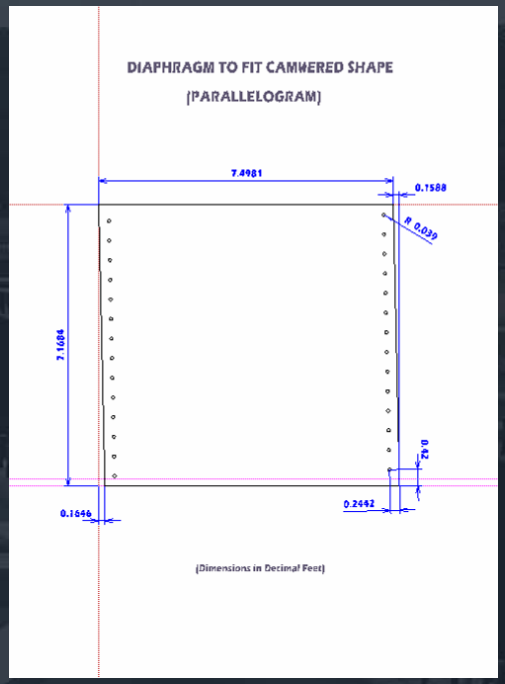


Detailing Considerations

- Diaphragm Fit Detailing



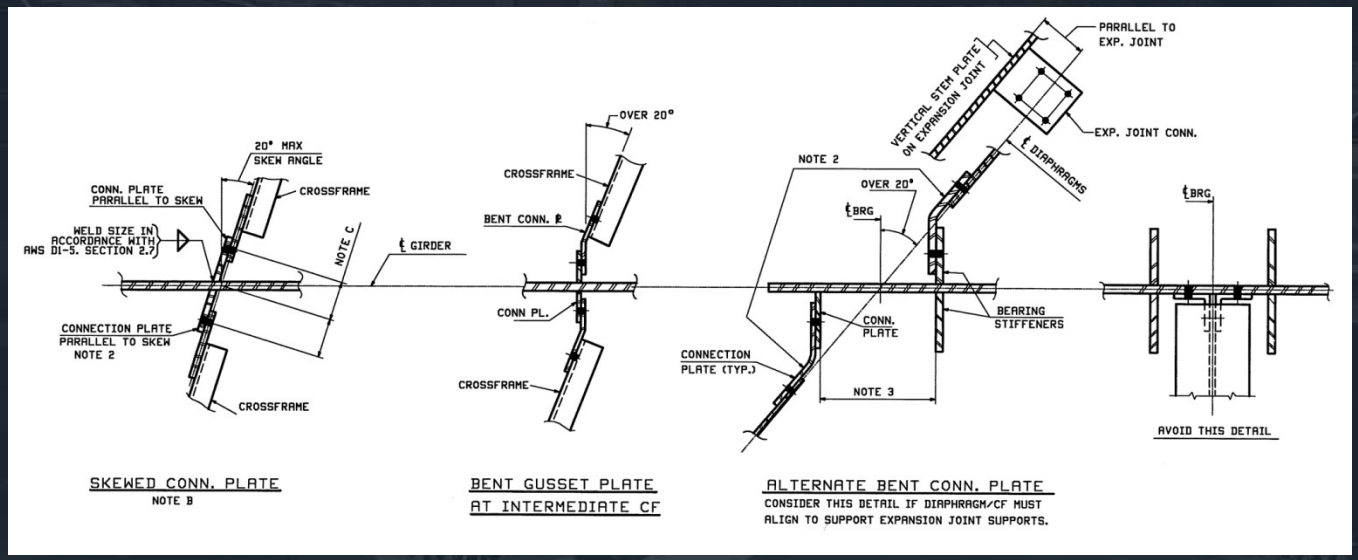
Diaphragm fit to final shape
(Total Dead Load Fit)
Rectangle



Diaphragm fit to cambered shape
(No Load Fit)
Parallelogram

Detailing Considerations

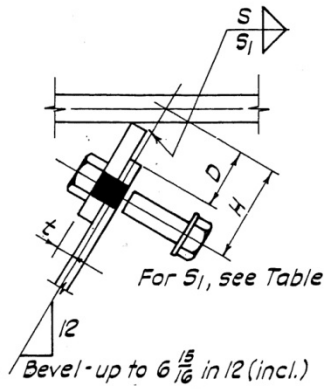
- Diaphragm Connection Detailing
  - Skewed plate vs. bent plate connections



