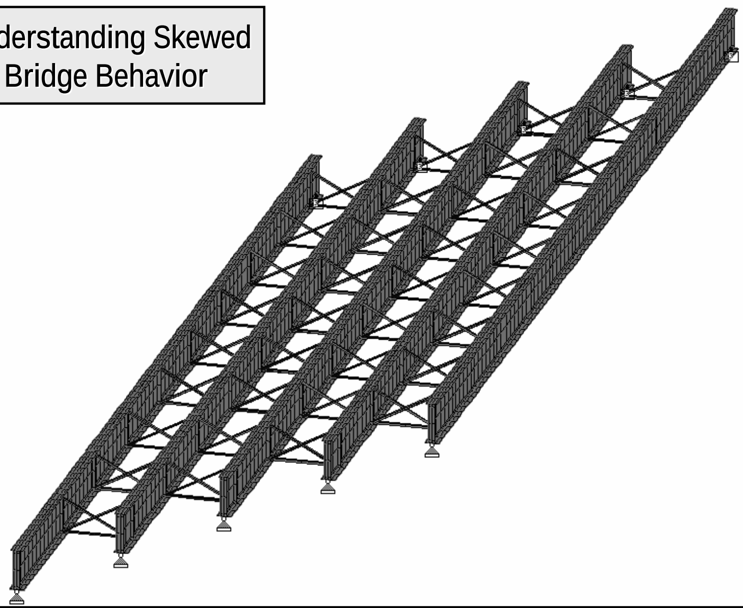
Understanding Skewed Bridge Behavior

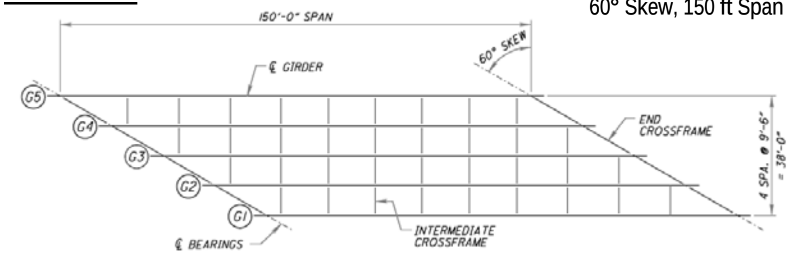


Skewed Bridge Behavior

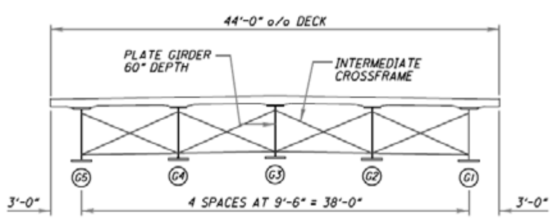
- Out-of-plane effects occur in skewed bridges that cannot be predicted by one-dimensional (line girder) analysis methods.
- AASHTO/NSBA “Guidelines for Design for Constructability” identifies two separate issues:
  - Intermediate Crossframe Effects
  - End Crossframe Effects
- Both Intermediate and End Crossframe Effects will be examined using a test case.

Test Case:

60° Skew, 150 ft Span



FRAMING PLAN

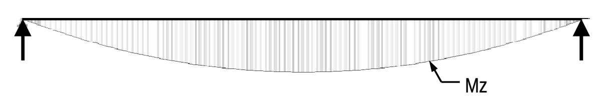


TRANSVERSE SECTION

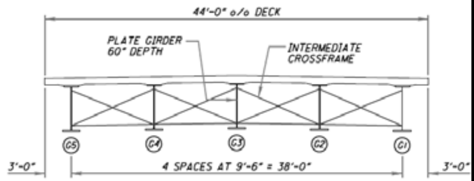
Analysis of Test Case, Line Girder Model:

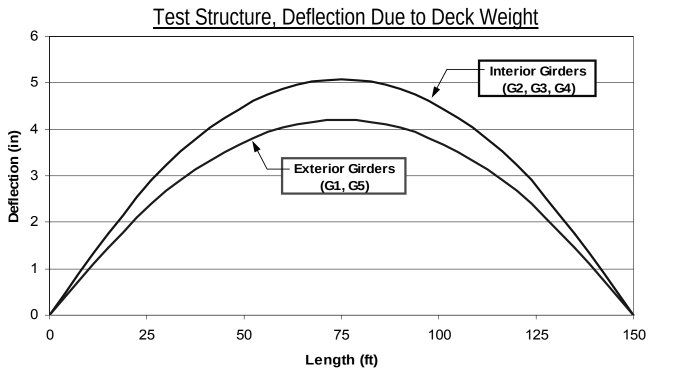
- We will conduct an initial analysis of the test structure using a Line Girder Model.
- This is the most commonly used analysis method for non-complex bridges, and is used by many common software packages. (MDX, Merlin Dash, BARS-PC)
- Each girder is modeled independently, with crossframe effects ignored.

Line Girder Model:



Line Girder Analysis Results
Crossframe Effects Ignored



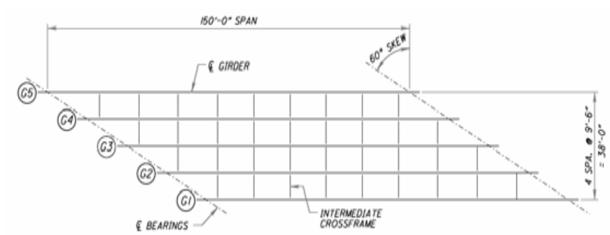


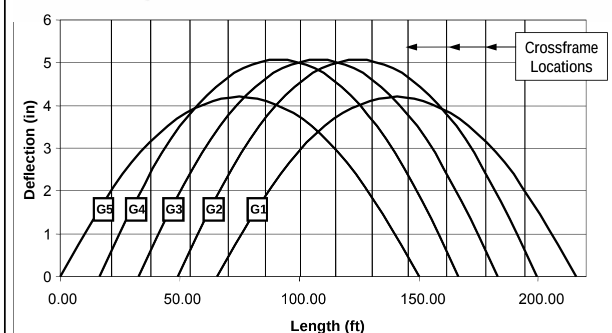
Line Girder Analysis Results
Crossframe Effects Ignored

Results Show:

- Large differential deflections between interior and exterior girders
- Abrupt changes in differential deflection across the width of the bridge

Test Structure, Deflection Due to Deck Weight

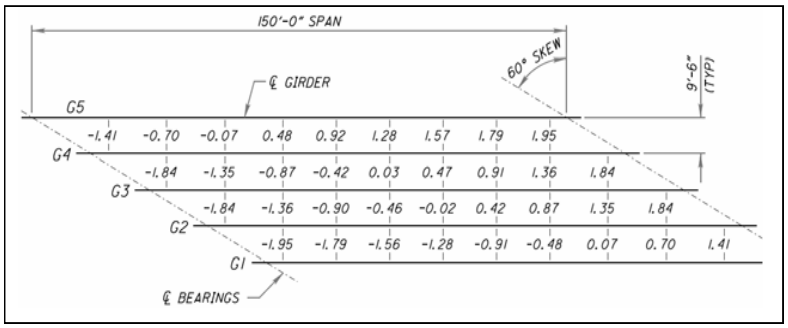




Line Girder Analysis Results

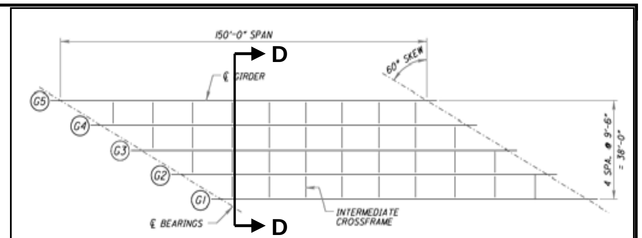
Crossframe Effects Ignored

Test Structure, Differential Deflections at Crossframe Locations:

