Presentation Outline

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

- Hoffman Estates, IL
- 30 miles NW of Chicago
- Twin bridges span over I-90
- Higgins Road: Currently 26,000 vehicles per day; 43,000 in 2040
- I-90: Currently 118,000 vehicles per day
Project Overview

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

Exist. EB Bridge:
• 3 continuous spans: 503 ft total length
• 81” deep plate girders
• skewed counterfort wall abut

Project Overview:
- High voltage power lines
- Large diameter water main
- Large diameter gas mains
- Oil pipeline
- Historic farm properties
- Forest preserve
Project Overview

- 70-degree skew
- Two spans @ 280 ft = 560 ft total length
- Deck width: 49'-3" with three lanes
- 6 plate girders
- Webs: 13/16" x 9'-6"
- Flanges: 1.5"x26" to 3"x34"
- X-type intermediate cross-frames
- Full-depth abutment diaphragm along skew
- Full-depth pier diaphragm normal to girders

Project Overview

- Stub abutments behind 600 ft long soldier pile walls
- Modular swivel type expansion joints at each abutment
- Multi-column pier supported on 4 rows of battered piles
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Behavior of Skewed Structures

- Girder differential vertical deflection causes lateral deflections and twist
- Shifting of load between girders creates torsion and changes the vertical and horizontal reactions
- Cross-frames attempt to equalize adjacent girder deflections
Framing Plan

- Integrated system behavior is recognized with framing plan arrangement
- Continuous versus staggered diaphragms
  - Manage Uplift
  - Flange Lateral Bending

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
Framing Plan

- Opposite direction of rotation between span 1 and 2

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

- 2D grid analysis inaccurate results:
  - Cross-frame forces
  - Bearing Reactions
  - Girder displacements
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

• 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 plans

• 3 choices:
  - No load fit (NLF)
  - Steel dead load fit (SDLF)
  - Total dead load fit (TDLF)
For SDLF and TDLF, the cross-frames are forced into place and the girders are twisted out of plumb during the erection. Cross-frames connect to girder locations that have different dead load deflections (differential).

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Steel Dead Load Fit (SDLF) chosen:
- Disc bearing can accommodate rotations
  - Concrete dead load
  - Live load
- Erection simpler and faster than TDLF
  - Due to larger girder size
- Limited construction windows

Detailing and Fit
Deck Placement Analysis

- Girder camber is dependent on the sequence of the deck placement
- Difference between single monolithic deck pour and accumulated deflection due to the deck placement sequence
- Verify deck stresses resulting from pour sequence will not result in cracking

Conceptual Erection Sequence Analysis

- AASHTO LRFD Requirements
  - Article 2.5.3 Constructability
  - “Where the bridge is of unusual complexity, such that it would be unreasonable to expect an experienced contractor to predict and estimate a suitable method of construction while bidding the project, at least one feasible construction method shall be indicated in the contract documents.”
Pier Design: Effect of Skew

- Opposite direction of rotation between span 1 and 2

Pier Design

- 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
- Intermediate circular columns to effectively resist fixed horizontal bearing reactions
**Pier Cap Design**

- **End Result:**
  - Horizontal bearing reactions approximately equal to vertical reactions
- **High torsional demand**
  - No. 10 bars all around
- **Special design considerations at fixed bearing locations**
  - Specialized approach with seismic-like detailing
    - Supplemental horizontal and vertical stirrups
    - Welded hoop bars
    - Embedded anchor bolts
    - Bar terminators
- **Use of parametric tools**
  - Clash detection
  - Verify sequence

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**Concrete Anchorage Design**

- **Specialized approach with seismic-like detailing**
  - Supplemental horizontal and vertical stirrups
  - Welded hoop bars
  - Embedded anchor bolts
  - Bar terminators
- **Use of parametric tools**
  - Clash detection
  - Verify sequence
Bearing Design

- High Load Multi-Rotational Bearings
- Disc bearings were specified (rotation at abutments > 0.05 radians)
Bearing Design

Concrete Placement Hole

Anchor bolts threaded through embedded plate

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Shop Fit-Up

Abutments
- Soldier pile wall to limit span lengths
- 600 foot long soldier pile walls parallel to I-90
- Long wing wall extensions
- Tricky conflicts with existing piles from non-skewed original bridge
Pier

- Welded hoop bars to confine core for anchorage
Pier Cap Detailing

- Issue:
  - Delta 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

- Issue:
  - Delta 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

- Placement of concrete along skew to load girders equally
Deck Placement

- Bridge Paver rails extended to approach

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
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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
- Consider shop assembly to verify fit-up
- Place deck concrete along skew
Acknowledgments

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- Erection Engineer: Benesch

QUESTIONS……