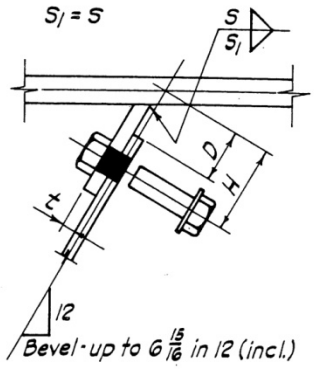
Detailing Considerations

- Diaphragm Connection Detailing
  - Skewed plate bolt entering / tightening clearances

For Skews Up to 30 Degrees



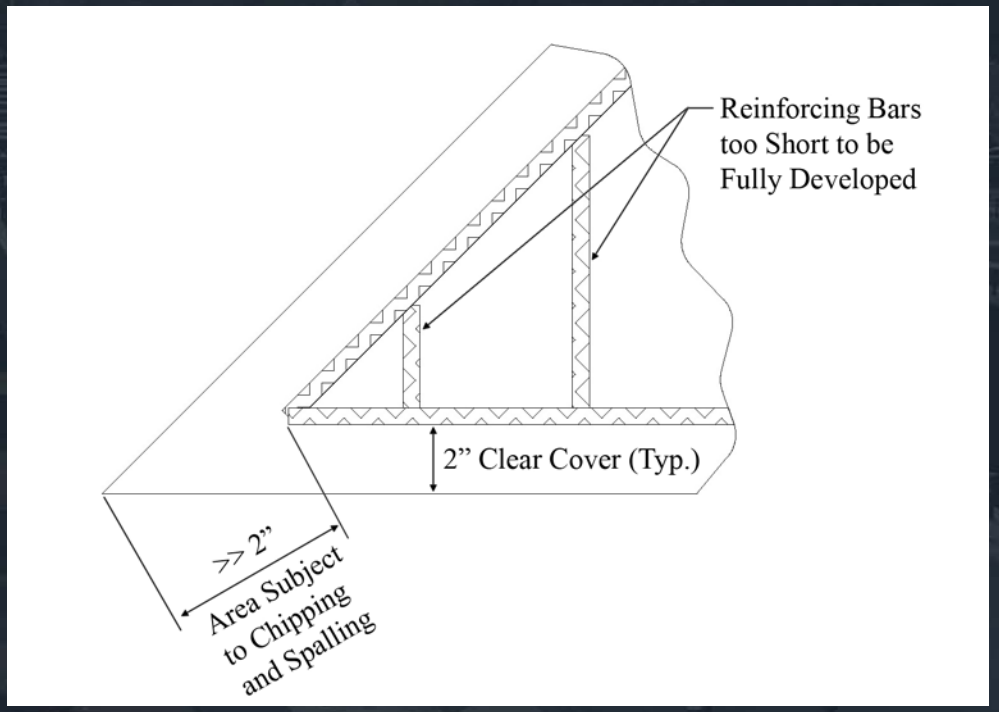
Type WP1 Skewed Connection
(Preferred)



Type WP2 Skewed Connection
(Alternate)

