Challenging Skew: Higgins Road Steel I-Girder Bridge over I-90
OTECE 2015 - October 27, 2015
Session 26

Brandon Chavel, PhD, P.E., Lance Peterman, P.E., S.E.
Presentation Outline

- Project Overview
- Design
  - Behavior of Skewed Structures
  - Framing Plan
  - 3D Finite Element Analysis
  - Detailing and Fit
  - Bearing Design
  - Deck Placement Analysis
  - Conceptual Erection Sequence
  - Pier Design
- Construction
- Summary
Presentation Outline

- Project Overview
- Design
  - Behavior of Skewed Structures
  - Framing Plan
  - 3D Finite Element Analysis
  - Steel Details and Fit Condition
  - Bearing Design
  - Deck Placement Analysis
  - Conceptual Erection Sequence
  - Pier Design
- Construction
- Summary
Project Location

- Hoffman Estates, IL
- 30 miles NW of Chicago
- Twin bridges span over I-90
- I-90 reconstructed and widened
- Heavily traveled corridor
  - (118,000 vehicles per day)
Project Overview – Existing Bridges

- WB 5 simple spans: 471 ft total length
- WB 60” deep plate girders
- WB fracture critical substructure
- WB no skew counterfort wall abut

- EB 3 continuous spans: 503 ft total length
- EB 81” deep plate girders
- EB skewed counterfort wall abut
Two 280 ft continuous spans: 560 ft total length
49’-3” wide deck to carry three lanes
70° skew all supports
Six plate girder cross section
   Webs are 9’-6” deep
X-type intermediate cross frames
Full depth diaphragm along skew at abutments
Full depth diaphragm normal to girders at pier
8” deck
Presentation Outline

▪ Project Overview

▪ Design
  o Behavior of Skewed Structures
  o Framing Plan
  o 3D Finite Element Analysis
  o Steel Details and Fit Condition
  o Bearing Design
  o Deck Placement Analysis
  o Conceptual Erection Sequence
  o Pier Design

▪ Construction

▪ Summary
Behavior of Skewed Structures

- Girder differential deflection causes cross-section lateral deflections and twist
- Non skewed diaphragms
  - Diaphragm Loads
  - Flange Lateral Bending
Behavior of Skewed Structures

- Transverse load paths through cross frames
- “Nuisance Stiffness” Effects
- Lateral reactions develop at the bearings
Presentation Outline

- Project Overview
- Design
  - Behavior of Skewed Structures
  - Framing Plan
  - 3D Finite Element Analysis
  - Steel Details and Fit Condition
  - Bearing Design
  - Deck Placement Analysis
  - Conceptual Erection Sequence
  - Pier Design
- Construction
- Summary
Framing Plan

- Opposite direction of rotation between span 1 and 2
Framing Plan

- Selectively remove cross frames near the pier
  - Nuisance stiffness, reduce transverse load paths
- Use full depth diaphragms at interior pier location
  - Attract load at two distinct locations
- Use staggered cross frame pattern at skewed ends
  - Eliminate the transverse load paths
Presentation Outline

- Project Overview
- Design
  - Behavior of Skewed Structures
  - Framing Plan
  - 3D Finite Element Analysis
  - Steel Details and Fit Condition
  - Bearing Design
  - Deck Placement Analysis
  - Conceptual Erection Sequence
  - Pier Design
- Construction
- Summary
3D Finite Element Analysis

- Properly model girder torsional stiffness and warping stiffness
- Can account for load shifting between girders
- Explicitly model all cross frame members and full-depth diaphragms
- Live load influence surface analysis

- 2D grid analysis inaccurate results:
  - Cross frame forces
  - Girder displacements
  - Ref: NCHRP Report 725
Presentation Outline

- Project Overview
- Design
  - Behavior of Skewed Structures
  - Framing Plan
  - 3D Finite Element Analysis
  - Steel Details and Fit Condition
  - Bearing Design
  - Deck Placement Analysis
  - Conceptual Erection Sequence
  - Pier Design
- Construction
- Summary
Steel Details

- Full-depth end diaphragm (length ~ 23.5 ft)
  - Too long for a K-type cross frame
- Auxiliary stiffeners (back-up stiffeners)
End Diaphragm

- Full depth diaphragm connected to bent stiffener plate
- Bolted jacking stiffener installed after end diaphragm due to conflict
Full Depth Diaphragm at Pier

- Detail to avoid interference with fixed bearing at skewed pier
Lateral Bracing

- Prevent stability problems during construction
  - Increases global buckling strength of the initial twin girder systems during steel erection
- Prevent excessive deflections due to wind loading during construction before deck is placed
- Placed at the top flange level near neutral axis to limit participation in resisting live load
- Bolted directly to flange
- Not full-length
Fit Condition

- Severe skew leads to:
  - Out of plumb webs after dead load is applied
  - Excessive bearing rotation
  - Try to control this rotation via detailing

- AASHTO Article 6.7.2
  - Fit condition to be specified in the contract documents
Fit Condition

- NSBA publication: *Skewed and Curved Steel I-Girder Fit*
- Describes fit and customary practices, 3 choices:
  - No load fit (NLF)
  - Steel dead load fit (SDLF)
  - Total dead load fit (TDLF)
- Provides recommendations
  - Straight square bridges: Any
  - Straight skewed bridges: SDLF or TDLF
  - Curved bridges (up to ~ 250’ span): SDLF, then NLF
Detailing and Fit

- For SDLF and TDLF the cross-frames are forced into place and the girders are twisted out of plumb during the erection.