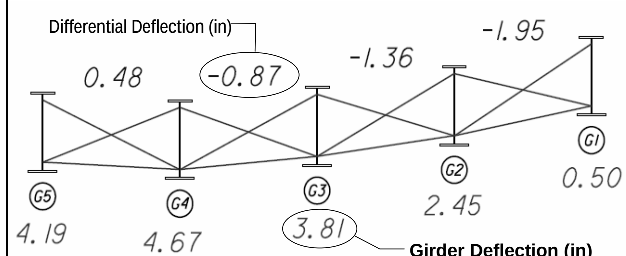


Line Girder Analysis Results

Crossframe Effects Ignored



Framing Plan

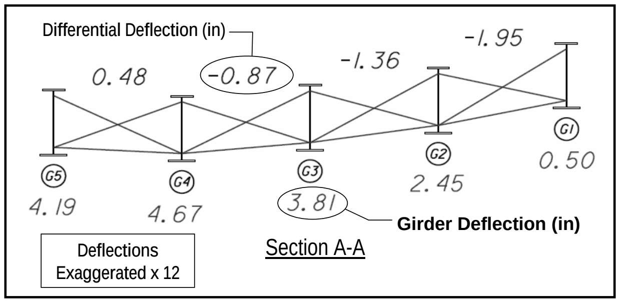


Section D-D

Deflections Exaggerated x 12

Line Girder Analysis Results

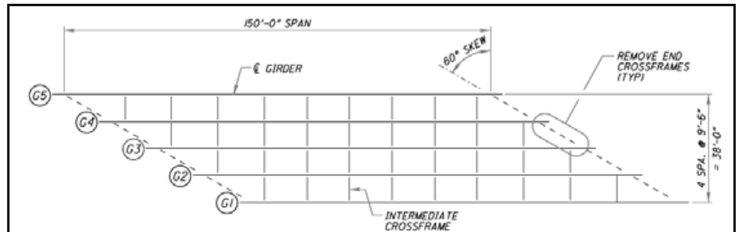
Crossfrane Effects Ignored



- Problem: If the girders are assumed to stay vertical, the crossframes will not permit differential deflections of this magnitude.
- Conclusion: Crossframe interaction needs to be included to accurately model structure behavior.

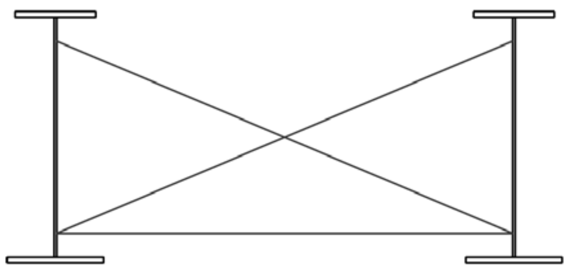
Intermediate Crossframe Effects

- We will now use a refined method to analyze the test structure with crossframe effects included.
- All intermediate crossframes are fully connected during the deck pour (no slotted holes).
- The end crossframes will be removed in order to isolate intermediate crossframe effects.
- The behavior of the bridge will be examined under wet concrete load only.

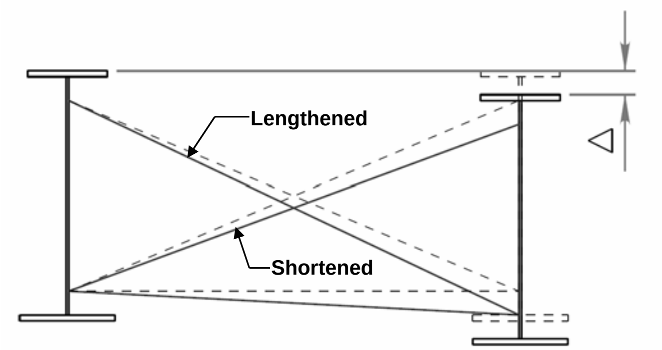


FRAMING PLAN

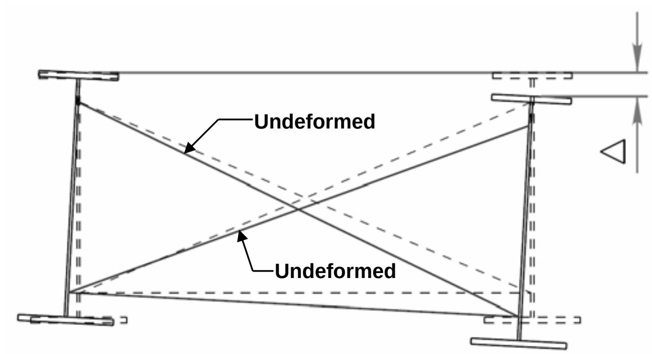
ODOT Standard Crossframe:



- Typical crossframes restrain girders against differential deflection and differential twist.



- Differential vertical deflection causes crossframes to deform if the girders do not twist.
- Large forces are needed to create axial deformations in the crossframe members, so resistance to this type of deflection is very high.

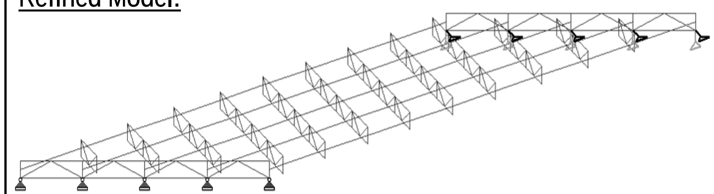


- Twisting of the girders allows differential deflection to occur without deforming the crossframe.
- Generally, the torsional stiffness of the girders is low compared to the stiffness of the crossframes, so this behavior is dominant.

Analysis of Test Case, Refined Model:

- In order to include crossframe effects in the analysis, we will need to use a Refined Model.
- Refined Model is a general term we will use to refer to any analysis that includes both the girders and the crossframes.
- Refined Models will be discussed in more detail in another presentation.

Refined Model:

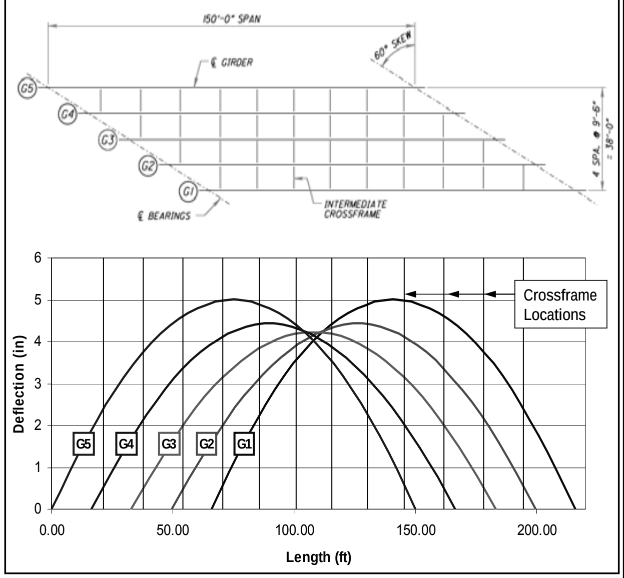


Refined Analysis Results
Intermediate Crossframe Effects Included

Results Show:

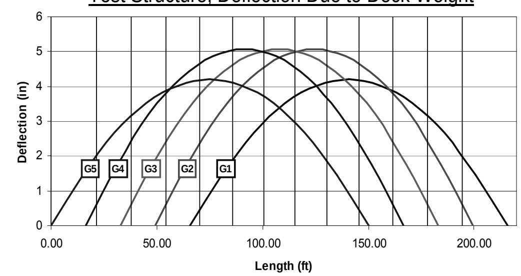
- More uniform differential deflection across the width of the bridge at crossframe locations (compared to line girder analysis)