Detailing Considerations

- Elements Other than Structural Steel
  - Acute corner reinforcing



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- Elements Other than Structural Steel
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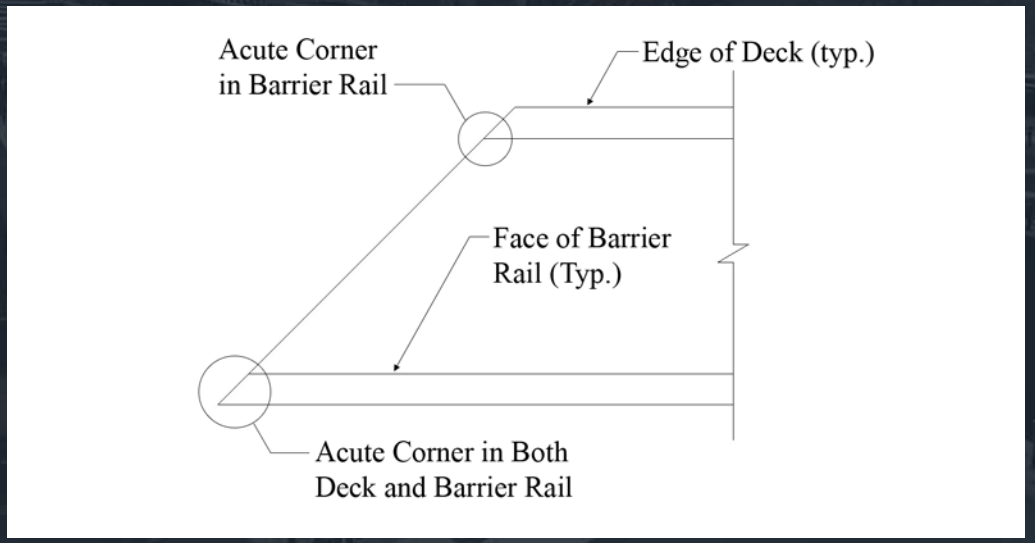
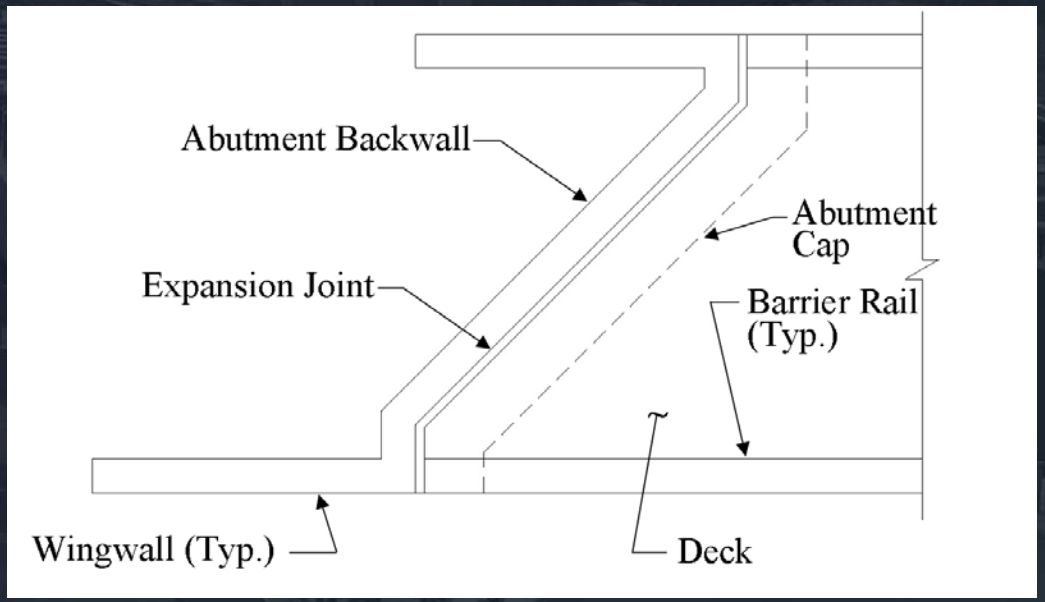


