HDR

Introduction to the new FHWA Bridge Geometry Manual

Who is it for and why do I need it?

HDR

Western Bridge Engineers' Seminar - 9/27/2023

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So…what is this manual?

So…what is this manual?

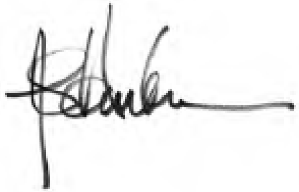
The foreword says it best…

- Successful bridge construction relies on accurate geometry
- Provides basic principles to evaluate a number of different types of bridge geometry.
- Intended for bridge engineers and technicians at all levels…not just those starting their careers.

FOREWORD

Documenting a bridge's geometry accurately on bridge layouts and detailed drawings during the design process is fundamental to successful bridge construction. Detailed bridge geometry provides the information necessary to establish analytical models for bridge superstructures and substructures. Geometric constraints often dictate the type of bridge to be built at a specific site. As such, determining bridge geometry is central to the work of bridge engineers and technicians.

The purpose of this manual is to provide bridge engineers and technicians with a basic framework for evaluating and computing the various components of bridge geometry. The manual includes practical examples for implementing the topics discussed. Reference is also made to numerous outside resources for further direction and discussion. The manual is organized into three Parts including General Topics, Concrete Topics, and Steel Topics. While separation among Parts maintains a focused approach, discussion topics inherently overlap with broad applicability across multiple chapters.



Joseph L. Hartmann, PhD, P.E.
Director, Office of Bridges and Structures
Office of Infrastructure
Federal Highway Administration

Cover photos source: HDR, PCI, PCI, PCI (clockwise from upper left)

So…what is this manual?

What types of geometry topics?

- The manual is broken up into three primary sections
  - General topics
  - Concrete topics
  - Steel Topics

Table of Contents

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A little history…

A little history…

Where it began

- The Federal Highway Administration began work on the manual with AASHTO and PCI, along with Corven Engineering
- Intent was to produce two separate documents (steel and concrete)
- The content was very concrete centric

A little history…

A combined effort

- FHWA decided to combine the two documents into one
- To provide a more well-rounded bridge perspective, HDR was selected under an IDIQ contract with FHWA to provide a section on geometry topics related to steel bridge members.
- With subconsultant, Markosky Engineering, the steel section was developed and tied the previously written content to the new content.

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The General Topics

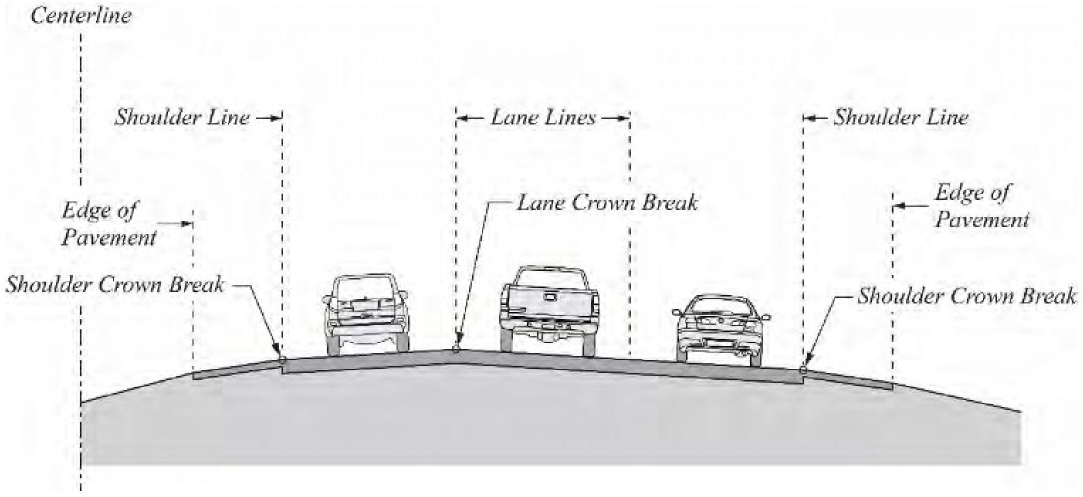
General Topics

Introduction

- Influence of Bridge Geometry on Bridge Type, Span Length, and Layout
  - Horizontal curvature
  - Vertical and lateral clearances
  - Skewed crossings
- Terminology
  - Roadway terminology
  - Bridge terminology

Source: PCI

Figure 1.6 Hammerhead Piers (T-Piers), Straddle Bents, and Integral T-Piers



Source: PCI

Figure 1.9 Locations within a Highway Cross Section

General Topics

Roadway Horizontal Geometry

- Coordinate systems
- Baselines
- Circular curves
- Stationing
- Spirals

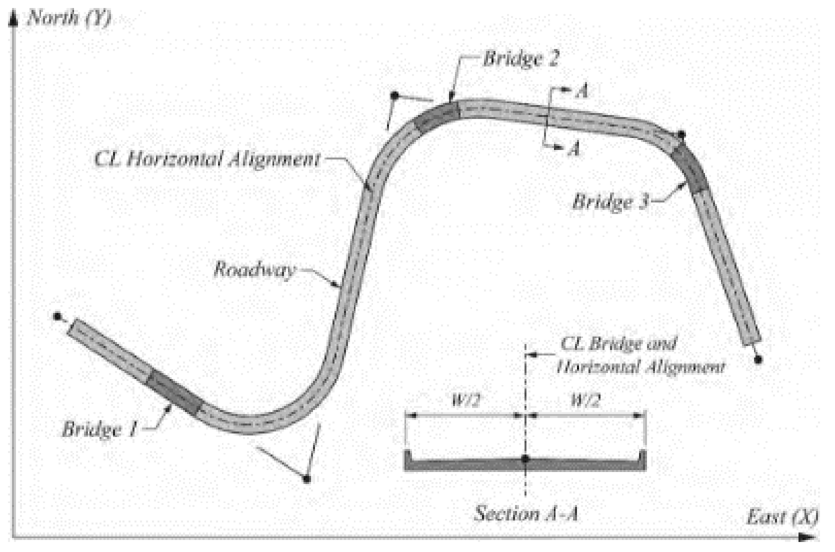


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Figure 2.1 Horizontal Roadway Alignment with Bridges

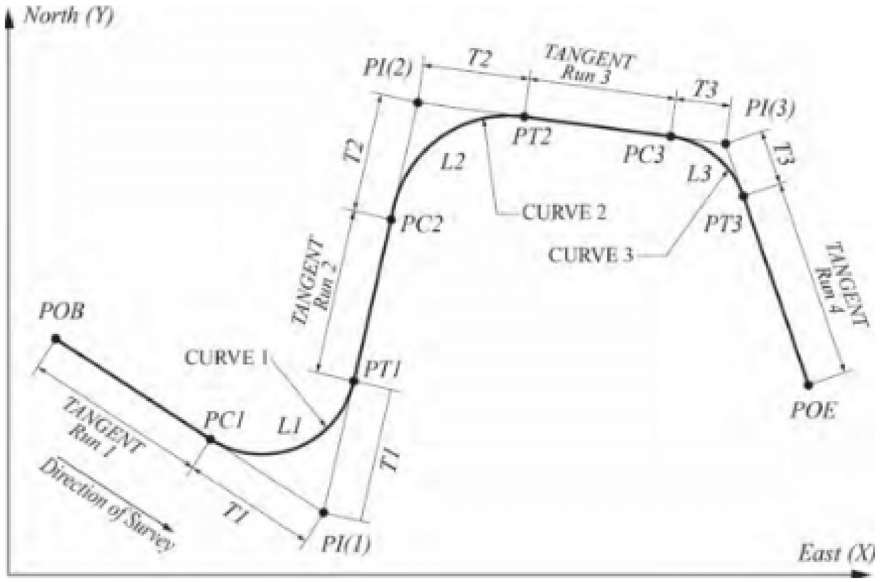

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Figure 2.9 Horizontal Alignment with Circular Curves Added

General Topics

Roadway Vertical Geometry

- Vertical grades
- Vertical curves
- And all the points in between

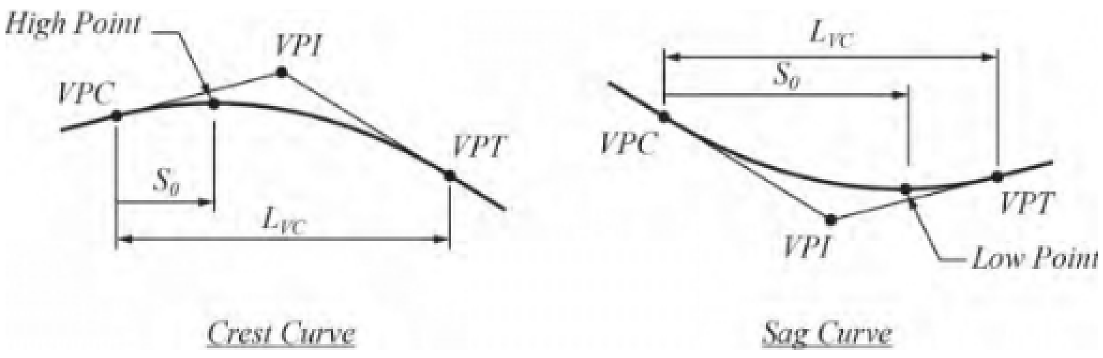

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Figure 3.7 High Point and Low Point for Crest and Sag Vertical Curves, respectively