Test Structure, Deflection Due to Deck Weight

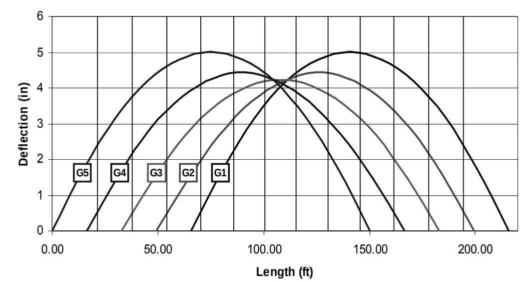


Line Girder Analysis Results
Crossframe Effects Ignored

Test Structure, Deflection Due to Deck Weight



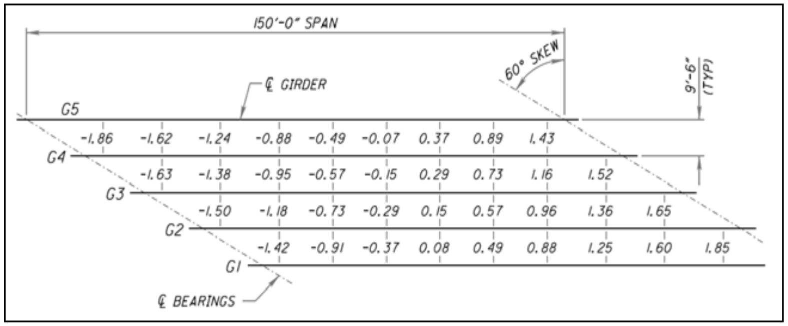
Refined Analysis Results
Intermediate Crossframe Effects Included



Refined Analysis Results

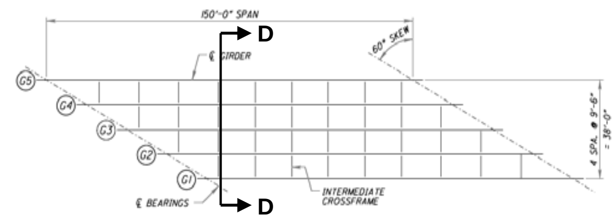
Intermediate Crossframe Effects Included

Test Structure, Differential Deflections at Crossframe Locations:

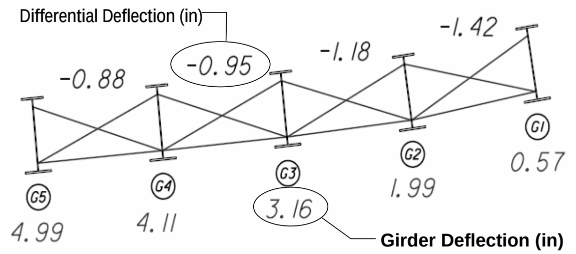


Refined Analysis Results

Intermediate Crossframe Effects Included



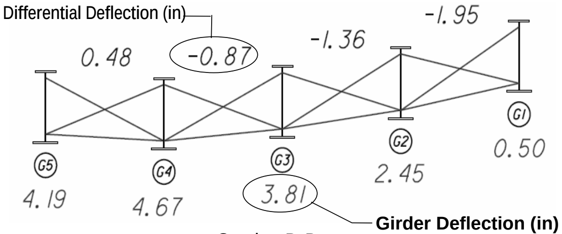
Framing Plan



Section D-D

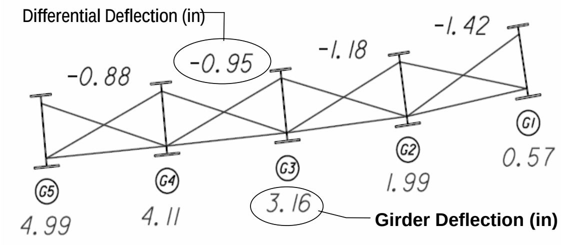
Deflections Exaggerated x 12

Line Girder Analysis Results
Crossframe Effects Ignored



Section D-D

Refined Analysis Results
Intermediate Crossframe Effects Included

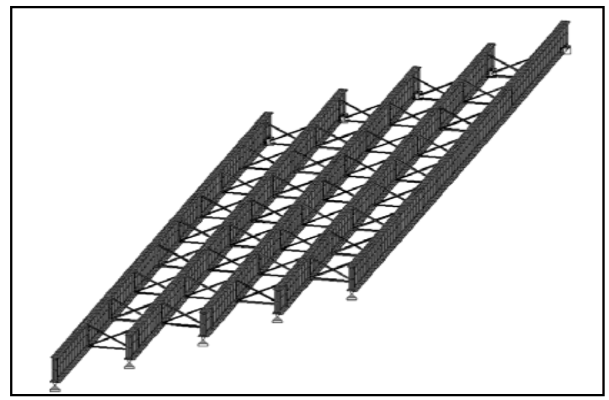


Section D-D

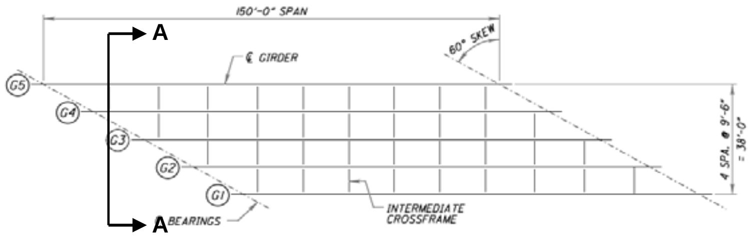
Deflections Exaggerated x 12

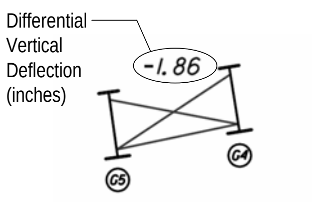
Deflected Shape Due to Intermediate Crossframe Effects

- The analysis results show that intermediate crossframe effects cause girder twist in skewed structures.
- The next several slides will step though the deflection of the test structure at each crossframe location.



Deflected Shape Due to Intermediate Crossframe Effects (Refined Analysis):

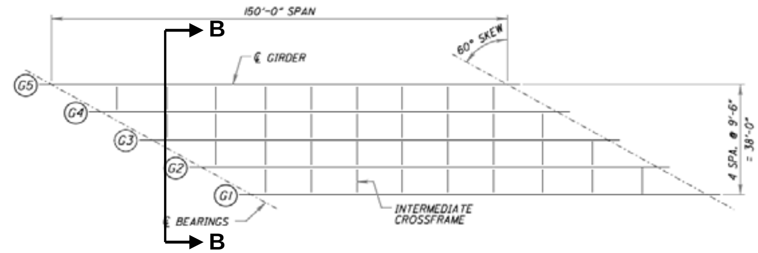


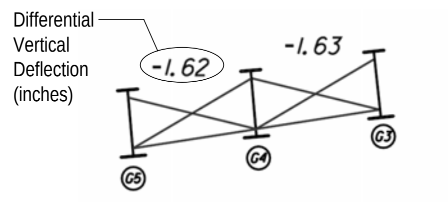


Section A-A

Deflections Exaggerated x 12

Deflected Shape Due to Intermediate Crossframe Effects (Refined Analysis):

