Overview of New Practices & Policy

Skewed Bridges

What does all this mean?
Preliminary Design Considerations

• What potential skewed solutions should be considered?
• What about non-skewed solutions?

Potential Skewed Solutions

1. Erect Girders Plumb
2. Erect Girders Out-of-Plumb
3. Stiffen Superstructure
4. “Lean-on” Bracing
Potential Solutions – Solution 1
Erect Girders Plumb

Erect girders plumb → Girders rotate out of plumb during deck placement (girders will be permanently twisted)

How much twist is too much?

ODOT Limit:
\[ N \leq 0.6^\circ \]
Or
1/8” per ft.
For Line Girder Analysis:
If $\delta \leq S/100$ then $N \leq 0.6^\circ$

Potential Solutions – Solution 2
Erect Girders out of Plumb

Erect girders out of plumb (twisted)
Girders rotate to plumb during deck placement
Potential Solutions – Solution 3
Stiffen Superstructure

- Add steel
  - Bigger flanges
  - Deeper webs
  - Add girder line(s)
- Use shored construction
  Use only upon approval from OSE

Potential Solutions – Solution 4
Lean-on Bracing

- Internal Lean-on Bracing (Solution “4I”)
- External Lean-on Bracing (Solution “4E”)

How Much?
Which One?
When?
Skewed Bridge Design Process
(Steel Beams/Girders)

Skewed Bridge Design Process
(Branch #1)
Skewed Bridge Design Process
(Branch #1)

30° < Skew ≤ 45°

Perform Line Girder Analysis

Differential Deflections < S/100

Yes

Design Using Line Girder Analysis

Check That Design Rates Using PC-BARS

Perform Line Girder Analysis for “Optimized” Design.

Remember:
Main girder elements act independently and effect of crossframes are ignored.
Skewed Bridge Design Process
(Branch #1)

- $30^\circ < \text{Skew} \leq 45^\circ$
- Perform Line Girder Analysis
- Design Using Line Girder Analysis
- Check That Design Rates Using PC-BARS
- Differential Deflections $< S/100$

Potential Skew Solution 1:
Erect Girders Plumb
Skewed Bridge Design Process
(Branch #1)

Perform Line Girder Analysis

Differential Deflections < S/100

Yes

Design Using Line Girder Analysis

Check That Design Rates Using PC-BARS

Check Design Rating Using PC-BARS

- Rating for New bridges must equal or exceed HS-25
- Rating assumes no future wearing surface
- Should be considered during preliminary element sizing

Skewed Bridge Design Process
(Branch #1)

Perform Line Girder Analysis

Differential Deflections < S/100

Yes

Design Using Line Girder Analysis

Check That Design Rates Using PC-BARS

Required for Preliminary Design
Skewed Bridge Design Process (Branch #2)

$30^\circ < \text{Skew} \leq 45^\circ$

- Perform Line Girder Analysis
- Differential Deflections $< 5/100$
  - No
  - Stiffen Design: 0% to ±25% Additional Steel
  - Yes
- Design Using Line Girder Analysis
- Check That Design Rates Using PC-BARS

Stiffen design: Increase “Optimized” steel design 0% to ±25% (By Weight)
- Increase depth
- Increase flange sizes
- Add girder(s)

Potential Skew Solution 3:
- Stiffen Superstructure
Skewed Bridge Design Process
(Branch #2)

1. **30° < Skew ≤ 45°**
   - Perform Line Girder Analysis

2. **Differential Deflections < 5/100**
   - No
     - **Stiffen Design:** 0% to ±25% Additional Steel
     - Yes
       - **Differential Deflections < 5/100**

3. **Design Using Line Girder Analysis**
4. **Check That Design Rates Using PC-BARS**

---

**Complete Design Using Line Girder Analysis for Stiffened Design**

**Potential Skew Solution 1:** Erect Girders Plumb
Skewed Bridge Design Process

(Branch #2)

<table>
<thead>
<tr>
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Required for Preliminary Design

Skewed Bridge Design Process

(Branch #3)

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Skewed Bridge Design Process
(Branch #3)

Perform Refined Analysis* to account for crossframe-girder interaction.