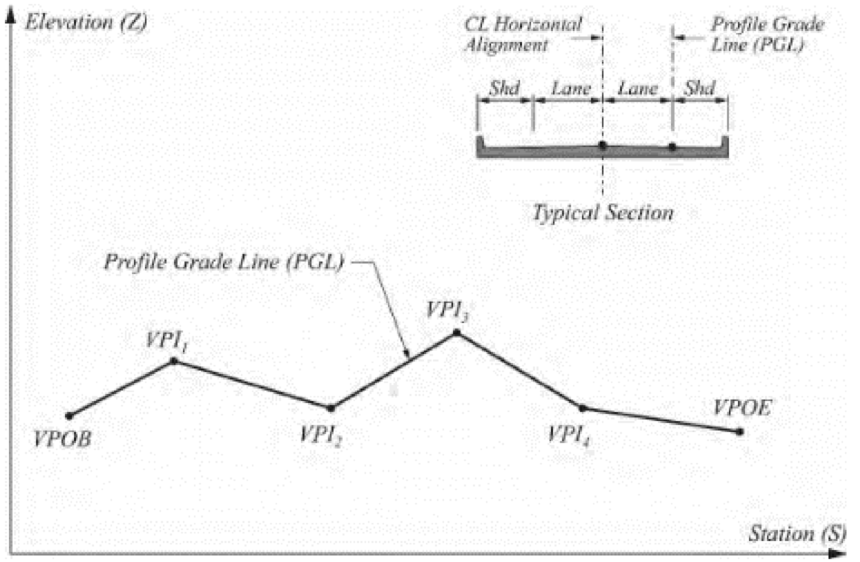

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Figure 3.1 Typical Vertical Profile

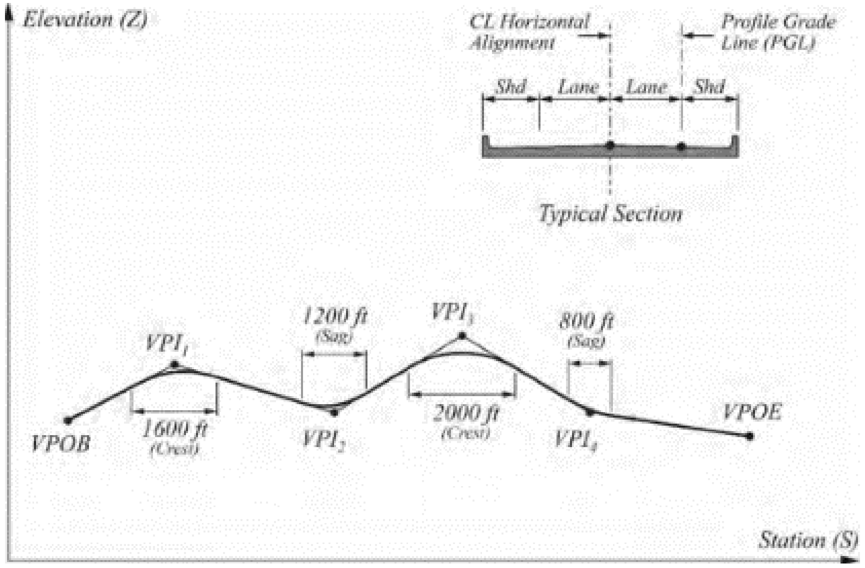

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Figure 3.6 Example Vertical Profile

General Topics

Roadway Superelevation

- Effects of roadway curvature
- Normal crown
- Pivot points and superelevation transitions

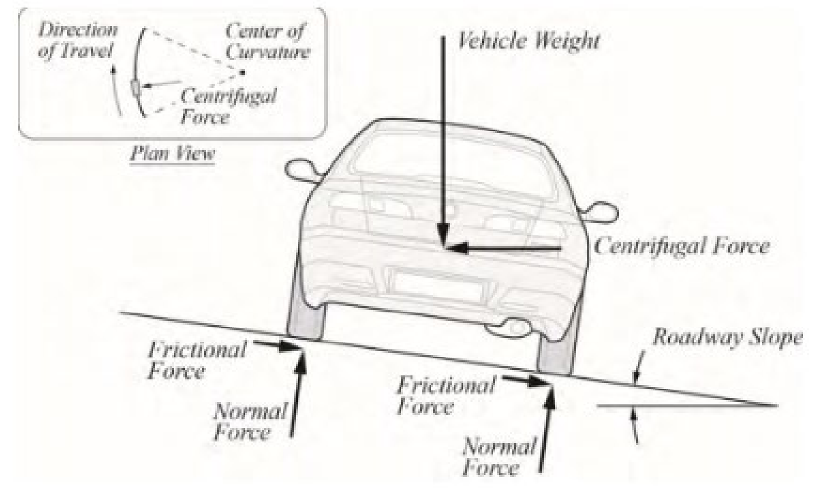

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Figure 4.2 Forces Acting on A Vehicle Following a Curved Alignment on a Superelevated Roadway Cross Slope

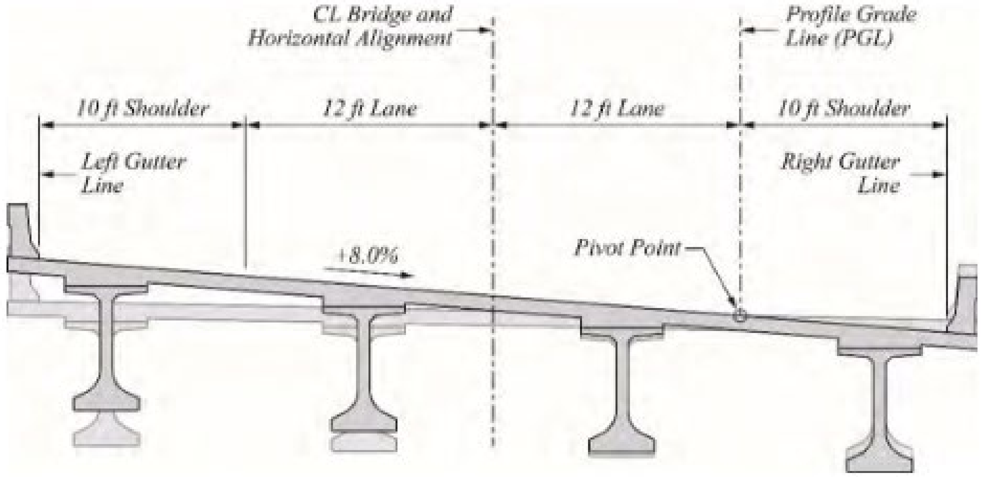

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Figure 4.11 Maximum Superelevation with Pivot Point at the Profile Grade Line

General Topics

Working with Horizontal Geometry

- Locating points on horizontal alignments
- Locating point offsets from horizontal alignments
- Projecting points onto horizontal alignments
- Creating offset horizontal alignments

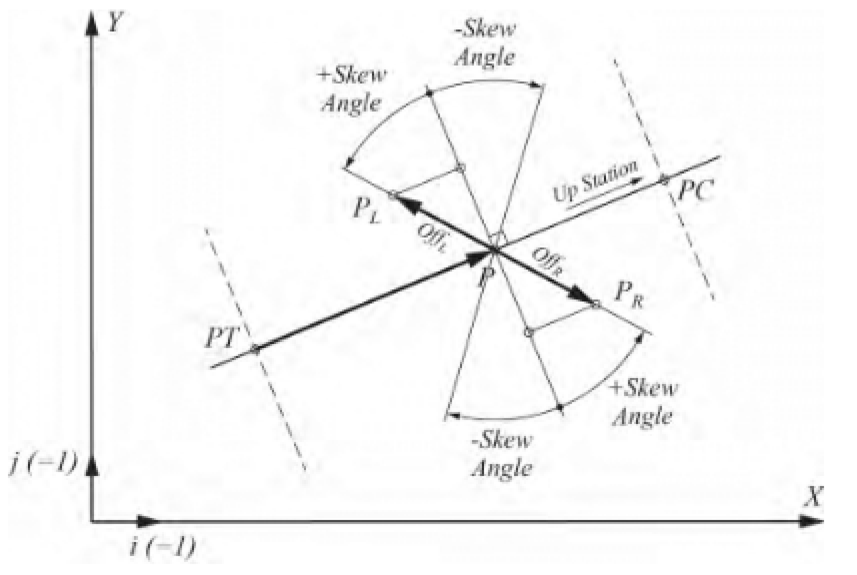

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Figure 5.4 Locating Points with a Skew Offset

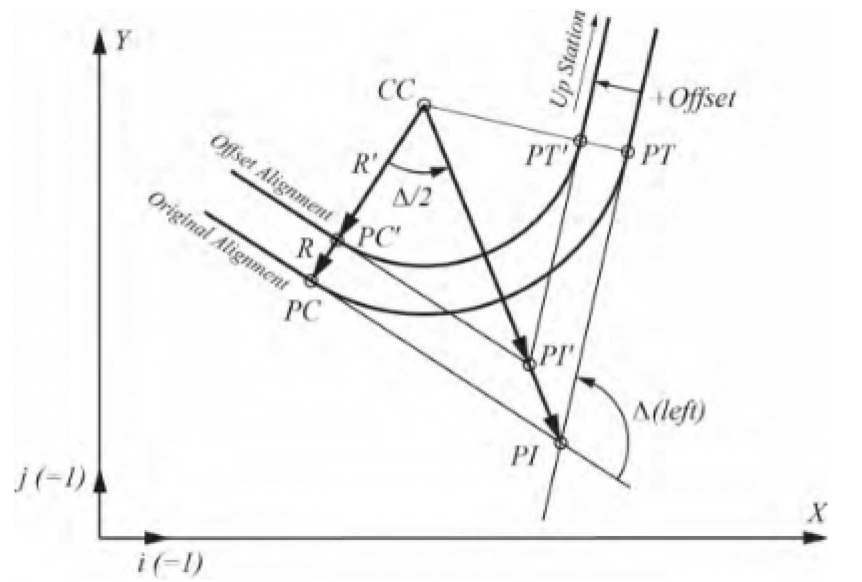

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Figure 5.11 Finding Offset Alignments