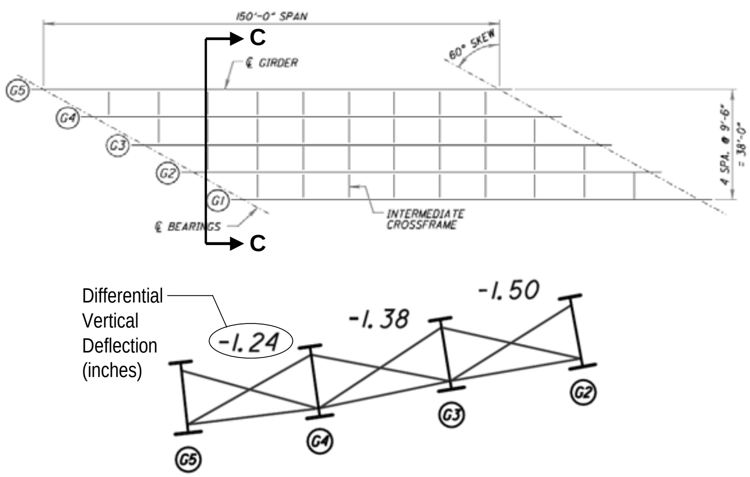




Section B-B

Deflections Exaggerated x 12

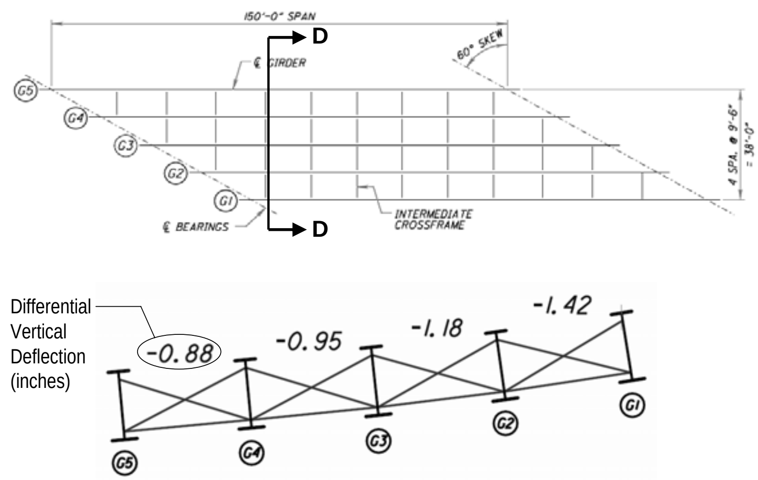
Deflected Shape Due to Intermediate Crossframe Effects (Refined Analysis):



Section C-C

Deflections Exaggerated x 12

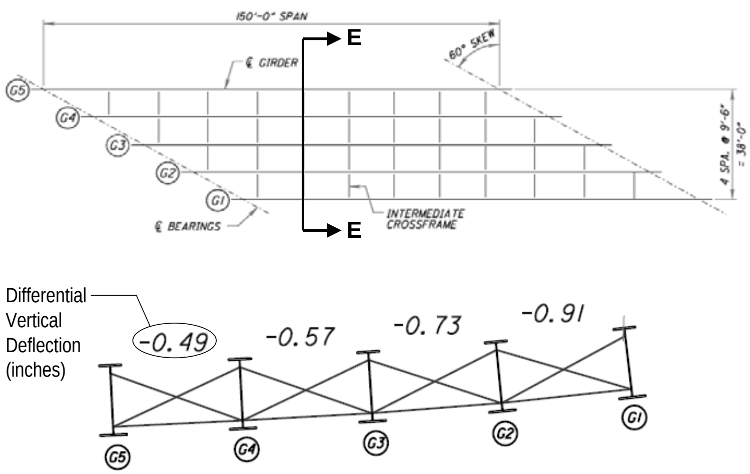
Deflected Shape Due to Intermediate Crossframe Effects (Refined Analysis):



Section D-D

Deflections Exaggerated x 12

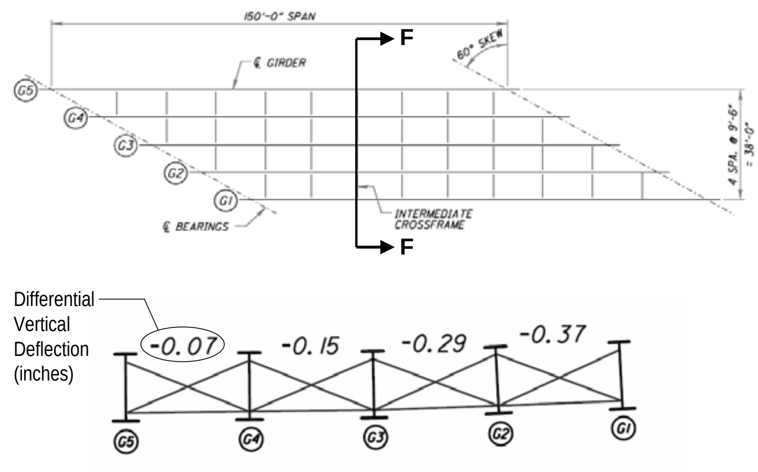
Deflected Shape Due to Intermediate Crossframe Effects (Refined Analysis):



Section E-E

Deflections Exaggerated x 12

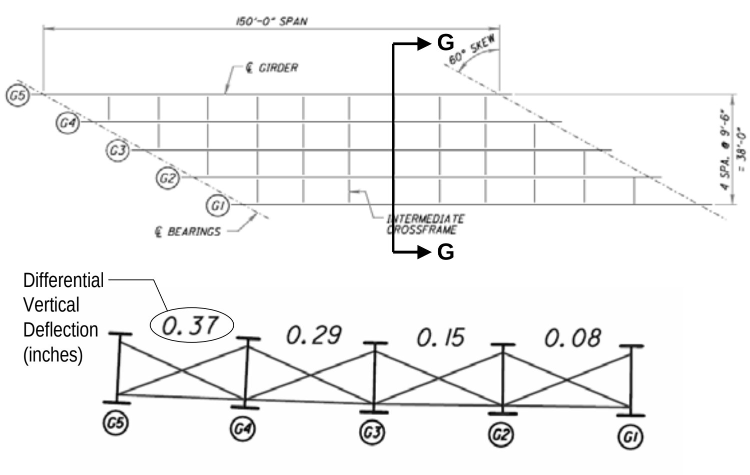
Deflected Shape Due to Intermediate Crossframe Effects (Refined Analysis):



Section F-F

Deflections Exaggerated x 12

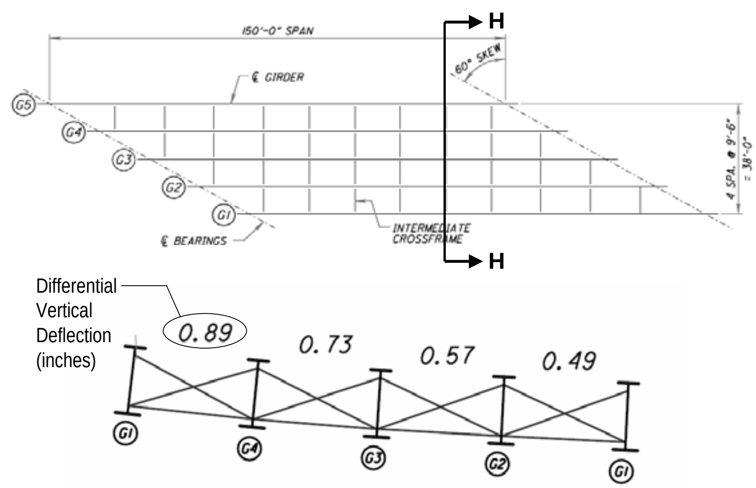
Deflected Shape Due to Intermediate Crossframe Effects (Refined Analysis):



