Challenging Skew: Higgins Road Bridge over I-90

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HDR Illinois Tollway Illinois Department of Transportation

Presentation Outline

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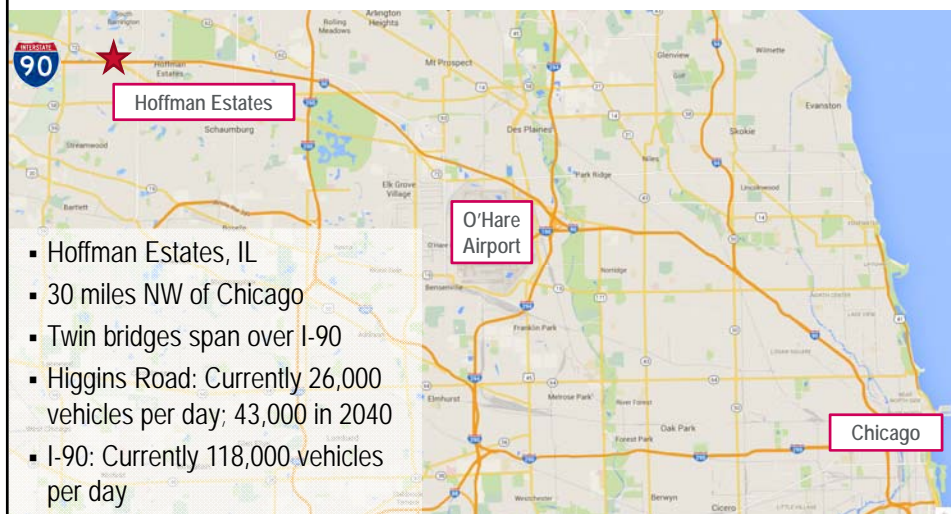- Construction
- Summary

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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

WB: I957

EB: I978

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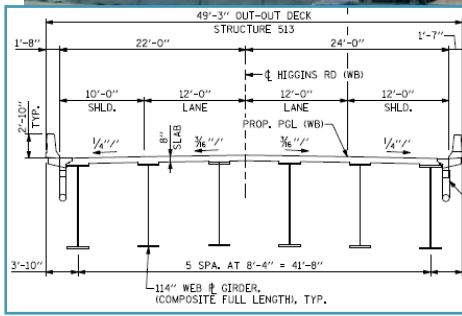* WB no skew counterfort wall abut

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

49'-3" OUT-OUT DECK
STRUCTURE 513

- 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
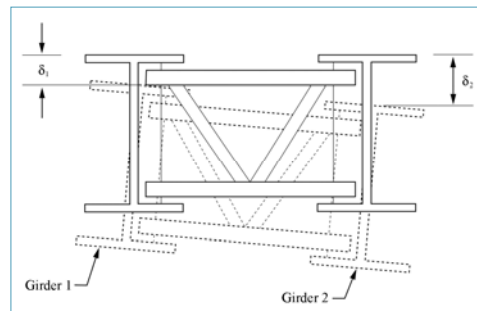- Multi-column pier supported on 4 rows of battered piles
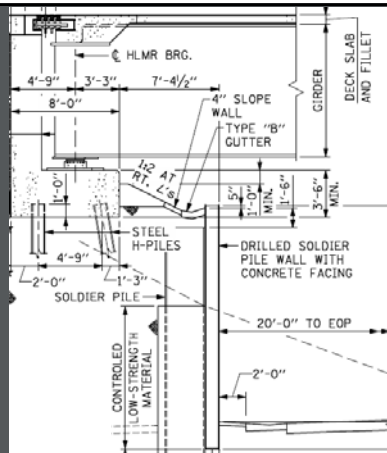
Presentation Outline