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The Concrete Topics

Concrete Topics

Geometry of Straight Bridges with Straight Precast Concrete Girders

- First example bridge is introduced
- Geometric calculations discussed include:
  - Locating coordinates of the bridge CL at each substructure unit
  - Locating edge of deck coordinates
  - Computing elevations along the bridge CL and edge of deck coordinates
- The concept of a beam/deck haunch is discussed

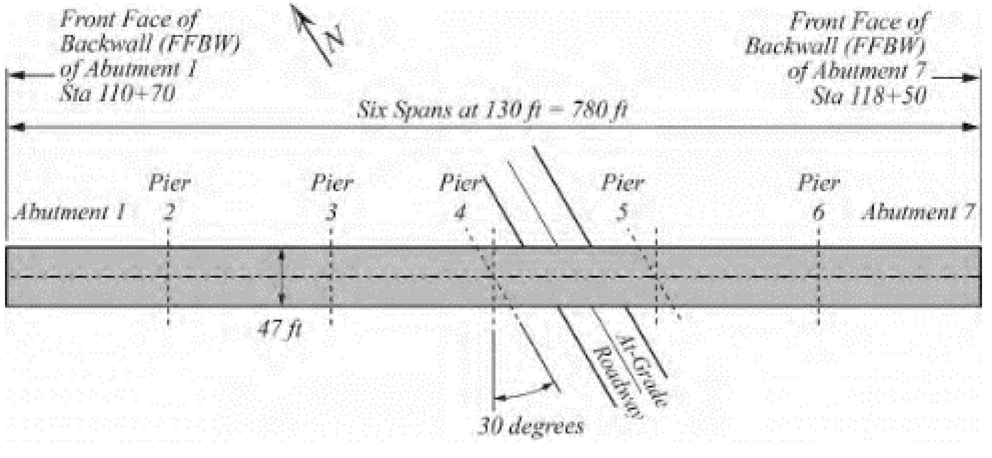

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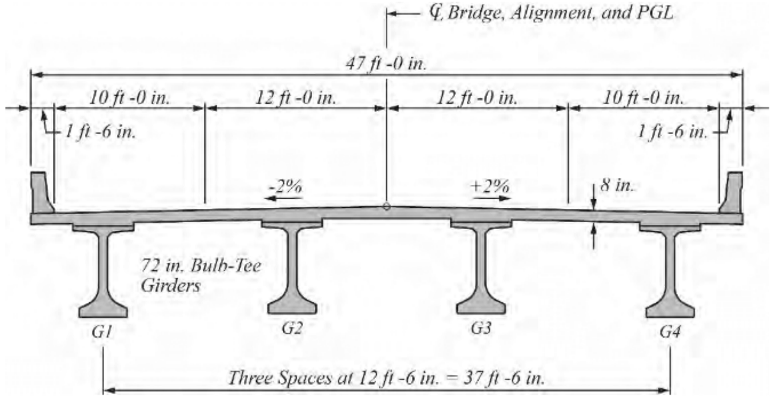
Figure 6.2 Plan View of Example Bridge (Bridge 1)



Source: PCI

Figure 6.3 Bridge 1 Cross Section

Table 6.2 Centerline Bridge Coordinates at Abutments and Piers

Pier	Station	*ΔSta*, ft	*ΔSta*(u_i), ft	*ΔSta*(u_j), ft	*CL X*(E), ft	*CL Y*(N), ft
Abt. 1	110+70	1070.0	898.00	581.80	1398.00	1918.20
2	112+00	1200.0	1007.10	652.49	1507.10	1847.51
3	113+30	1330.0	1116.21	723.18	1616.21	1776.82
4	114+60	1460.0	1225.31	793.86	1725.31	1706.14
5	115+90	1590.0	1334.41	864.55	1834.41	1635.45
6	117+20	1720.0	1443.51	935.24	1943.51	1564.76
Abt. 7	118+50	1850.0	1552.62	1005.92	2052.62	1494.08

Concrete Topics

Geometry of Straight Bridges with Straight Precast Concrete Girders

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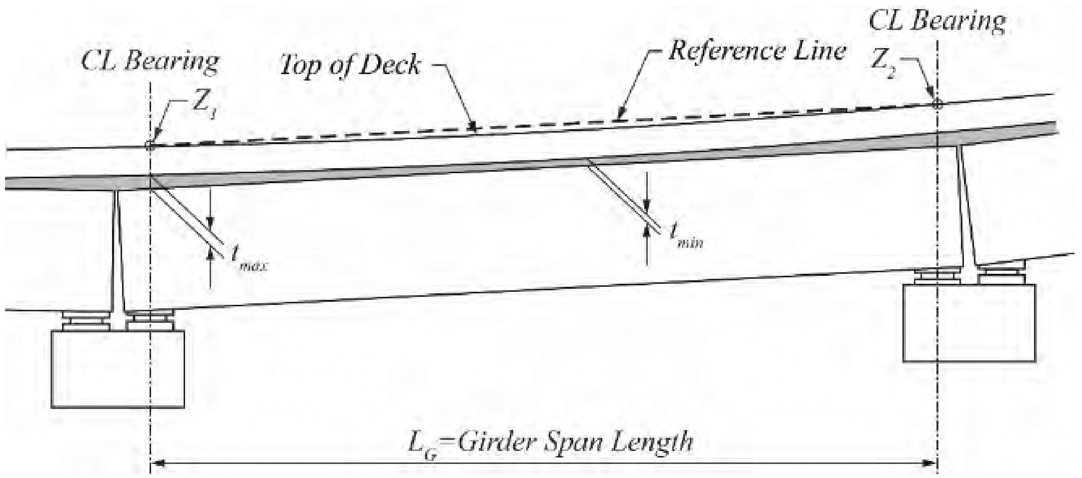

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Figure 6.12 Varying Haunch for Sag Curves with Girder with No Camber

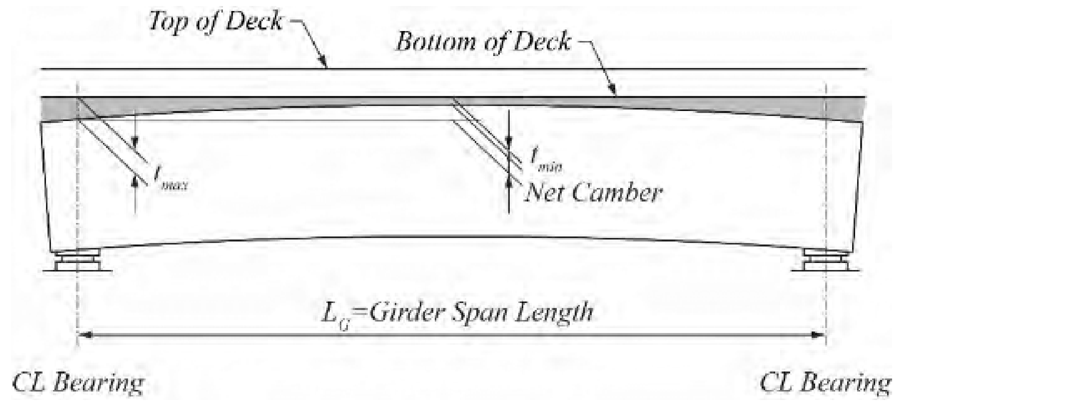

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Figure 6.15 Haunch Variation to Accommodate Net Camber

Concrete Topics

Geometry of Concrete Curved Bridges with Straight Precast Concrete Girders

- The concept of tangent chorded beams with a curved deck is introduced.
- Sample calculations include:
  - Establishing an offset alignment along CL of exterior beam
  - Calculate coordinates and elevations
  - Determining chord lengths and middle ordinates
  - Haunch thicknesses along length of beam