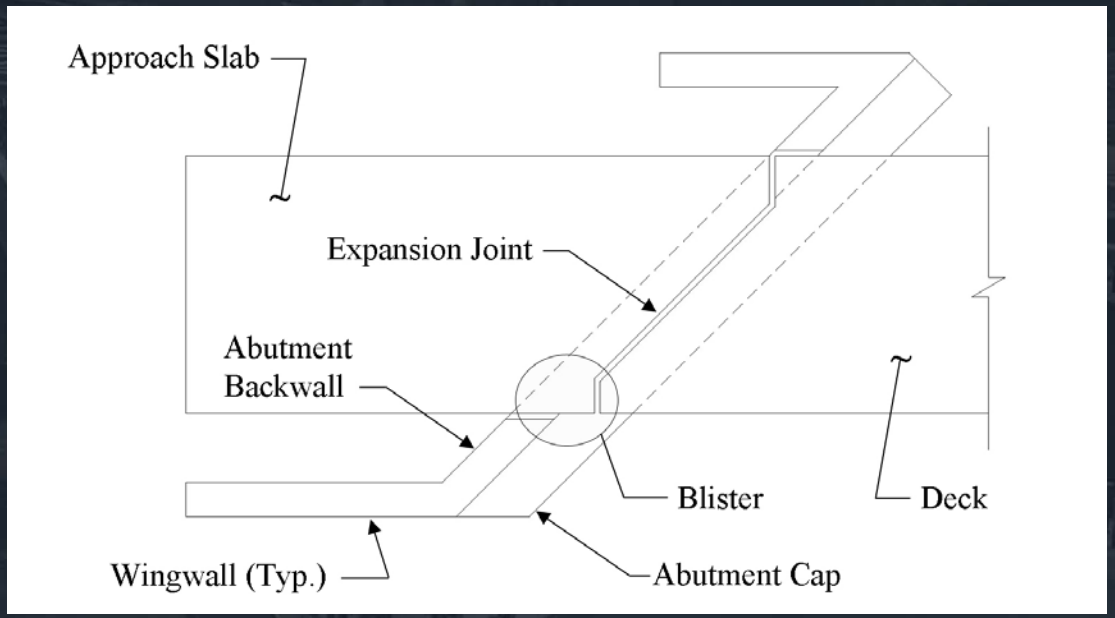
Detailing Considerations

- Elements Other than Structural Steel
  - "Breakback" detailing



Detailing Considerations

- Elements Other than Structural Steel
  - "Blister" detailing



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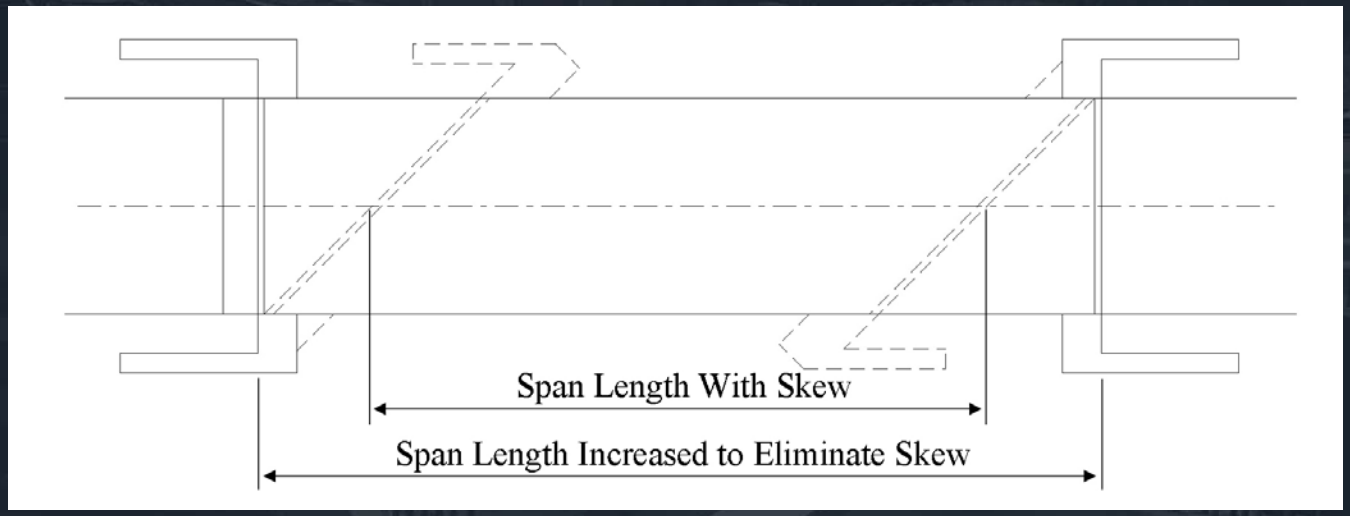
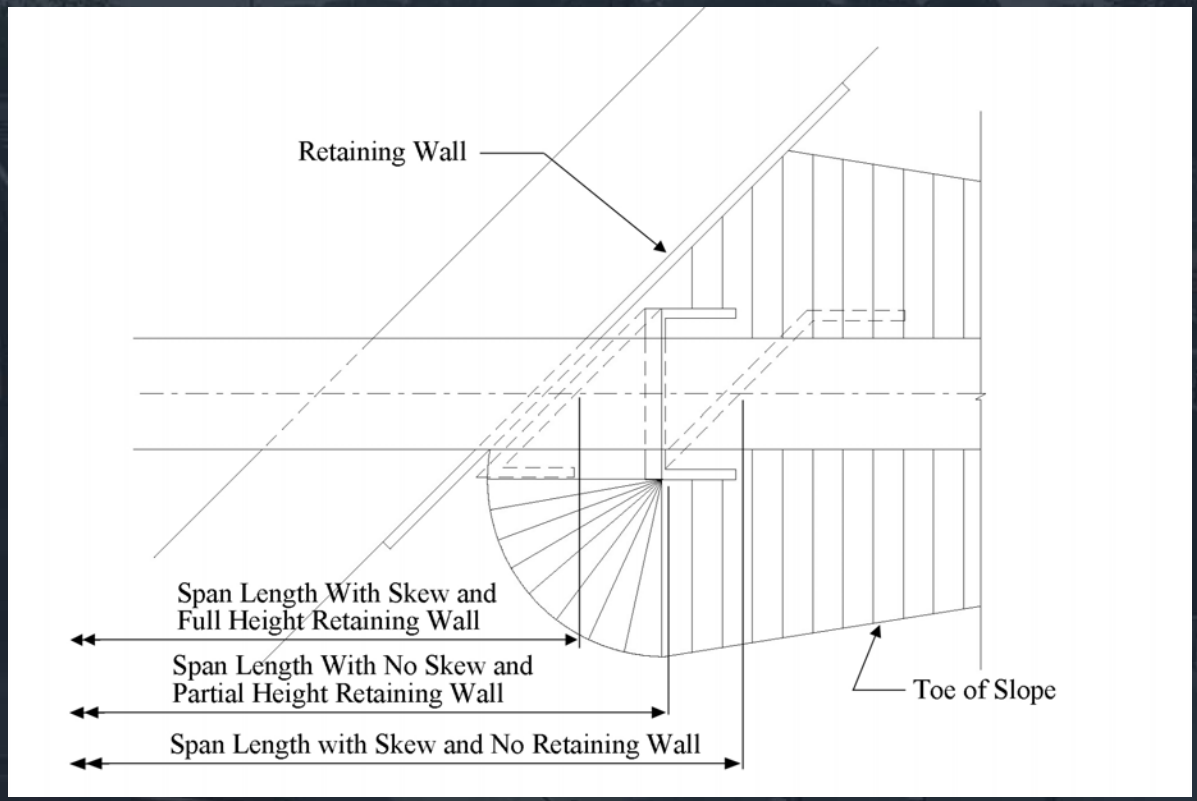
Reducing Severity of Skew