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
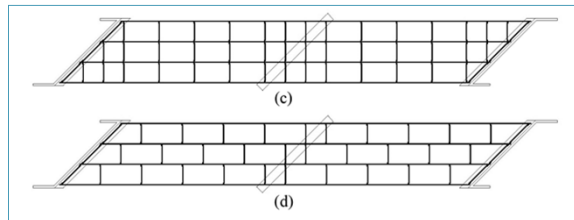
Framing Plan

- 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
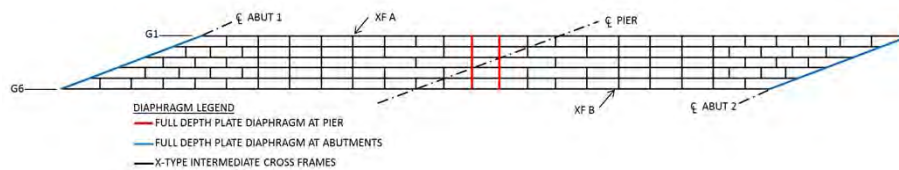
Framing Plan

▪ Opposite direction of rotation between span 1 and 2

SPAN 1 – LOOKING TOWARDS ABUT 2   SPAN 2 – LOOKING TOWARDS ABUT 2
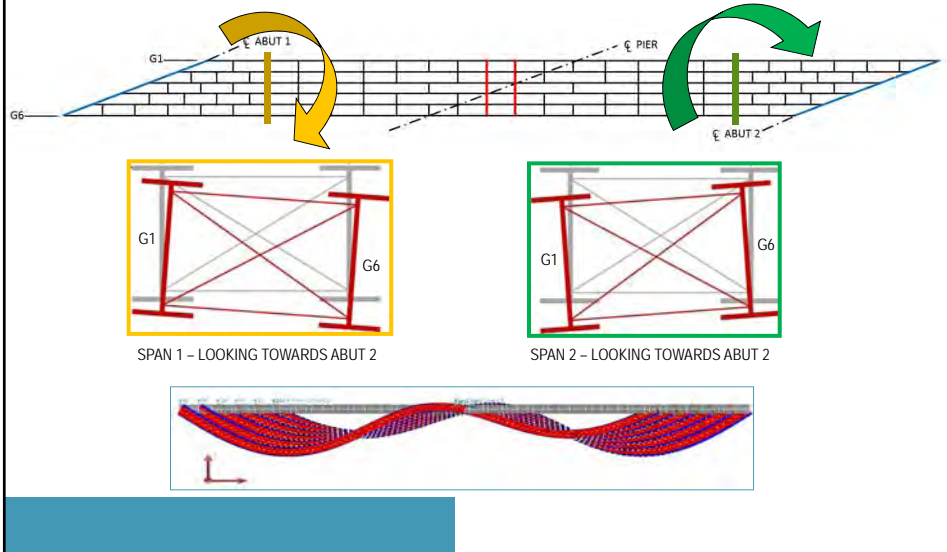
3D Finite Element Analysis