* Begin Refined Analysis by sizing primary members using member sizes from “Optimized” Line Girder Analysis.
Skewed Bridge Design Process (Branch #3)

30° < Skew ≤ 45°

1. Perform Line Girder Analysis
2. Differential Deflections < S/100
   - No
   - Stiffen Design: 0% to ± 25% Additional Steel
3. Differential Deflections < S/100
   - No
   - Perform Refined Analysis
4. Girder Twist < 1/8”/ft?
   - Yes
   - Finish Design Using Refined Analysis
   - Erect Girders Vertical and Allow To Rotate
   - Check That Design Rates Using PC-BARS
   - Potential Skew Solution 1: Erect Girders Plumb
5. No
   - Required for Preliminary Design
   - Complete Design Using Refined Analysis
Skewed Bridge Design Process
(Branch #4)

30° < Skew ≤ 45°

Perform Line Girder Analysis

Differential Deflections < S/100

No

Stiffen Design: 0% to ± 25% Additional Steel

No

Perform Refined Analysis*

Stiffen Design: 0% to ± 25% Additional Steel

No

Girder Twist < 1/8"/ft?

Yes

Finish Design Using Refined Analysis: Erect Girders Vertical And Allow To Rotate

Check That Design Rates Using PC-BARS

Girder Twist < 1/8"/ft?

No

Potential Skew Solution 3: Stiffen Super. Increase "Optimized" steel design 0% to ± 25% (by weight) then recheck twist.
Skewed Bridge Design Process

(Branch #4)

30° < Skew ≤ 45°

Perform Line Girder Analysis

Differential Deflections < S/100

No

Stiffen Design: 0% to ± 25% Additional Steel

Differential Deflections < S/100

No

Perform Refined Analysis*:

Girder Twist < 1/8”/ft?

Yes

No

Stiffen Design: 0% to ± 25% Additional Steel

Girder Twist < 1/8”/ft?

Yes

Finish Design Using Refined Analysis:

Erect Girders Vertical And Allow To Rotate

Check That Design Rates Using PC-BARS

Required for Preliminary Design

Skewed Bridge Design Process

(Branch #5)

30° < Skew ≤ 45°

Perform Line Girder Analysis

Differential Deflections < S/100

No

Stiffen Design: 0% to ± 25% Additional Steel

Differential Deflections < S/100

No

Perform Refined Analysis*:

Girder Twist < 1/8”/ft?

Yes

No

Stiffen Design: 0% to ± 25% Additional Steel

Girder Twist < 1/8”/ft?

Yes

Implement Internal Lean-on Bracing with Refined Analysis*:

Erect Girders Vertical And Allow To Rotate

Check That Design Rates Using PC-BARS
Skewed Bridge Design Process
(Branch #5)

Potential Skew Solution 4:
Implement Internal Lean-on Bracing using Refined Analysis *

* Begin Refined Analysis for Lean-on bracing by sizing primary members using member sizes from “Optimized” Line Girder Analysis.

Check Girder Twist

Girder Twist < 1/8”/ft?

Yes

Implement Internal Lean-on Bracing with Refined Analysis*

Check That Design Rates Using PC-BARS

No

Perform Refined Analysis*

Skewed Bridge Design Process
(Branch #5)

Potential Skew Solution 3:
If “No” increase “Optimized” steel design 0 to ±25% (by weight) and recheck twist.
Skewed Bridge Design Process
(Branch #5)

30° < Skew ≤ 45°

Performs Line Girder Analysis

Differential Deflections < S/100

No

Girder Twist < 1/8’/ft?

Yes

No

Stiffen Design: 0% to ± 25% Additional Steel

Stiffen Design: 0% to ± 25% Additional Steel

Perform Refined Analysis*

Finish Design Using Refined Analysis: Erect Girders Vertical and Allow To Rotate

Implement Internal Lean-on Bracing with Refined Analysis*

Check That Design Rates Using PC-BARS

No

Skewed Bridge Design Process
(Branch #6)

30° < Skew ≤ 45°

Performs Line Girder Analysis

Differential Deflections < S/100

No

Girder Twist < 1/8’/ft?