- Steel Dead Load Fit (SDLF) chosen
  - Disc bearing accommodates rotations
    - Concrete dead load
    - Live load
  - Erection simpler & faster than TDLF
  - Limited construction windows
Presentation Outline

- Project Overview
- Design
  - Behavior of Skewed Structures
  - Framing Plan
  - 3D Finite Element Analysis
  - Steel Details and Fit Condition
  - Bearing Design
  - Deck Placement Analysis
  - Conceptual Erection Sequence
  - Pier Design
- Construction
- Summary
Bearing Design

Guided Expansion Bearing

Non Guided Expansion Bearing

Fixed Bearing

$BRG. N. ABUT.$

$PIER$

$69'16.0'', TYP.$

$GIRD. TYP.$

SCHEMATIC BEARING PLAN
Fixed Bearing Design

- Large horizontal reactions from skew
- Horizontal reactions increase with distance from centerline of bridge
Presentation Outline

- Project Overview
- Design
  - Behavior of Skewed Structures
  - Framing Plan
  - 3D Finite Element Analysis
  - Steel Details and Fit Condition
  - Bearing Design
  - Deck Placement Analysis
- Conceptual Erection Sequence
  - Pier Design
- Construction
- Summary
Deck Placement Analysis

- Girder camber is dependent on the sequence of the deck placement
- Differences in deflection
  - Single monolithic deck pour ≠ deck placement sequence
- Verify deck stresses resulting from pour sequence will not result in cracking
Presentation Outline

- Project Overview
- Design
  - Behavior of Skewed Structures
  - Framing Plan
  - 3D Finite Element Analysis
  - Steel Details and Fit Condition
  - Bearing Design
  - Deck Placement Analysis
  - Conceptual Erection Sequence
  - Pier Design
- Construction
- Summary
Conceptual Erection Sequence

STAGE 1

STAGE 2

STAGE 3
Conceptual Erection Sequence Analysis

- Use LARSA 3D FEM to check:
  - Temporary Support Structure Placement
    - maintain three I-90 lanes in each direction
  - Hold Crane Placement
  - Girder Stresses, Deflections, Reactions (no uplift)

- Potential issues:
  - Reduced Girder buckling capacity
  - Loading is less than in the final condition, but the girder capacity is also less
Presentation Outline

- Project Overview
- Design
  - Behavior of Skewed Structures
  - Framing Plan
  - 3D Finite Element Analysis
  - Steel Details and Fit Condition
  - Bearing Design
  - Deck Placement Analysis
  - Conceptual Erection Sequence
  - Pier Design
- Construction
- Summary
Pier Design

- 130’ long
- Severe skew and fixed bearing condition led to high lateral forces in opposite directions
- Segmented pier:
  - Better accommodate internal thermal force demands
  - Reduce torsion in pier cap
- Circular columns directly under girders to effectively carry vertical reaction
Pier Cap
Presentation Outline

- Project Overview
- Design
  - Behavior of Skewed Structures
  - Framing Plan
  - 3D Finite Element Analysis
  - Steel Details and Fit Condition
  - Bearing Design
  - Deck Placement Analysis
  - Conceptual Erection Sequence
  - Pier Design
- Construction
- Summary
Shop Fit-Up
Abutments

- Stub abutments on battered piles behind soldier pile wall
- Soldier pile wall to limit span lengths
  - 600 foot long soldier pile walls parallel to I-90
  - Minimized structure excavation in tight space
- Avoid conflicts with existing piles
Pier Cap Detailing

Bar Terminator

Anchorage Reinforcement
Steel Erection
Deck Placement

- Issue:
  - Difference between paver maximum skew and bridge skew
  - Steel framing potential twist in an unintended manner

- Solution:
  - Place concrete along bridge skew ahead of paver skew and use retarder to delay set
Deck Placement

- Deck overhang brackets for 9’-6” deep plate girder
Swivel Type Modular Expansion Joint

- Multi-directional movement capability
- Detail girders and end diaphragms to accommodate joint
- Special closure pour at joints
  - To minimize movement due to dead load effects (racking)
  - To reduce shrinkage effects
Presentation Outline

- Project Overview
- Design
  - Behavior of Skewed Structures
  - Framing Plan
  - 3D Finite Element Analysis
  - Steel Details and Fit Condition
  - Bearing Design
  - Deck Placement Analysis
  - Conceptual Erection Sequence
  - Pier Design
- Construction
- Summary
Summary

- Consider 3D FE analysis for severely skewed supports
- Recognize alternative load paths at severely skewed supports
- Be cognizant of high lateral forces at fixed bearings of a skewed support
- Specify fit condition for the girders and cross frames
- Provide feasible erection scheme for complex projects
- Place deck concrete along skew
Acknowledgments

- Client: Illinois Tollway
- General Contractor: Dunnet Bay Construction
- Steel Fabricator: Industrial Steel Construction
- Steel Erector: Danny’s Construction
QUESTIONS......