▪ 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
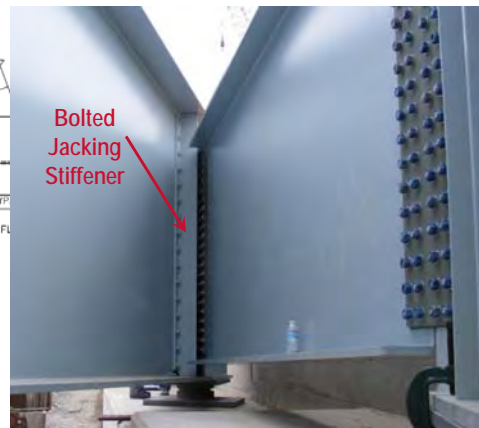 ○ Bearing Reactions
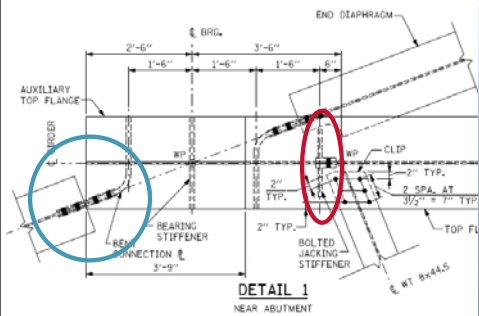 ○ Girder displacements
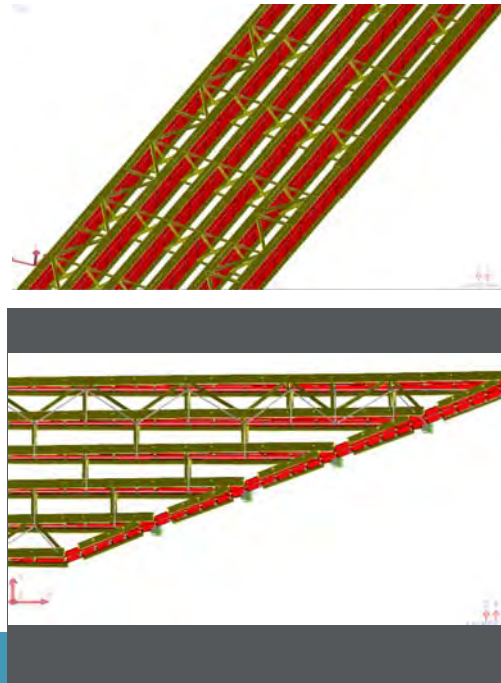
Steel Details

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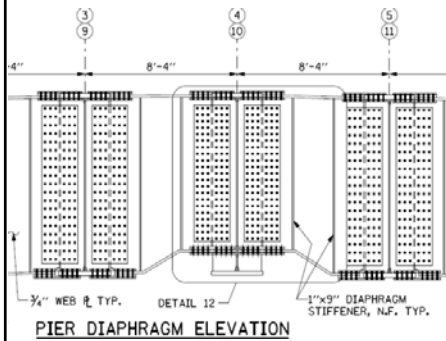- Auxiliary stiffeners (back-up stiffeners)
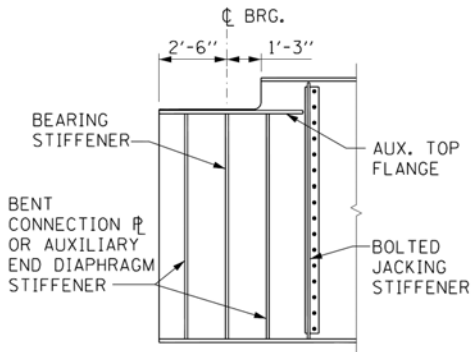
End Diaphragm

- 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

PIER DIAPHRAGM ELEVATION

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 plans
- 3 choices:
  - No load fit (NLF)
  - Steel dead load fit (SDLF)
  - Total dead load fit (TDLF)

Cross-frames connect to girder locations that have different dead load deflections (differential).