Section G-G

Deflections Exaggerated x 12

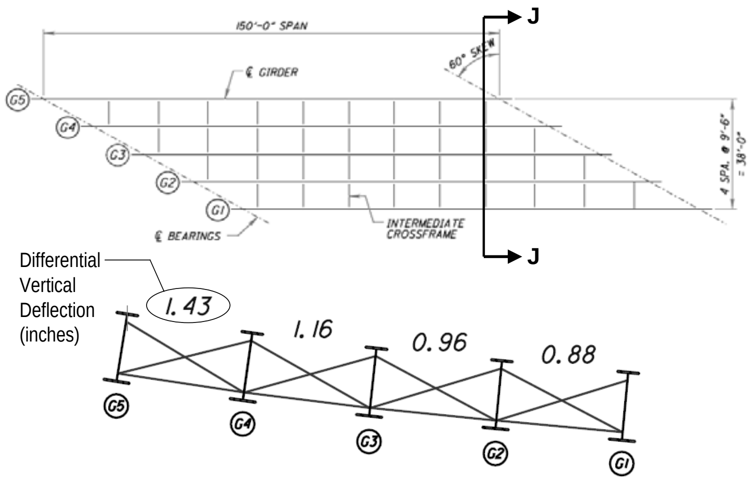
Deflected Shape Due to Intermediate Crossframe Effects (Refined Analysis):



Section H-H

Deflections Exaggerated x 12

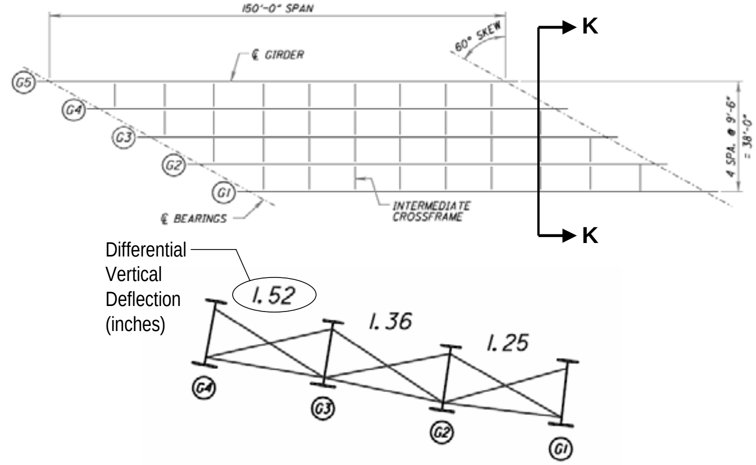
Deflected Shape Due to Intermediate Crossframe Effects (Refined Analysis):



Section J-J

Deflections Exaggerated x 12

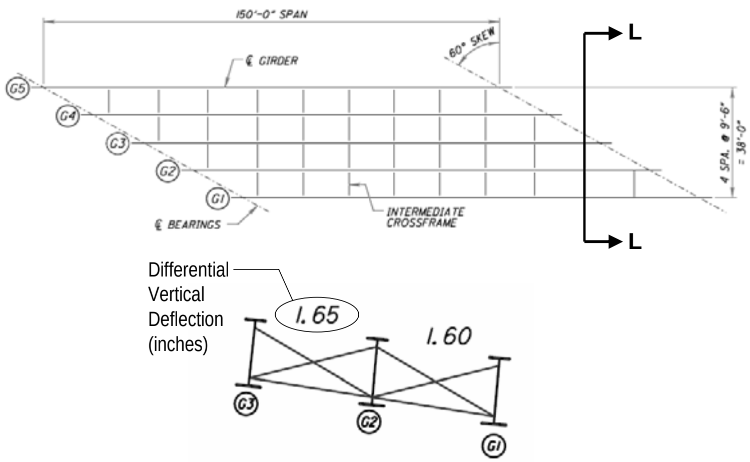
Deflected Shape Due to Intermediate Crossframe Effects (Refined Analysis):



Section K-K

Deflections Exaggerated x 12

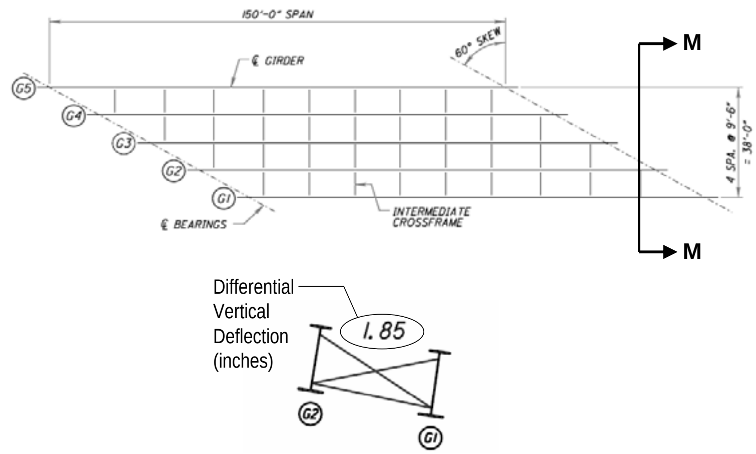
Deflected Shape Due to Intermediate Crossframe Effects (Refined Analysis):



Section L-L

Deflections Exaggerated x 12

Deflected Shape Due to Intermediate Crossframe Effects (Refined Analysis):

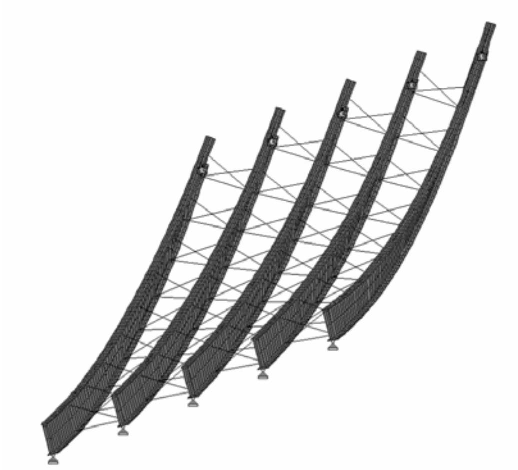


Section M-M

Deflections Exaggerated x 12

Animation of Deflection Under Wet Concrete Load with Intermediate Crossframe Effects Included (Exaggerated Scale):

Deflected Shape Under Wet Concrete Load with Intermediate Crossframe Effects Included (Exaggerated Scale):

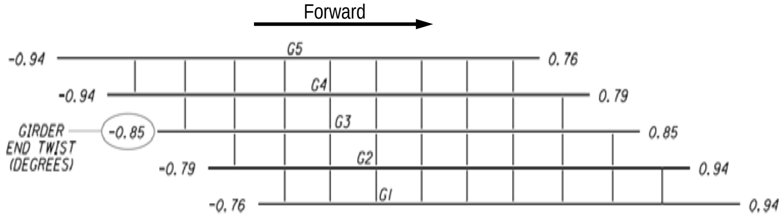


Girder Twist due to Intermediate Crossframe Effects

- In a single span skewed structure, twist is generally highest at the supports.
- End twist for the test case is shown below.