- Increasing Span Length & Squaring Abutments



Reducing Severity of Skew

- Small Retaining Walls



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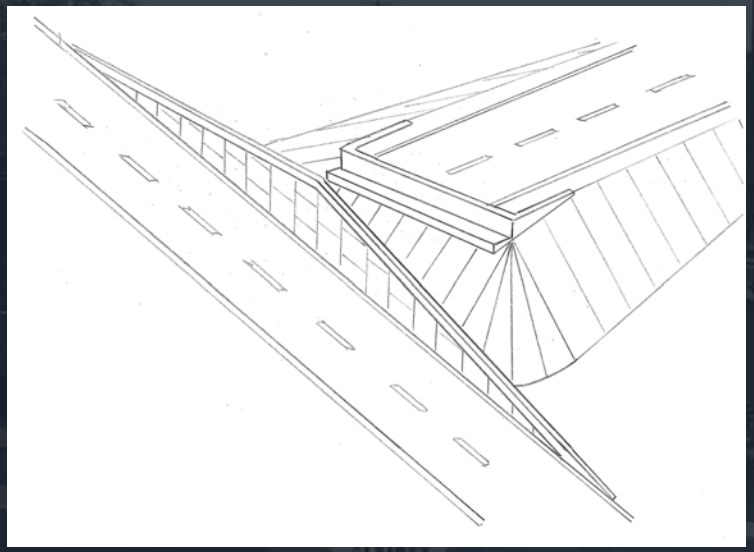

Reducing Severity of Skew

- Integral Pier Caps

Reducing Severity of Skew

- Dapped Girder Ends w/Inverted-Tee Bent Cap

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Current Research

- Research Areas
  - NCHRP Research Project 12-79
  - System Behavior / Analysis Methods Research
  - Lean-on Bracing Research
- Universities
  - Georgia Tech
  - University of Texas at Austin
  - NC State University
  - Penn State University
  - Others

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Summary

- Skew complicates design, detailing, fabrication, and construction of bridges
- Try to minimize skews if possible
- Understand anticipated behavior of the bridge
- Choose appropriate analysis method
- Detail to mitigate effects of skew

Questions?