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

*Figure courtesy of Ronnie Medlock (High Steel).*
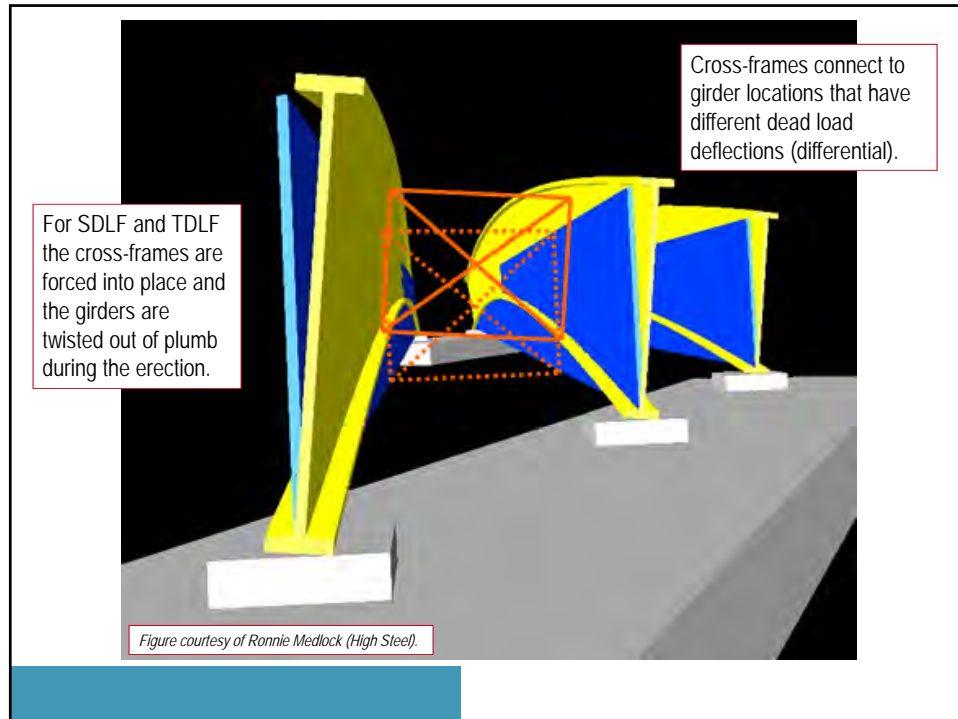
Detailing and Fit

- 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 can accommodate rotations
    - Concrete dead load
    - Live load
  - Erection simpler and faster than TDLF
    - Due to larger girder size
 - Limited construction windows

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
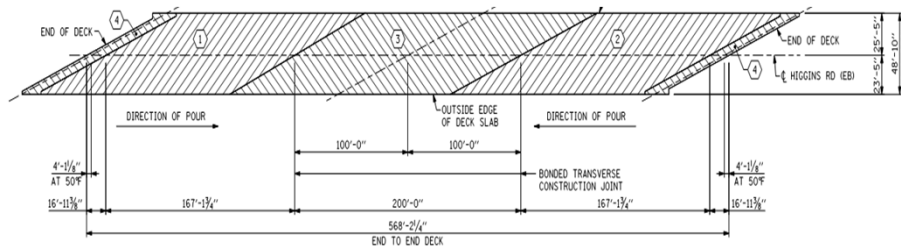

Conceptual Erection Sequence Analysis

- 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*."
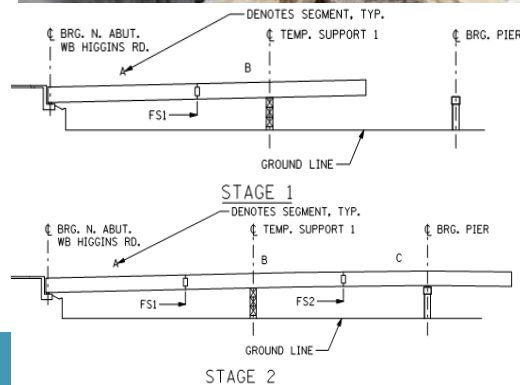
Pier Design: Effect of Skew

▪ Opposite direction of rotation between span 1 and 2
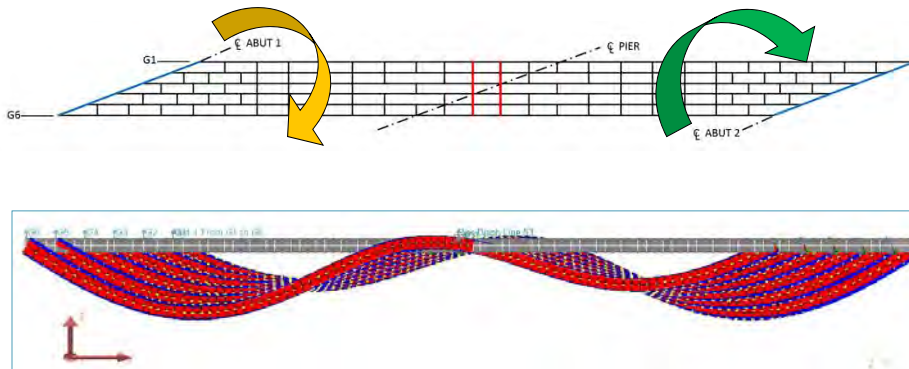