Yes

No

Stiffen Design: 0% to ± 25% Additional Steel

Stiffen Design: 0% to ± 25% Additional Steel

Perform Refined Analysis*

Implement Internal Lean-on Bracing with Refined Analysis*

Check That Design Rates Using PC-BARS

No

Required for Preliminary Design
Skewed Bridge Design Process
(Branch #6)

30° < Skew ≤ 45°
Perform Line Girder Analysis

Differential Deflections < S/100
No

Stiffen Design: 0% to ± 25%
Additional Steel
No

Perform Refined Analysis*

Differential Deflections < S/100
No

Girder Twist < 1/8”/ft?
No

Check That Design Rates Using PC-BARS
Implement Internal Lean-on Bracing with Refined Analysis*

Potential Skew Solution 4:
Implement External Lean-on Bracing with Refined Analysis*

* Size primary members using “Optimized” steel design from Line Girder analysis.

Skewed Bridge Design Process
(Branch #6)

30° < Skew ≤ 45°
Perform Line Girder Analysis

Differential Deflections < S/100
No

Stiffen Design: 0% to ± 25%
Additional Steel
No

Perform Refined Analysis*

Differential Deflections < S/100
No

Girder Twist < 1/8”/ft?
No

Check That Design Rates Using PC-BARS
Implement Internal Lean-on Bracing with Refined Analysis*

Implement External Lean-on Bracing*

Required for Preliminary Design
Skewed Bridge Design Process
(Branch #7)

Skew > 45°

Perform Refined Analysis

Girder Twist < 1/8"/ft?
Yes

Finish Design Using Refined Analysis Erect Girders Vertical And Allow To Rotate

Check That Design Rates Using PC-BARS

Skewed Bridge Design Process
(Branch #7)

Skew > 45°

Perform Refined Analysis

Girder Twist < 1/8"/ft?
Yes

Finish Design Using Refined Analysis Erect Girders Vertical And Allow To Rotate

Check That Design Rates Using PC-BARS
Skewed Bridge Design Process

(Branch #7)

* Begin Refined Analysis by sizing primary members using member sizes from “Optimized” Line Girder Analysis.

Required for Preliminary Design
Skewed Bridge Design Process
(Branch #8)

Skew > 45°

- Perform Refined Analysis

Girder Twist < 1/8”/ft?

- Stiffen Design: 0% to ± 25% Additional Steel
- No
- Girder Twist < 1/8”/ft?
- Yes
- Finish Design Using Refined Analysis
- Erect Girders Vertical And Allow To Rotate
- Check That Design Rates Using PC-BARS

Yes

Skewed Bridge Design Process
(Branch #8)

Skew > 45°

- Perform Refined Analysis

Girder Twist < 1/8”/ft?

- Stiffen Design: 0% to ± 25% Additional Steel
- No
- Girder Twist < 1/8”/ft?
- Yes
- Finish Design Using Refined Analysis
- Erect Girders Vertical And Allow To Rotate
- Check That Design Rates Using PC-BARS

Required for Preliminary Design
Skewed Bridge Design Process
(Branch #9)

Skew > 45°

- Perform Refined Analysis*

Girder Twist < 1/8"/ft? Yes

- Check That Design Rates Using PC-BARS

- Stiffen Design: 0% to ± 25% Additional Steel

No

Girder Twist < 1/8"/ft?

- Implement Internal Lean-on Bracing with Refined Analysis*

Required for Preliminary Design

Skewed Bridge Design Process
(Branch #9)

Skew > 45°

- Perform Refined Analysis*

Girder Twist < 1/8"/ft? Yes

- Check That Design Rates Using PC-BARS

- Stiffen Design: 0% to ± 25% Additional Steel

No

Girder Twist < 1/8"/ft?

- Implement Internal Lean-on Bracing with Refined Analysis*

23
Skewed Bridge Design Process
(Branch #10)

Skew > 45°

No

Girder Twist < 1/8"/ft?