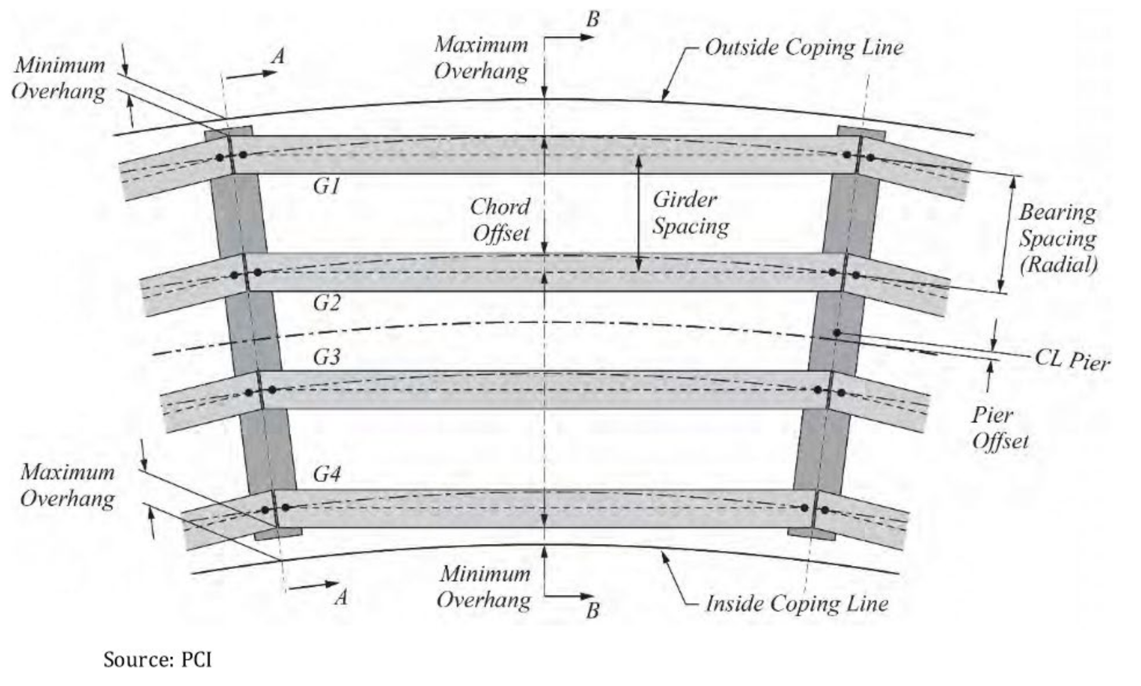

Figure 7.2 Curved Bridge with Chorded Girders

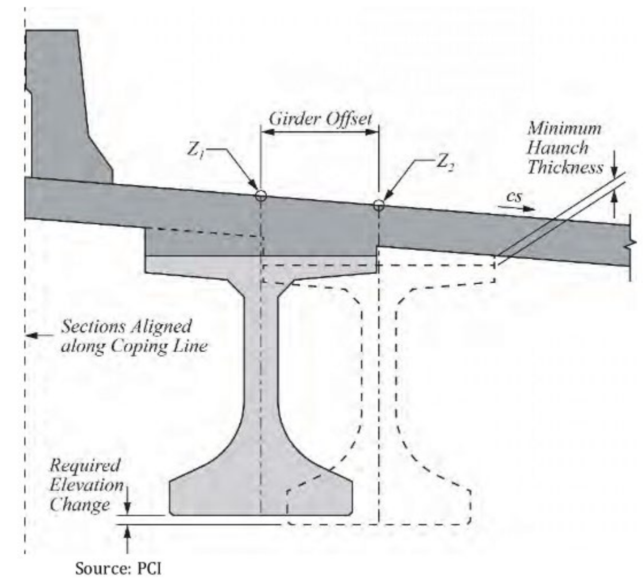

Figure 7.6 Haunch Adjustment for Chorded Girders

Concrete Topics

Geometry of Precast Segmental Bridges

- A brief introduction to precast concrete segmental bridges
- Common construction methods
- Match-Casting by the Short-Line Method

Source: PCI

Figure 8.1 Foothills Parkway Bridge No. 2

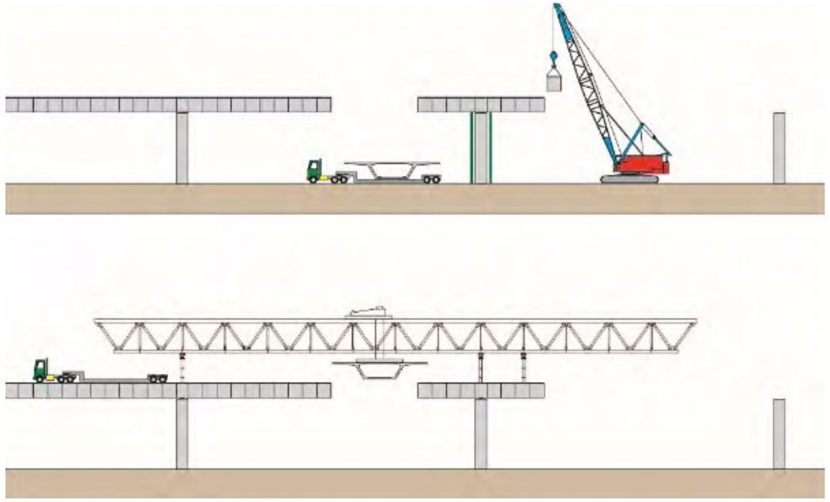

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Figure 8.3 Common Balanced Cantilever Erection Schematics

Concrete Topics

Geometry of Precast Segmental Bridges

- Concepts and equations for establishing precast concrete segment geometry using global coordinates
  - Centerline of segment beginning and end points
  - Segment wingtip and geometry control coordinates
  - Locating pier segments
  - Overall geometry control during construction

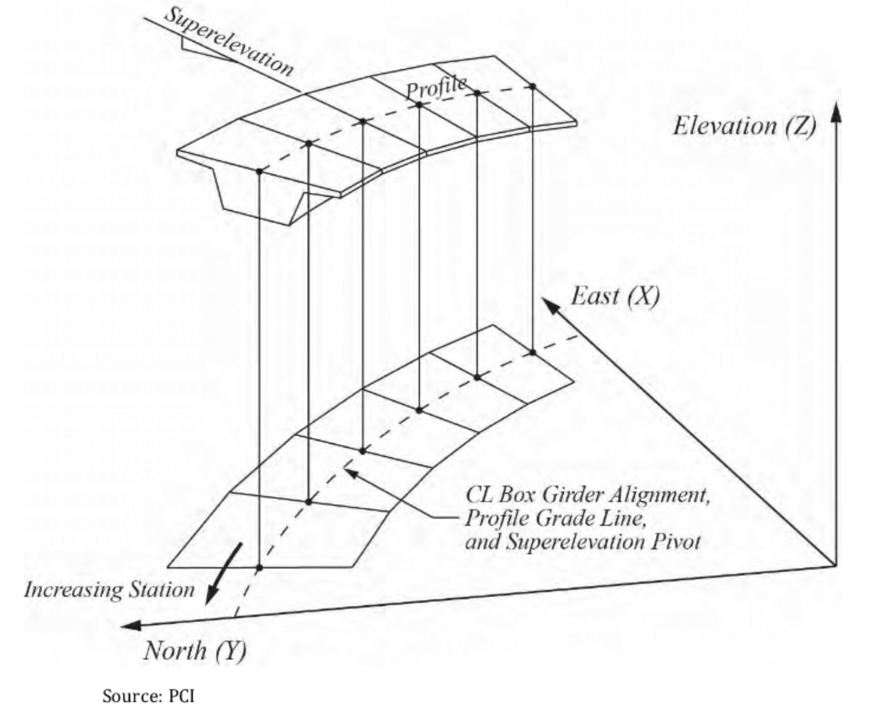

Figure 8.13 Centerline Segment Points

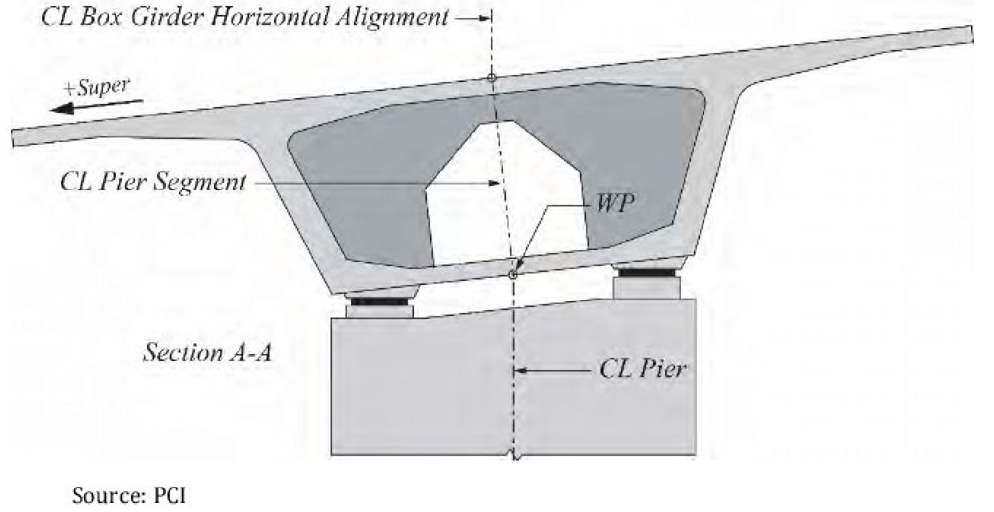

Figure 8.14 Side View and Cross Section at a Pier

Concrete Topics

Geometry of Precast Segmental Bridges

- Concepts and equations for establishing precast concrete segment geometry using global coordinates
  - Centerline of segment beginning and end points
  - Segment wingtip and geometry control coordinates
  - Locating pier segments
  - Overall geometry control during construction