Definition of Girder Twist ϕ :

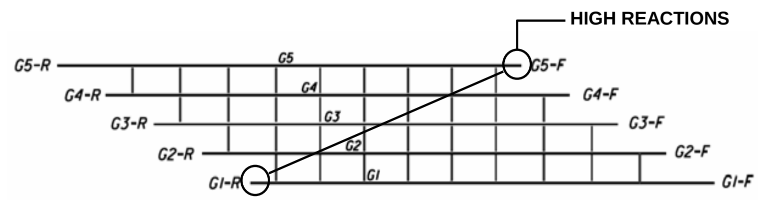
Test Structure, Refined Analysis, Intermediate Crossframes Only:



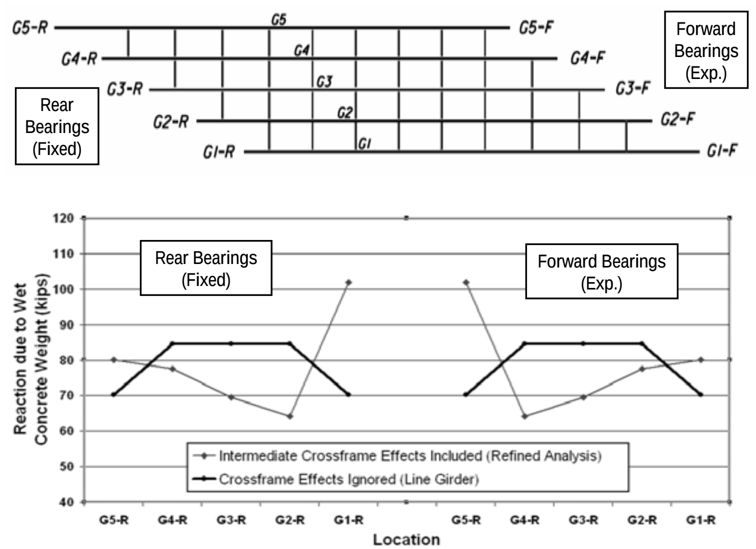
Sign Convention: (+ Clockwise, Looking Forward - Counterclockwise, Looking Forward)

Support Reactions due to Intermediate Crossframe Effects

- Intermediate crossframe effects cause vertical support reactions to be concentrated at the obtuse corners of a skewed structure.
- Significant redistribution of reactions occurs throughout the structure.

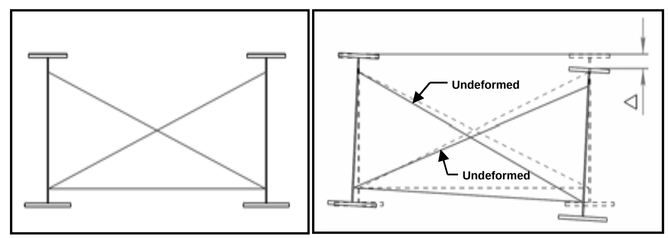


Support Reactions Due to Wet Concrete Weight, Refined Analysis:



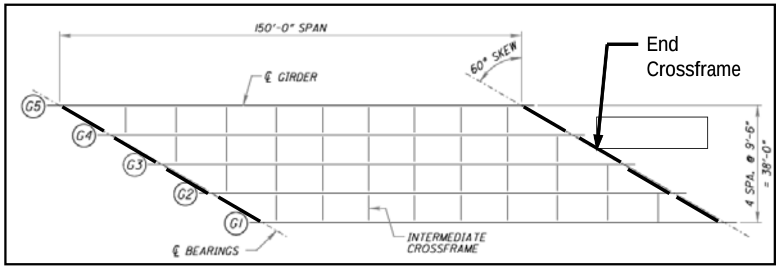
Conclusions for Intermediate Crossframe Effects:

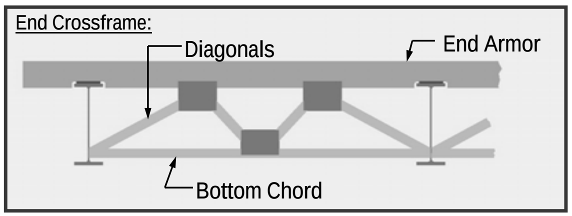
- There are natural differences in dead load deflections at opposite ends of intermediate crossframes in skewed structures.
- Differential deflections occurring at intermediate crossframe locations cause girders to twist.
- Intermediate crossframe effects must be included in analysis of highly skewed structures in order to accurately predict behavior.



End Crossframe Effects

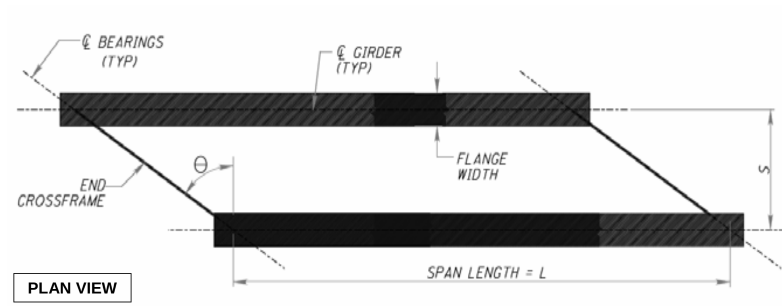
- End crossframes produce twisting effects that are independent of the intermediate crossframe behavior.



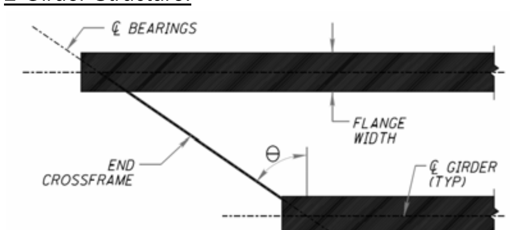


End Crossframe Effects

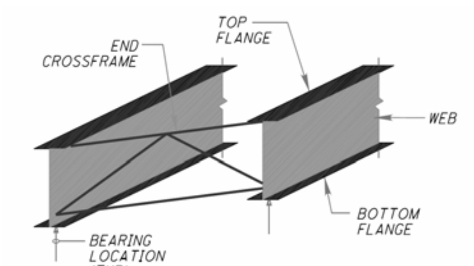
- To illustrate end crossframe behavior, we will examine a 2-girder structure with end crossframes only (no intermediate bracing).



2-Girder Structure:



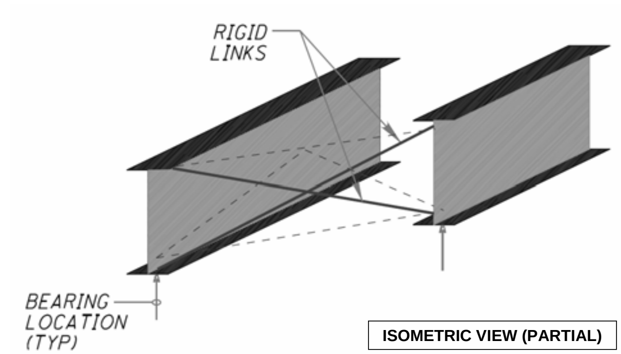
PLAN VIEW (PARTIAL)



ISOMETRIC VIEW (PARTIAL)

The end crossframe is oriented on the skew and connects the bearing points of the adjacent girders.

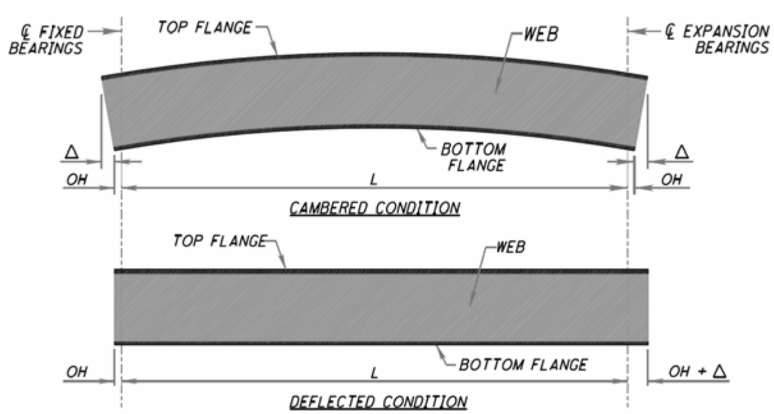
2-Girder Structure:



ISOMETRIC VIEW (PARTIAL)

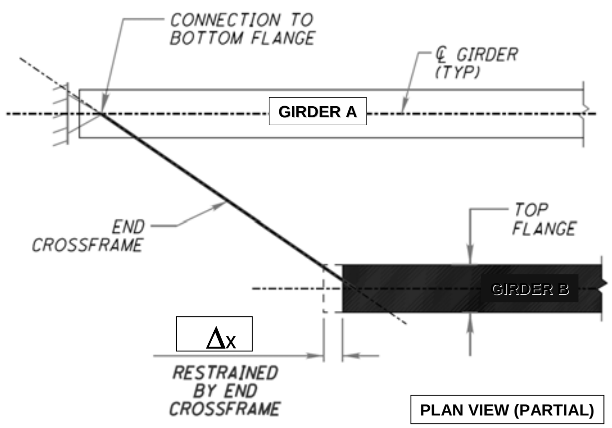
- The end diaphragm can be thought of as a pair of rigid links connecting the top flange of one girder to the bottom flange of the adjacent girders.