Pier Design

▪ 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
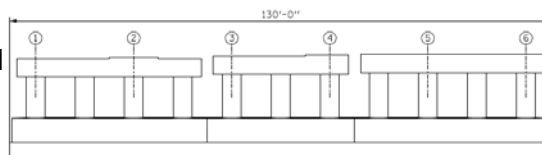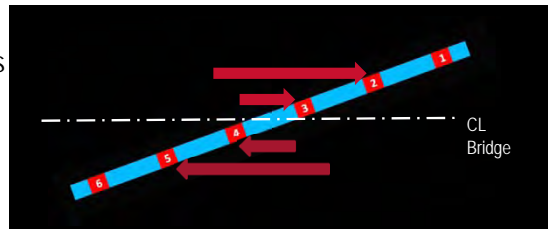
Pier Cap Design

- 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
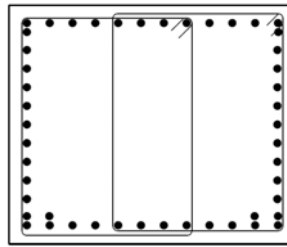
Concrete Anchorage Design

- 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

SCHEMATIC BEARING PLAN

Bearing Design

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

FIXED DISC BEARING ASSEMBLY
AT PIER - GIRDERS ②,⑤,⑧,⑪
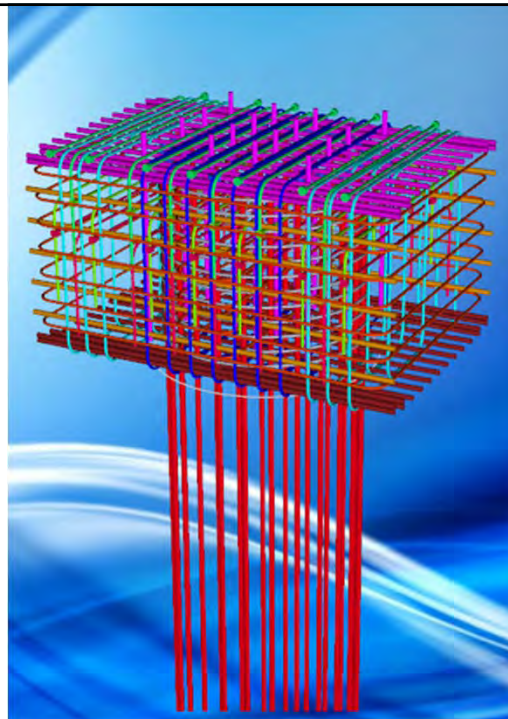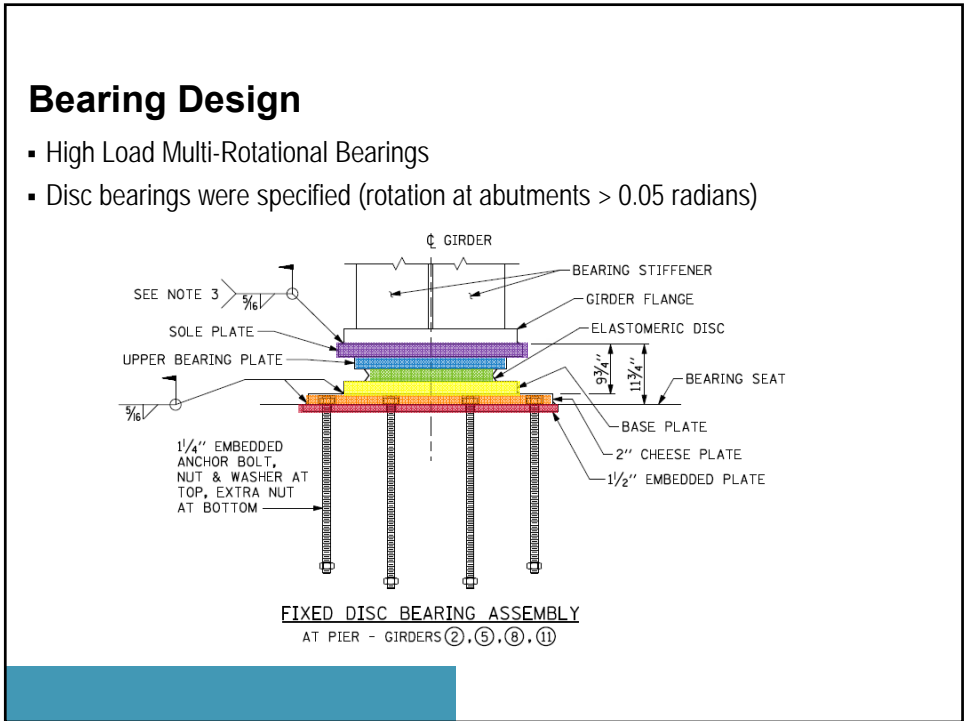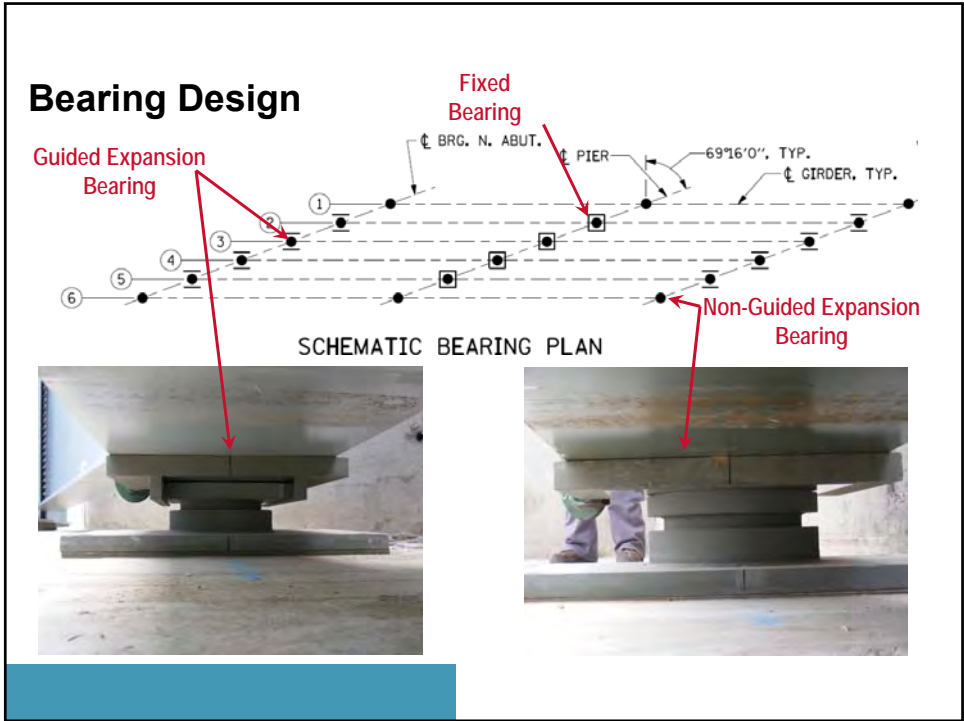
Bearing Design