Check That Design Rates Using PC-BARS

Implement Internal Lean-on Bracing with Refined Analysis*

Perform Refined Analysis*

Girder Twist < 1/8"/ft?

Stiffen Design: 0% to ± 25% Additional Steel

Girder Twist < 1/8"/ft?

No

Implement External Lean-on Bracing*

Required for Preliminary Design
Skewed Bridge Design Process
(Steel Beams/Girders)

30° < Skew ≤ 45°
- Perform Line Girder Analysis
- Differential Deflections < 5/100
- Design Using Line Girder Analysis
- Check That Design Rates Using PC-BARS
- Implement External Lean-on Bracing*
- Girder Twist < 1/8”/ft?

Skew > 45°
- Perform Refined Analysis*
- Differential Deflections < 5/100
- Girder Twist < 1/8”/ft?
- Perform Refined Analysis*
- Stiffen Design: 0% to ± 25%
- Additional Steel
- Differential Deflections < 5/100
- Girder Twist < 1/8”/ft?
- Perform Refined Analysis*
- Stiffen Design: 0% to ± 25%
- Additional Steel
- Girder Twist < 1/8”/ft?
- Design Using Line Girder Analysis
- Check That Design Rates Using PC-BARS
- Implement Internal Lean-on Bracing with Refined Analysis*
- Girder Twist < 1/8”/ft?
- Finish Design Using Refined Analysis Erect Girders Vertical And Allow To Rotate
- Check That Design Rates Using PC-BARS

What about skewed Prestressed I-Beams Superstructures?
Skewed Bridge Design Process
Prestressed Beams/Girders: Skew > 30°

- Perform Line Girder Analysis
- Differential Deflections < S/100
  - Yes: Stiffen Design
  - No: Design Using Line Girder Analysis
- Stiffen Design
  - Yes: Alternate Superstructure Type
  - No: Check That Design Rates Using PC-BARS
- Check That Design Rates Using PC-BARS

Skewed Bridge Design Process
(Branch #1)

- Perform Line Girder Analysis
- Differential Deflections < S/100
  - Yes: Design Using Line Girder Analysis
  - No: Check That Design Rates Using PC-BARS
Skewed Bridge Design Process
(Branch #1)

Perform Line Girder Analysis for “Optimized” Design.

Design Using Line Girder Analysis

Check That Design Rates Using PC-BARS

Perform Line Girder Analysis

Differential Deflections < S/100

Yes

Differential Deflections < S/100

Yes

Check That Design Rates Using PC-BARS
Skewed Bridge Design Process
(Branch #1)

Perform Line Girder Analysis

Differential Deflections < S/100

Yes

Design Using Line Girder Analysis

Complete Design Using Line Girder Analysis for “Optimized” Design

Check That Design Rates Using PC-BARS

Potential Skew Solution 1: Erect Girders Plumb

Skewed Bridge Design Process
(Branch #1)

Perform Line Girder Analysis

Differential Deflections < S/100

Yes

Design Using Line Girder Analysis

Check That Design Rates Using PC-BARS
Skewed Bridge Design Process
(Branch #1)

1. Perform Line Girder Analysis
2. Check that Differential Deflections $< S/100$
   - Yes: Design Using Line Girder Analysis
   - No: Stiffen Design
3. Check that Design Rates Using PC-BARS

Skewed Bridge Design Process
(Branch #2)

1. Perform Line Girder Analysis
2. Check that Differential Deflections $< S/100$
   - Yes: Design Using Line Girder Analysis
   - No: Stiffen Design
3. Check that Design Rates Using PC-BARS
Skewed Bridge Design Process
(Branch #2)

Perform Line Girder Analysis

Differential Deflections < S/100

Yes

Stiffen Design

• Add beam line
• Increase beam size

No

Design Using Line Girder Analysis

Check That Design Rates Using PC-BARS

Skewed Bridge Design Process
(Branch #2)

Perform Line Girder Analysis

Differential Deflections < S/100

Yes

Stiffen Design

No

Design Using Line Girder Analysis

Check That Design Rates Using PC-BARS

Stiffen Design:

Yes

Yes

No
Skewed Bridge Design Process
(Branch #2)

Perform Line Girder Analysis

Differential Deflections < 5/100

No

Yes

Stiffen Design

Check That Design Rates Using PC-BARS

Required for Preliminary Design

Skewed Bridge Design Process
(Branch #3)

Perform Line Girder Analysis

Differential Deflections < 5/100

No

Stiffen Design

Alternate Superstructure Type

No
Skewed Bridge Design Process
(Branch #3)

Non-skewed Alternatives

Designers should consider:
- Longer spans that eliminate or reduce skew
- Straddle Bents that span the under-bridge feature

For alternatives with similar costs:
ODOT will prefer reduced skews over “Lean on” construction.
Detail Design Considerations

- Stakeholder Responsibilities
- Intermediate Crossframes
- End Crossframes
- End Diaphragms
- Bearings

Stakeholder Responsibilities

Designer Responsibilities:
- Structural design during deck placement & final condition
- Structural stability during deck placement
**Stakeholder Responsibilities**

**Contractor Responsibilities:**
- Detailing bracing members to fit under steel dead load with girders plumb at erection
- Structural stability during erection
- Structural stability during deck placement (if different than plan)

**Intermediate Crossframes**

2004 ODOT BDM Design Requirements

"On skewed structures, in order to accommodate adjacent stringer deflections, at any intermediate crossframe location, the erection bolt holes in the crossframe members should be detailed as slotted holes. Hole dimensions shall be 1/16" wider than the nominal bolt diameter and 3/16" longer than the nominal bolt diameter. Holes in the stiffeners shall be 3/16" larger than the diameter of the erection bolts. Final bolting and welding shall not be completed until after the deck concrete has been placed."
Intermediate Crossframes

No Slots in Crossframe members:

Slots cause:
  • Insufficient bracing
  • Exaggerated deflections/rotations

Intermediate Crossframes

- Bracing members should be fully tightened and welded during deck placement

Type 3

Fully Tighten Bolts

Field weld

Type 4
Intermediate Crossframes

Design bracing members for Refined Analysis Loads

- Start with GSD-1-96
- Add beef where necessary

End Crossframes: Skews > 30°
DO NOT INSTALL END CROSSFRAME DIAGONALS UNTIL DECK PLACEMENT IN ADJACENT SPAN IS COMPLETE.

- Diagonals
- End Armor
- Bottom Chord
End Crossframes: Skews > 30°
DO NOT INSTALL END CROSSFRAME DIAGONALS UNTIL DECK PLACEMENT IN ADJACENT SPAN IS COMPLETE.

- Eliminates girder end rotation caused by decambering
- Simplifies refined analysis model
- Reduces locked-in stresses
- Temporary bracing should be investigated

End Diaphragms
Steel Superstructures (Skew > 30°) OR Concrete Superstructures (Skew > 10°)

Place diaphragms after deck placement in adjacent span is complete.

Stage 1
Stage 2
End Diaphragms
Steel Superstructures (Skew > 30°) OR Concrete Superstructures (Skew > 10°)

- Eliminates girder end rotation caused by decambering
- Simplifies refined analysis model
- Reduces locked-in stresses in end diaphragm & main members and reduces potential for cracking
- Temporary end bracing should be considered

Bearings Rotations
Design Bearings for the out-of-plane rotations.
- Use results from refined analysis
- OR -
- 1/8" per ft. (max.)
Bearings

Load Plates

Do not bevel load plate in transverse direction.

- Forces girder web out-of-plane during erection
- Complicates bearing fabrication

Bearings

Size Bearings for Refined Analysis Reactions

Crossframe Effects Included

Fixed Bearings

Expansion Bearings

Reaction (kips)

Crossframe Effects Neglected
Policy Changes
Bridge Design Manual (BDM)

New Appendix Section:
ODOT Guide for the Design of Skewed Superstructures

Summary

An itemized summary is provided at the back of the seminar handout and is available for download at our website:

www.dot.state.oh.us/se/skew/skew.htm
Questions ??

Email Questions to:
OSE@dot.state.oh.us