Deflection of a Cambered Girder:



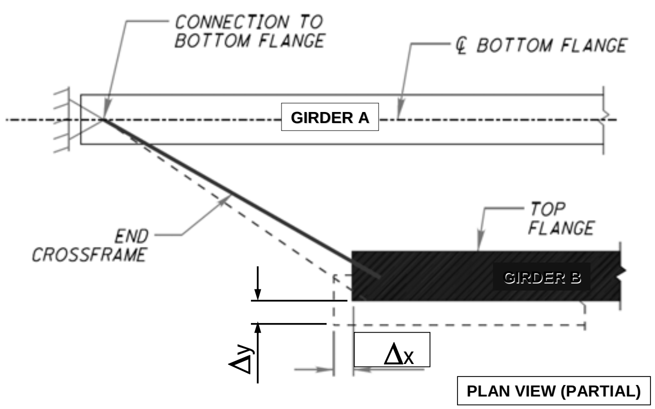
- When a girder deflects, the top flange moves longitudinally relative to the bottom flange at the beam ends. We will define this distance as Δ.

2-Girder Structure:



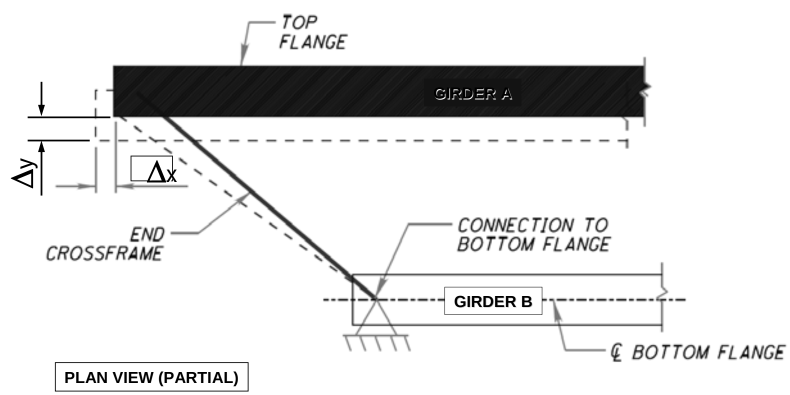
- The end crossframe of a skewed structure restrains the longitudinal translation of the top flange.

2-Girder Structure:



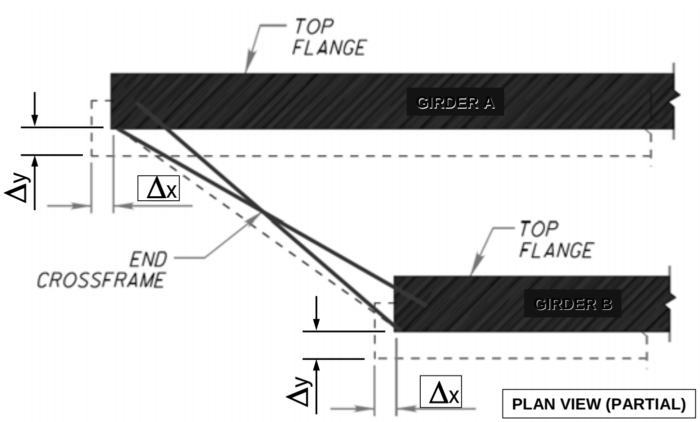
- The end crossframe forces the top flange to move radially about the adjacent bearing point. The resulting motion produces twist in the girders.

2-Girder Structure:



- A similar effect occurs in the adjacent girder

2-Girder Structure:

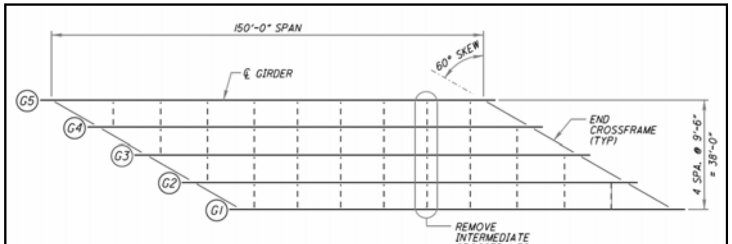


PLAN VIEW (PARTIAL)

- The movement of the top flange is approximately perpendicular to the centerline of bearings.

End Crossframe Effects

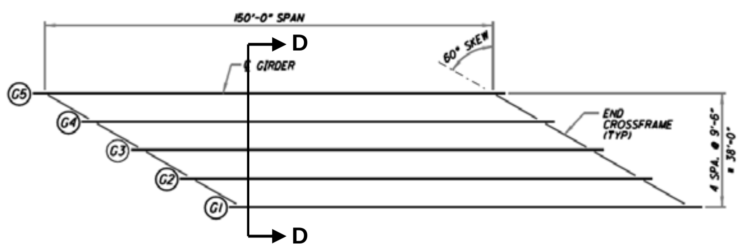
- We will now perform a refined analysis of the test structure with end crossframe effects included.
- All end crossframes are fully connected during the deck pour (no slotted holes).
- The intermediate crossframes will be removed in order to isolate end crossframe effects.
- The behavior of the bridge will be examined under wet concrete load only.



FRAMING PLAN

Girder Twist Due to End Crossframe Effects:

- By cutting sections along the length of the bridge it can be shown that the twist caused by end crossframe effects is very similar to that caused by intermediate crossframe effects.

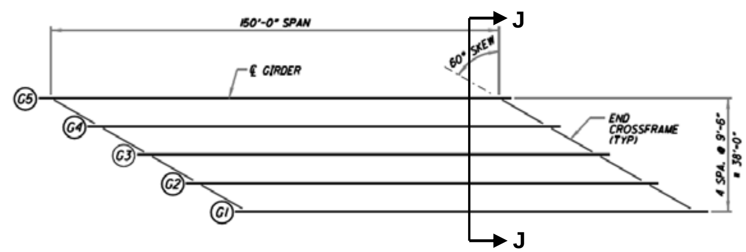


Framing Plan

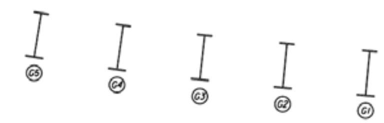
Section D-D

Girder Twist Due to End Crossframe Effects:

- By cutting sections along the length of the bridge it can be shown that the twist caused by end crossframe effects is very similar to that caused by intermediate crossframe effects.