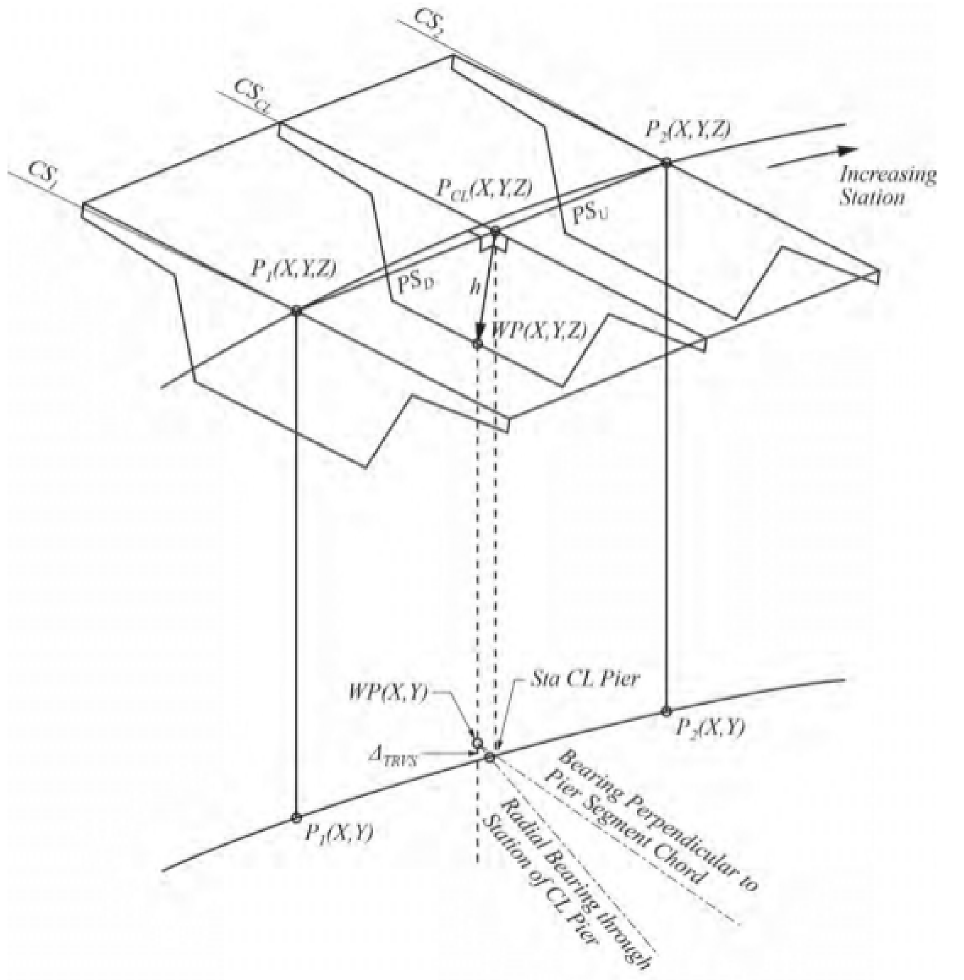

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Figure 8.17 3D Iterative Approach to Locating Pier Segments

Concrete Topics

Geometry of Precast Concrete U-Girder Bridges

- Geometric considerations for girder precasting and erection
  - Horizontal layout
  - Segment length and superelevation
  - Transformation from casting bed to a location in the bridge
- Example calculations are provided
  - Determining working points
  - Figuring out segment lengths
  - Transforming 10th points from local to global

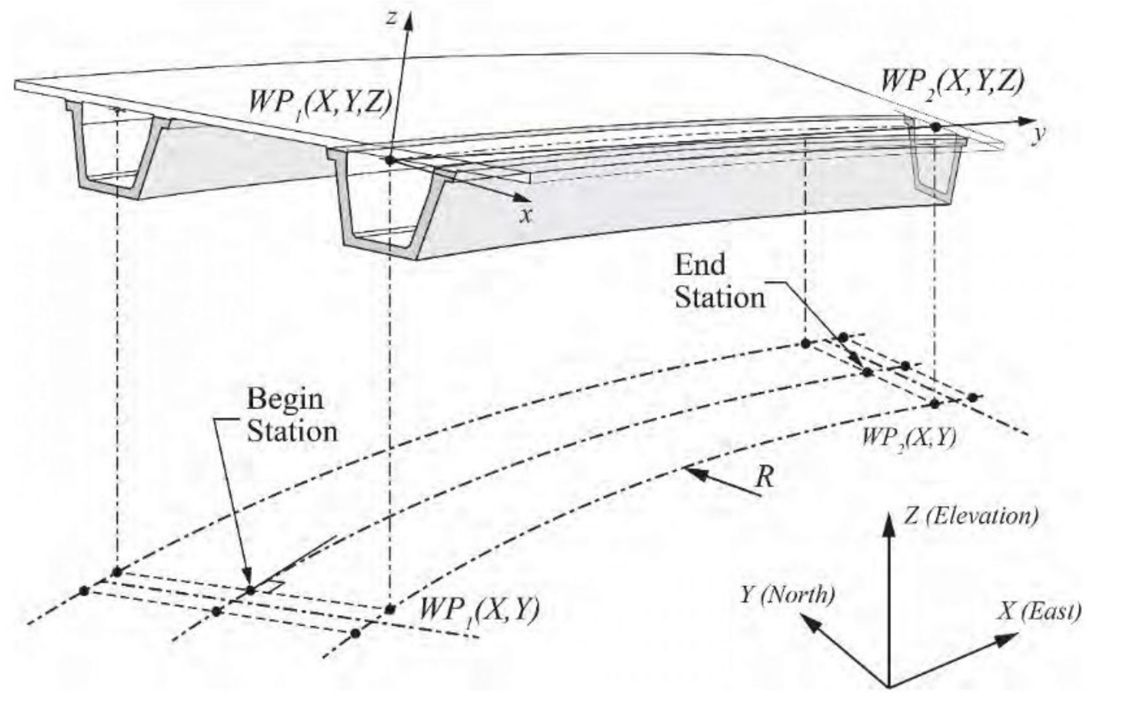

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Figure 9.7 Determining the Girder Segment Chord Length

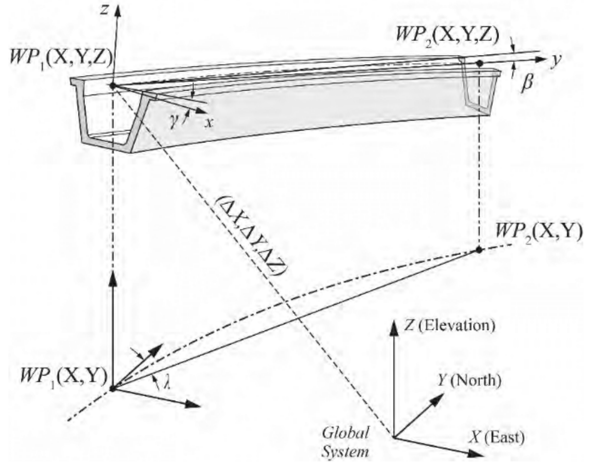

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Figure 9.12 3D Location of Curved Girder Segment

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The Steel Topics

Steel Topics

Geometry of Steel I-Girder Bridges

- Vertical camber and other vertical displacement considerations
  - Deck placement effects
  - Staged Construction effects
  - Vertical camber for curved steel I-girders

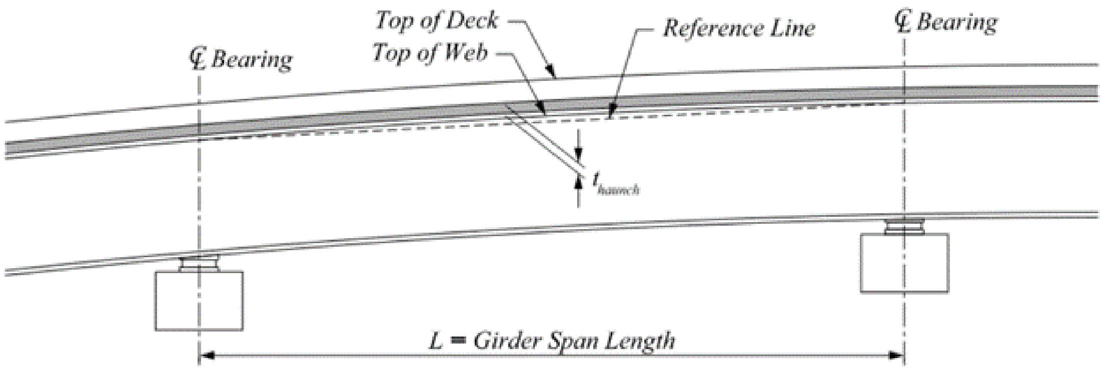

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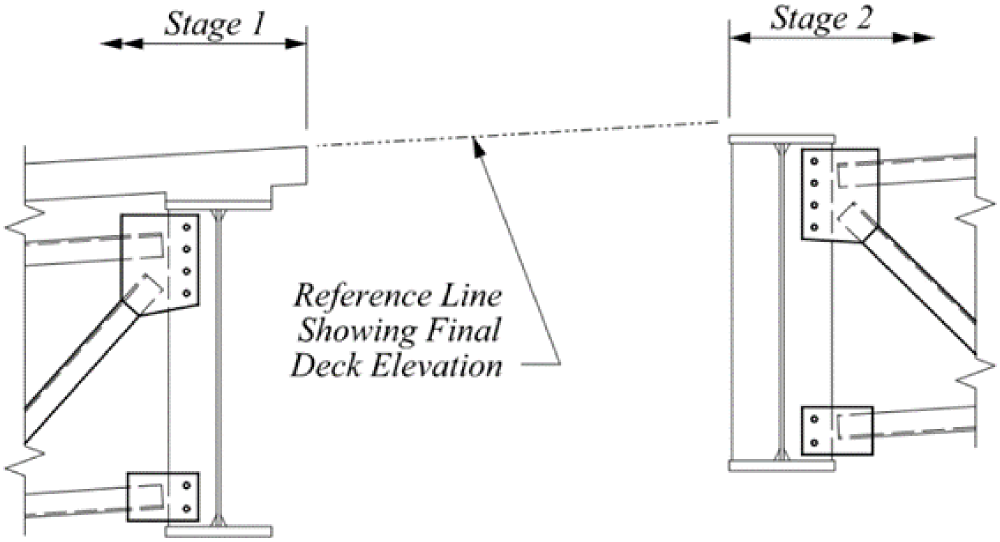
Figure 10.2 Steel Girder Span Profile Grade Adjustment for Crest Curves