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
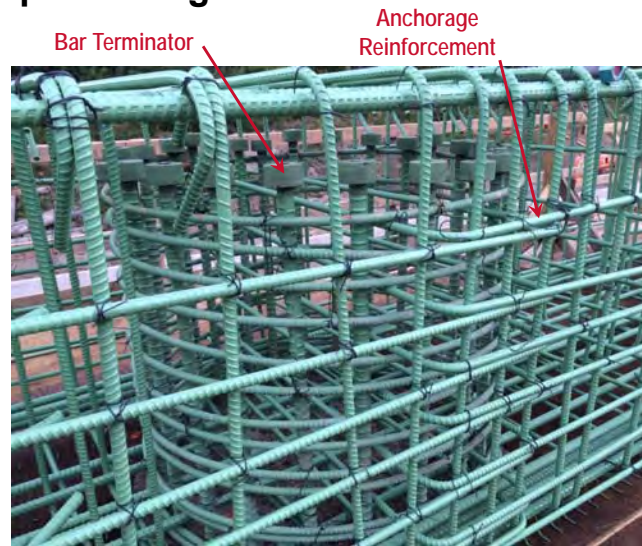- Tricky conflicts with existing piles from non-skewed original bridge

Pier

Pier

▪ Welded hoop bars to confine core for anchorage

Pier Cap Detailing

Bar Terminator

Anchorage
Reinforcement
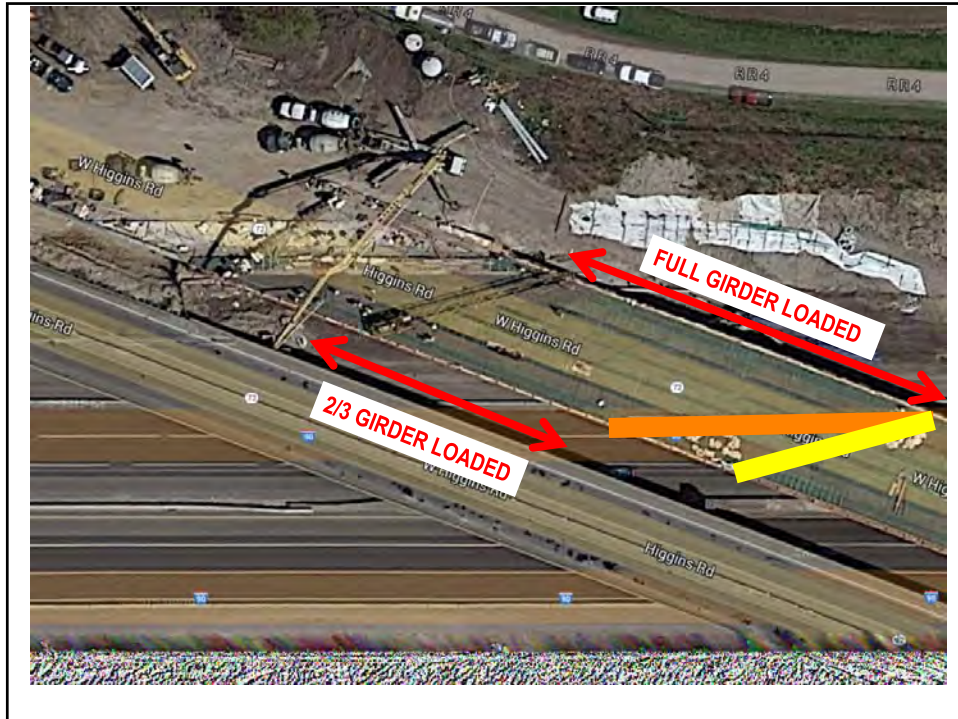

Deck Placement

▪ Issue:

  o Delta between paver maximum skew and bridge skew

  o Steel framing potential twist in an unintended manner

▪ Solution:

  o 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

- Client: Illinois Tollway
- Owner: IDOT
- General Contractor: Dunnet Bay Construction
- Steel Fabricator: Industrial Steel Construction
- Steel Erector: Danny's Construction
- Resident Engineer: HR Green
- Erection Engineer: Benesch

QUESTIONS……