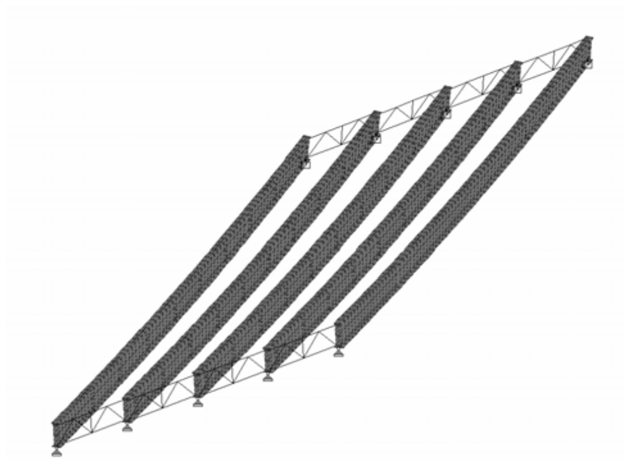


Framing Plan



Section J-J

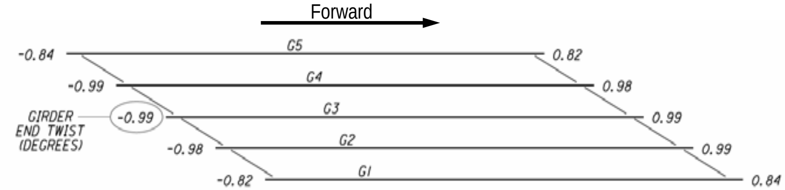
Animation of Deflection Under Wet Concrete Load with End Crossframe Effects Only (Exaggerated Scale):



Deflected Shape Under Wet Concrete Load with End Crossframe Effects Only (Exaggerated Scale):

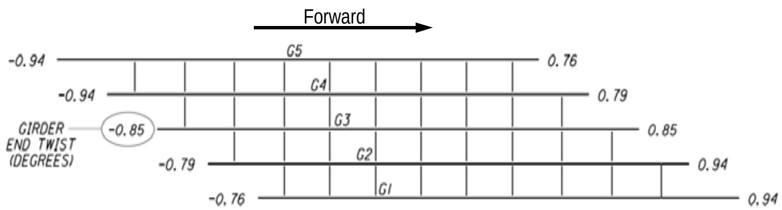
Test Structure, Girder End Twist

End Crossframes Only:



Sign Convention: (+ Clockwise, Looking Forward - Counterclockwise, Looking Forward)

Intermediate Crossframes Only:

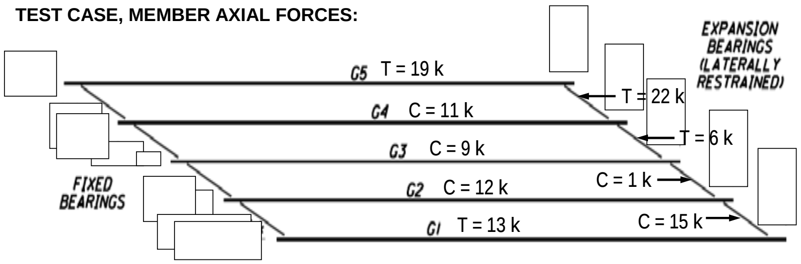


Sign Convention: (+ Clockwise, Looking Forward - Counterclockwise, Looking Forward)

End Crossframe Support Reactions

- End crossframe effects do not cause redistribution of vertical reactions, but they do produce horizontal loads on restrained bearings.
- For the test case, the rear abutment bearings are fully restrained against translation, and the forward abutment bearings are free to move longitudinally but restrained laterally.
- The bearing restraints result in axial forces in the girders and end crossframes due to differential movements caused by de-cambering of the beams (or differential lengthening of the bottom flanges).

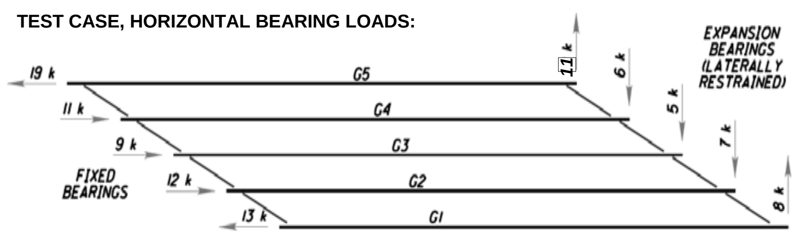
TEST CASE, MEMBER AXIAL FORCES:



Test Case, Support Reactions

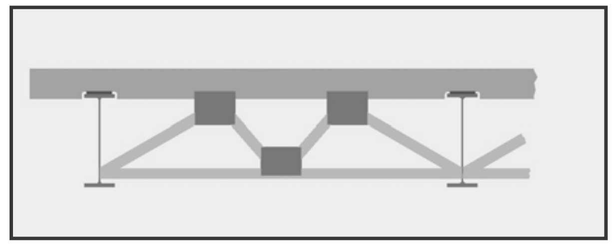
- The resulting horizontal components of the support reactions for the test case are shown below.
- These forces need to be accounted for in the bearing design if end crossframes are left connected during the deck pour.

TEST CASE, HORIZONTAL BEARING LOADS:



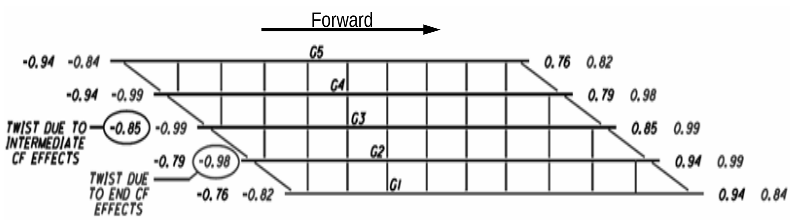
Conclusions for End Crossframe Effects:

- End crossframes in skewed structures cause girders to twist. The magnitude of the twist is similar to that caused by intermediate crossframes.
- End crossframes in skewed structures produce longitudinal and lateral forces at restrained bearing locations.
- If end crossframes are fully connected prior to the deck pour, end crossframe effects must be considered in the design.



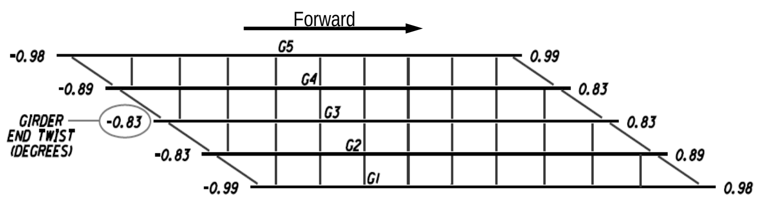
Combined Effects: Girder End Twist

End Crossframes Only / Intermediate Crossframes Only:



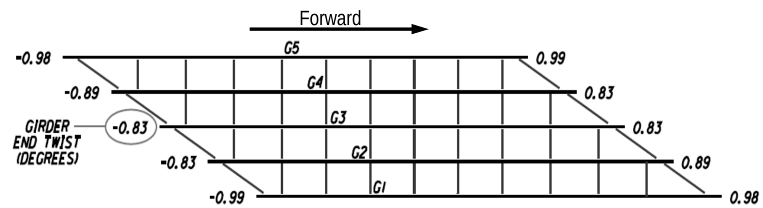
Sign Convention: (+ Clockwise, Looking Forward - Counterclockwise, Looking Forward)

Combined effects:



Sign Convention: (+ Clockwise, Looking Forward - Counterclockwise, Looking Forward)

Combined Effects: Girder End Twist



Sign Convention: (+ Clockwise, Looking Forward - Counterclockwise, Looking Forward)

Conclusions:

- Intermediate and end effects are not additive.
- Interaction between effects redistributes twist slightly, but the overall magnitude remains about the same when effects are combined.

Common Questions:

Q: Will using skewed intermediate crossframes prevent girder twisting?

A: No. Skewed intermediate crossframes behave like end crossframes. They will produce twist due to differential movements between the bottom and top flanges of adjacent girders.

Common Questions:

Q: Will reducing crossframe spacing keep girders from twisting?

A: No. Tighter crossframe spacing does not address the basic problem, which is differential movement between adjacent girders. Adding crossframes may reduce crossframe member forces and increase girder stability, but twisting will still occur.

Summary:

- Both intermediate and end crossframes produce twist in skewed bridges.
- Intermediate crossframes cause significant redistribution of support reactions and girder forces (shear and moment) in heavily skewed structures.
- End crossframes may cause significant lateral and longitudinal reactions to occur at restrained bearings
- Both intermediate and end crossframe effects need to be accounted for in design of highly skewed bridges.

QUESTIONS ?

E-mail questions to:

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