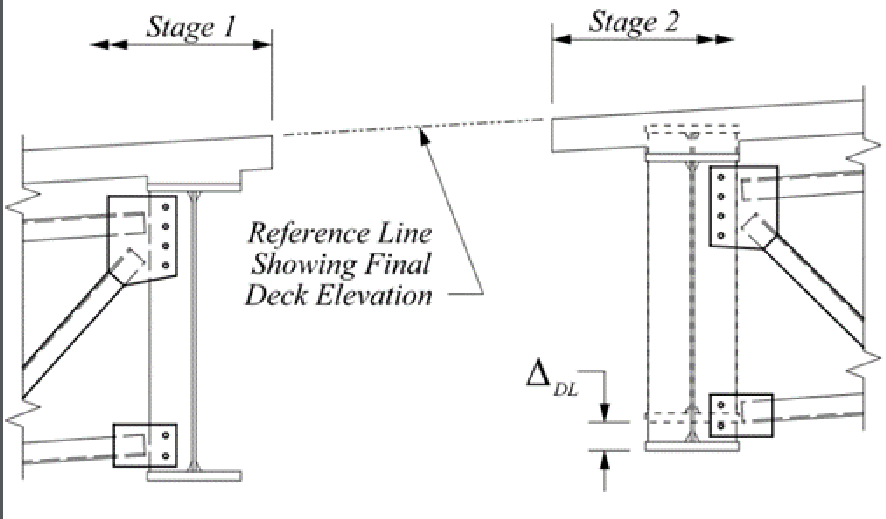
Source: FHWA

Figure 10.9 Detail of Stage 1 Construction Complete and Stage 2 before Deck Pour

Steel Topics

Geometry of Steel I-Girder Bridges

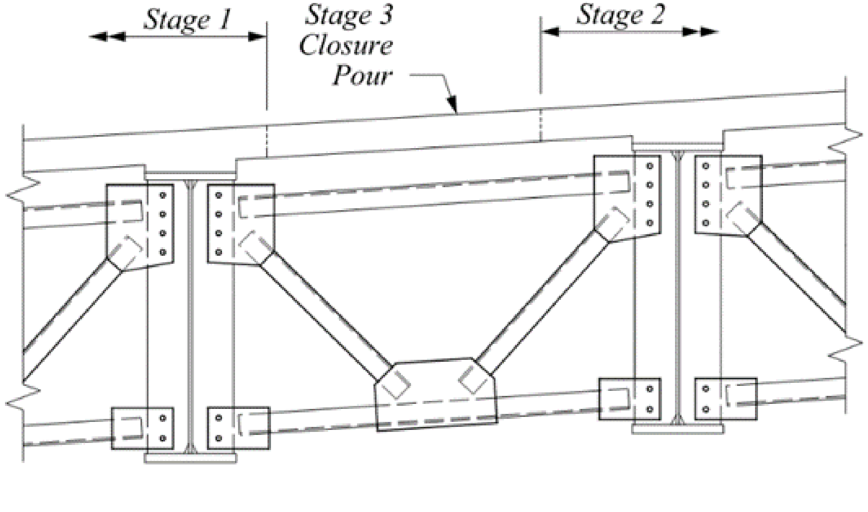
- Vertical camber and other vertical displacement considerations
  - Deck placement effects
  - Staged Construction effects
  - Vertical camber for curved steel I-girders



Δ_{DL} = Deflection due to deck slab dead load in Stage 2

Source: FHWA

Figure 10.10 Detail of Stage 2 Deflected Position



Source: FHWA

Figure 10.11 Detail of Completed Construction with Stage 3 Closure

Steel Topics

Geometry of Steel I-Girder Bridges

- Example bridge
  - Establish offset alignment to outside girder
  - Deck elevations at 1/10th points
  - Vertical curve adjustment for camber

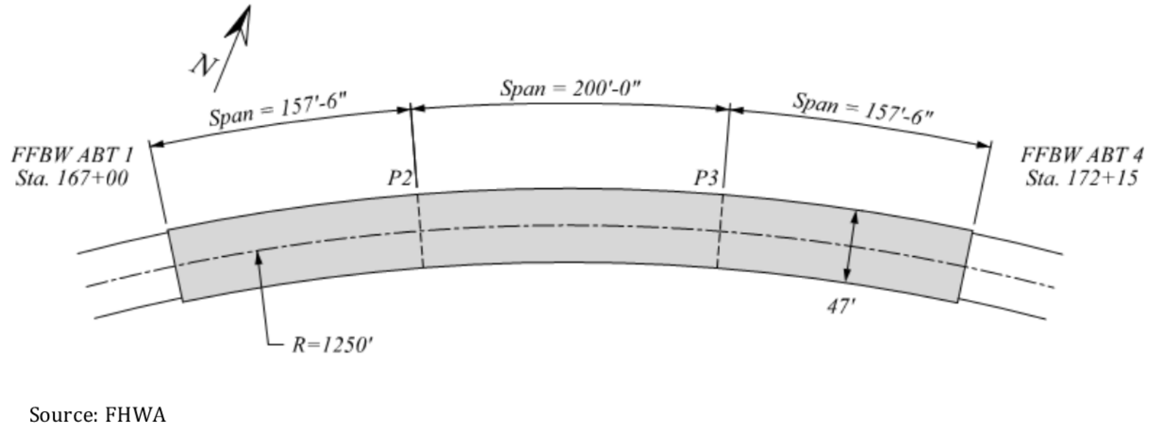


Figure 10.15 Plan View of Bridge 2 with a Three-Span Layout

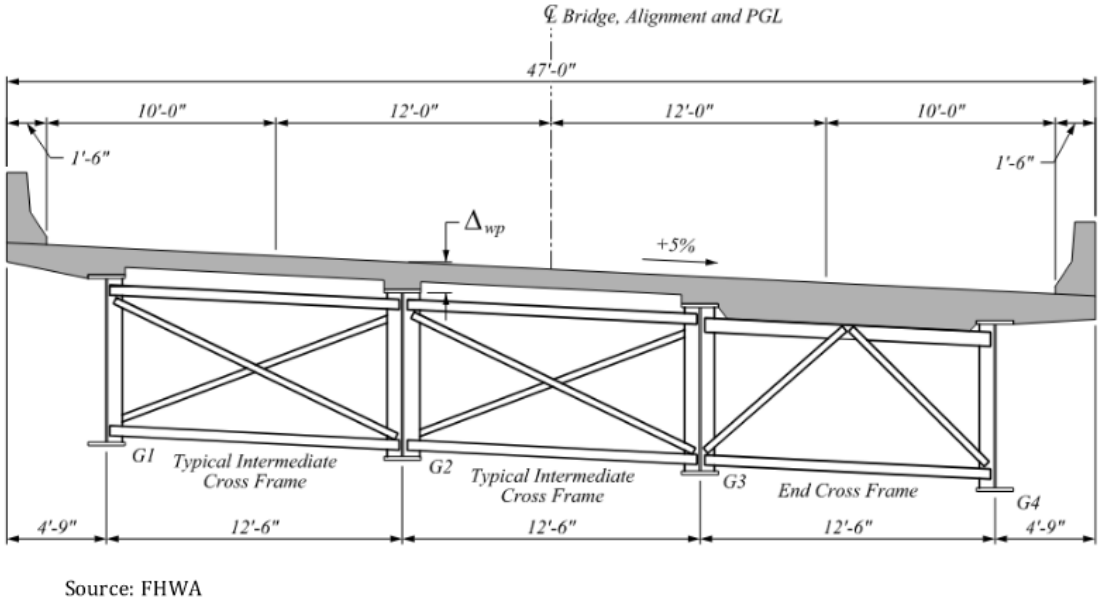


Figure 10.16 Bridge 2 Cross Section for Curved Steel Plate Girder Example

Steel Topics

Geometry of Steel I-Girder Bridges

- Example bridge
  - Establish offset alignment to outside girder
  - Deck elevations at 1/10th points
  - Vertical curve adjustment for camber

Table 10.7 Deck Elevations along Girder G4 Alignment (all elevations/dimensions in feet)

Location (1/10 Points) (Column 1)	PGL Station (Column 2)	PGL Elevation (Column 3)	Offset (Column 4)	CS (Column 5)	CL G4 Elevation (Column 6)
CL Pier 2	168+57.50	140.0569	18.75	0.05	139.1194
0.10	168+77.50	140.2699	18.75	0.05	139.3324
0.20	168+97.50	140.4749	18.75	0.05	139.5374
0.30	169+17.50	140.6719	18.75	0.05	139.7344
0.40	169+37.50	140.8609	18.75	0.05	139.9234
0.50	169+57.50	141.0419	18.75	0.05	140.1044
0.60	169+77.50	141.2149	18.75	0.05	140.2774
0.70	169+97.50	141.3799	18.75	0.05	140.4424
0.80	170+17.50	141.5369	18.75	0.05	140.5994
0.90	170+37.50	141.6859	18.75	0.05	140.7484
CL Pier 3	170+57.50	141.8269	18.75	0.05	140.8894

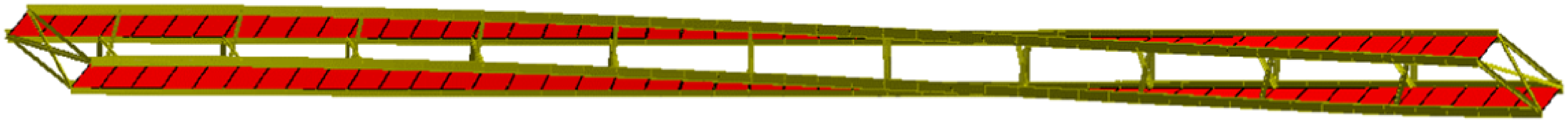
Table 10.8 Girder G4 Adjustment for Vertical Curvature in Span 2 (all elevations/dimensions in feet)

Location (1/10 Points) (Column 1)	Station (Column 2)	Top of Deck Elevation at CL G4 (Column 3)	Top of Web Elevation at CL G4 (Column 4)	Reference Line Elevation (Column 5)	Δ_{vc} (Column 6)
CL Pier 2	168+57.50	139.1194	137.8944	137.8944	0
0.10	168+77.50	139.3324	138.1074	138.0714	0.0360
0.20	168+97.50	139.5374	138.3124	138.2484	0.0640
0.30	169+17.50	139.7344	138.5094	138.4254	0.0840
0.40	169+37.50	139.9234	138.6984	138.6024	0.0960
0.50	169+57.50	140.1044	138.8794	138.7794	0.1000
0.60	169+77.50	140.2774	139.0524	138.9564	0.0960
0.70	169+97.50	140.4424	139.2174	139.1334	0.0840
0.80	170+17.50	140.5994	139.3744	139.3104	0.0640
0.90	170+37.50	140.7484	139.5234	139.4874	0.0360
CL Pier 3	170+57.50	140.8894	139.6644	139.6644	0

Steel Topics

Geometry of Steel I-Girder Bridges

- Steel I-girder behavior and geometry changes under load
  - Straight skewed bridge behavior related to perpendicular crossframes and differential deflections
  - Girder layover at bearings
  - Horizontally curved I-girders



Source: FHWA

Figure 10.18 3D Top View of Magnified Girder Deflection and Twist for Two Simple Span I-Girders Connected with Perpendicular Cross Frames, with Skewed Supports and Subjected to Vertical Loading After the Cross Frames Have Been Installed

Steel Topics

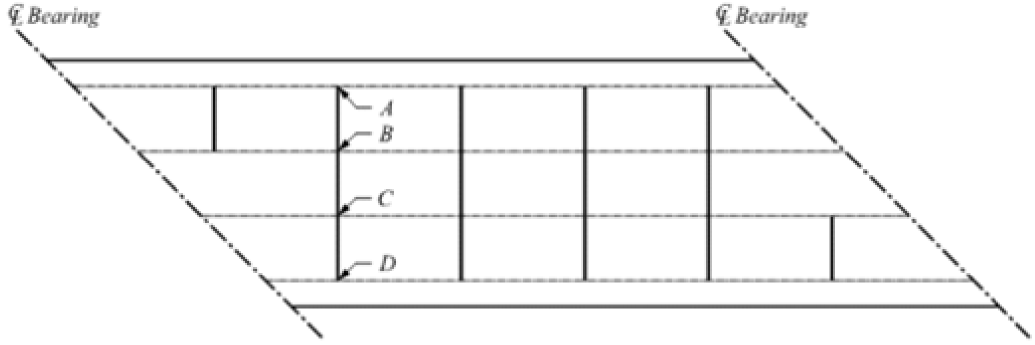
Geometry of Steel I-Girder Bridges

- Geometric Modeling
  - Skew Index
  - Connectivity Index

$$I_s = \frac{w_g \tan\theta}{L_s}$$

(Eqn. 10.4)

Where: I_s = bridge skew index
w_g = maximum width between exterior girders of the bridge cross-section in feet
L_s = span length in feet at the centerline of the bridge cross-section
θ = maximum skew angle of the bearing lines in degrees measured from a line taken perpendicular to the span centerline



Source: FHWA

Figure 10.19 Framing Plan Showing Differential Deflections Due to Skew

Table 10.9 Vertical Displacements at Points A, B, C, and D as Indicated in Figure 10.19

Point	A	Differential (A-B)	B	Differential (B-C)	C	Differential (C-D)	D
Deflection (in.)	6.12	-0.78	5.34	-2.05	3.29	-2.44	0.85

$$I_C = \frac{15000}{R(n_{cf}+1)m}$$

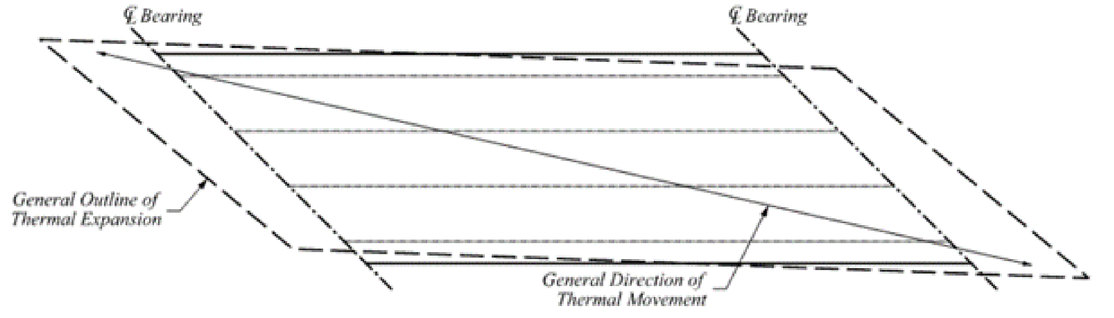
(Eqn. 10.5)

Where: R = the minimum radius of curvature at the centerline of the bridge cross-section in feet throughout the length of the bridge
n_{cf} = the number of cross frames in the span
m = a constant taken equal to 1 for simple-span bridges and 2 for continuous-span bridges

Steel Topics

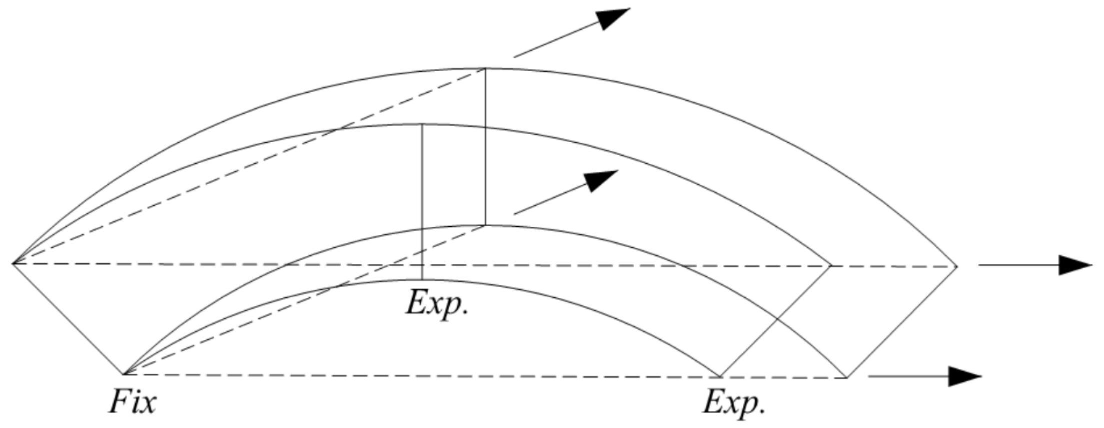
Geometry of Steel I-Girder Bridges

- Geometric considerations of thermal movements
  - Skewed behavior
  - Curved behavior
  - Different impacts, such as how the behavior of the skewed bridge will impact integral and semi-integral abutment design



Source: FHWA

Figure 10.20 Plan View Showing Typical Thermal Movement on a Single Span Steel Girder Bridge with Parallel Skewed Supports



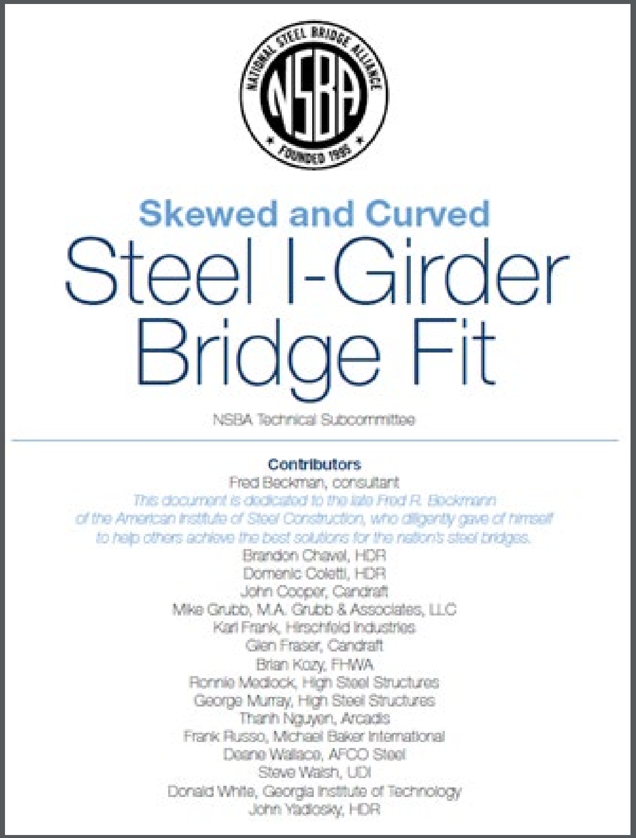
Source: FHWA

Figure 10.21 Thermal Movement with Rear Support Fixed

Steel Topics

Geometry of Steel I-Girder Bridges

- Bridge Fit Conditions
  - NLF (No Load Fit)
  - SDLF (Steel DL Fit)
  - TDLF (Total DL Fit)
- Drop



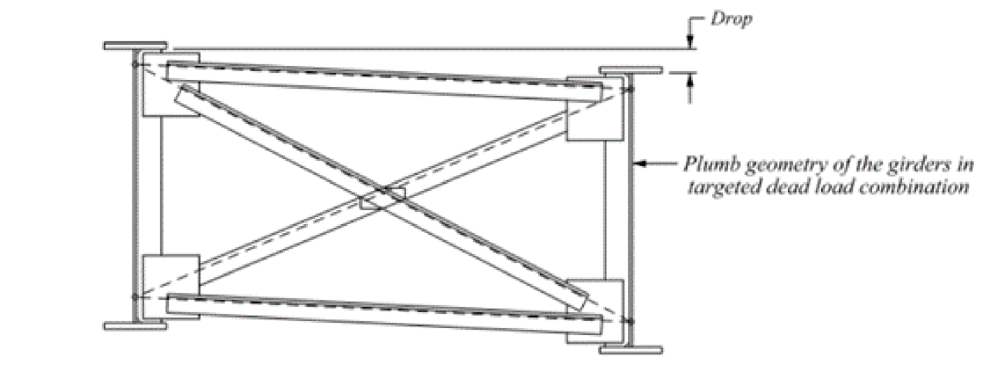


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Figure 10.23 Drop of an Intermediate Cross Frame Between Two Adjacent Girders

Steel Topics

Geometry of Steel I-Girder Bridges

- Variable depth I-girders
  - Deeper webs over interior supports
  - Can be advantageous to use a haunched girder given certain site conditions and bridge geometry (span lengths and vertical clearances).
  - Transition can be parabolic or linear

Source: FHWA

Figure 10.25 Application of Parabolic Variable Depth Girders

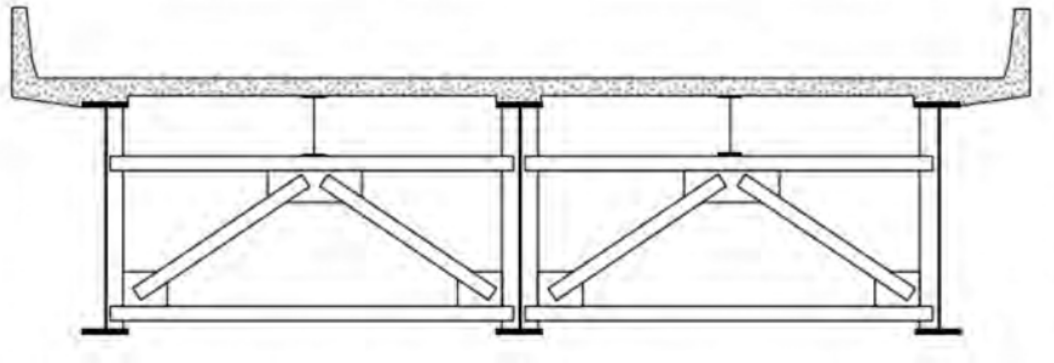
Source: FHWA

Figure 10.26 Application of Straight Taper Variable Depth Girders

Steel Topics

Geometry of Girder-Substringer Systems

- Live load distribution factors
  - More rigorous 2D grid or 3D models
- Geometry considerations
  - Longitudinal and lateral thermal effects
  - Skew
- Camber considerations
  - Cross frame fit up
  - Substringer / cross frame connection



Source: FHWA

Figure 11.2 Cross-Section of a Girder-Substringer System

Source: HDR

Figure 11.3 Shenandoah River Bridge in West Virginia

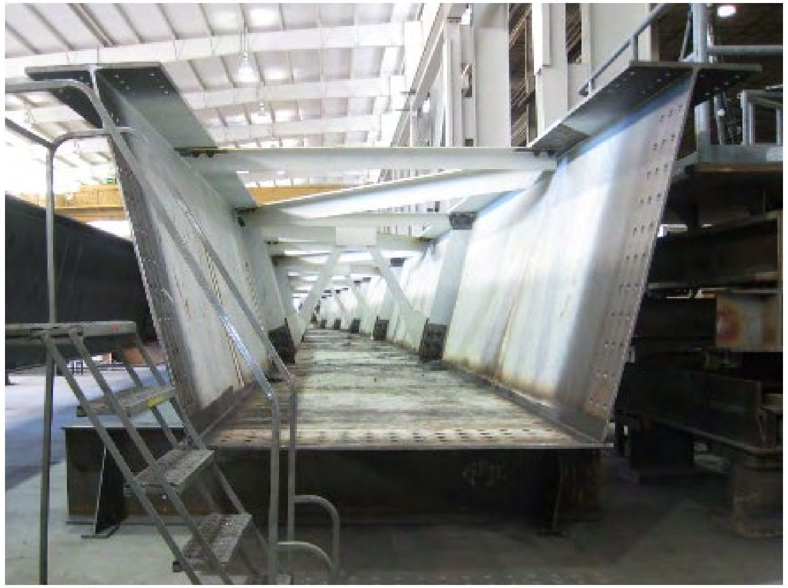
Steel Topics

Geometry of Steel Trapezoidal Box Girder Bridges

- Superstructure fabrication
  - Skew can increase costs
  - Field piece size and splice locations
- Internal and external diaphragms
- Top flange lateral bracing

Source: HDR

Figure 12.1 Dual Steel Trapezoidal Box Girders



Source: HDR

Figure 12.2 Internal Intermediate Cross Frames and Top Flange Lateral Bracing

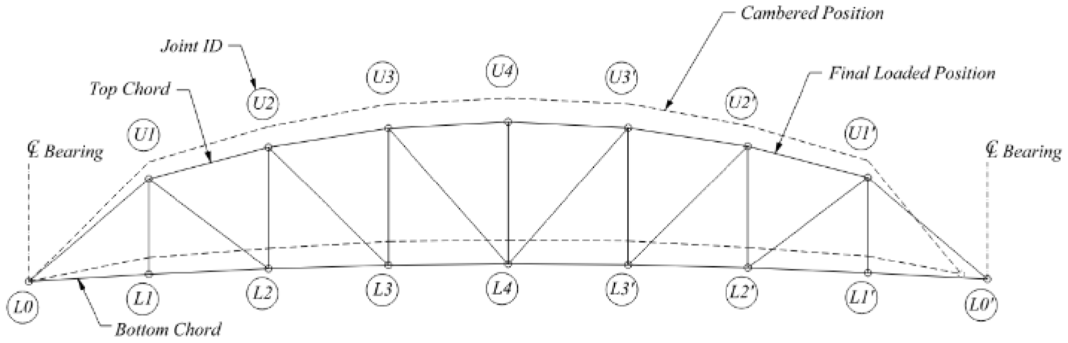
Steel Topics

Geometry of Truss Bridges

- General geometric considerations
  - Different types of trusses and selection
- Camber and constructability considerations
  - Construction sequence important for establishing geometry of truss
  - Plans need to indicate the assumptions used to develop member lengths and connection elevations presented in the plans

Source: HDR

Figure 13.4 Deck Truss Bridge, Liberty Bridge over the Monongahela River in Pittsburgh, Pennsylvania



Source: FHWA

Figure 13.5 Truss Deflections from Cambered Position to Final Position

Steel Topics

Geometry of Steel Arch Bridges

- Arch configuration
  - Span length generally dictates arch geometry (box versus trussed member)
  - Rise to span ratios
- Camber and constructability considerations
  - Erection method will influence geometry considerations to be detailed in the plans as well as the design loading
  - Camber and deflections influenced by construction sequence

Source: HDR

Figure 14.1 Greenfield Bridge in the City of Pittsburgh, an Open-Spandrel Deck Arch Structure Completed in 2017

Source: HDR

Figure 14.4 Erection of the Arch Rib of the Greenfield Bridge in the City of Pittsburgh Using Temporary Supports

6

Conclusion/Questions?

Conclusion / Questions?

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Reports

- Evaluation of Steel Bridge Details for Susceptibility to Constraint-Induced Fracture (.pdf) (November 29, 2021)
- Bridge System Reliability and Reliability-Based Redundancy Factors (.pdf) (September, 2019)
- Fatigue Resistant Rib-to-Floor Beam Connections for Orthotropic Steel Decks with Potential for Automated Fabrication (.pdf) (September, 2019)
- Proposed LRFD Specifications for Noncomposite Steel Box-Section Members (.pdf) (July, 2019)
- Report on Techniques for Bridge Strengthening (.pdf) (April, 2019)
  - Steel Truss Member Strengthening Design Example
  - Plate Girder Shear And Flexural Strengthening Design Example
  - Stringer Retrofit Composite Action and Continuity Changes Design Example
  - Concrete Cap Strengthening Design Example
- Influence of Material Toughness on Fracture Reliability in Steel Bridges (.pdf) (October, 2018)
- Bridge Data File Protocols for Interoperability and Life Cycle Management (April, 2016)
- Bridge Information Modeling Standardization (April, 2016)
- Bridge Information Modeling (BrIM) Using Open Parametric Objects (.pdf) (December, 2015)
- Serviceability Limits and Economical Steel Bridge Design (.pdf) (August, 2011)
- Seismic Performance of Steel Plate Girder Bridges with Integral Abutments (.pdf) (August, 2011)
- Computer Integrated Steel Bridge Design and Construction - Expanding Automation - Final Report (.pdf) (April, 2001)
- Steel Bridge Fabrication Scan - Summary Report
- Assuring Bridge Safety and Serviceability in Europe (August 2010)
- Curved Steel Bridge Research Project. I-Girder Bending Component Tests. Philosophy and Design of the I-Girder Bending Component Tests (.pdf) (July, 2019)

Manuals

- Manual for Heat Straightening, Heat Curving and Cold Bending of Bridge Components (.pdf) (March 2023)
- Guide for Orthotropic Steel Deck Level 1 Design (.pdf) (December, 2022)
- Bridge Geometry Manual (.pdf) (April, 2022)
- Bridge Welding Reference Manual (.pdf) (September 2019; with errata, September 2020)
- Manual for Refined Analysis in Bridge Design and Evaluation (.pdf) (May, 2019)
- Design and Evaluation of Steel Bridges for Fatigue and Fracture Reference Manual (.pdf) (December, 2016)

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