SEAOI 13th Annual Midwest Bridge Symposium
April 28, 2016

Planning, Design & Construction of

IL-104 BRIDGE
OVER
ILLINOIS RIVER
in
MEREDOSIA, IL

Presentation Outline

1. Project Overview
2. Phase I Study (Preliminary Engineering)
3. Bridge Type Study
4. Bridge Design
5. Innovative Details
6. Analysis - Design
7. Construction
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Project Location

[Map of Illinois showing project location]
Why the project is needed?

Existing Bridge is:

- **Structurally Deficient** – Built in 1936 / 80 years old
  
  Sufficiency Rating < 15 (out of 100)
  
  Low Rating => Numerous significantly deteriorated elements;
  
  Requires close monitoring / maintenance / repairs

- **Functionally Obsolete** – Narrow Lanes / No Shoulders / Unsafe

**Solution:**

Replace the existing bridge
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New Bridge - What size to build?

Based on traffic volume, current design standards and the functional requirements -

![Diagram of proposed IL 104 bridge](image-url)
Where to build?

- 255' north of existing
- Keep traffic thru town
- Build new bridge while maintaining traffic on existing bridge
- Remove existing bridge after shifting traffic on new bridge

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Bridge Type Study – Bridge Profile

Illinois River ➔ A Navigational Waterway

U.S. Coast Guard’s Navigational Clearance Requirements:

- Horizontal Clearance = 555 ft.
- Vertical Clearance = 55 ft. above 2% Flowline
- Profile Grade = 4% Max.

2100' +/-

Bridge Type Study: Bridge Limits & Layout

Focus – Main Navigation Span
Bridge Type Study: Focus – 600’ Main Navigation Span

**Cable-stayed**

**Truss**

**Tied-arch**

**, Bridge Type Study: Focus – 600’ Main Navigation Span

**Evaluation Criteria:**

- **Site Constraints**
  - Span length
  - Span arrangement

- **Overall Costs**
  - Construction cost
  - Life cycle cost

- **Other Attributes**
  - Constructability
  - Inspection and Maintenance
  - IDOT Experience

<table>
<thead>
<tr>
<th>Bridge Type</th>
<th>Estimated Initial Construction Cost</th>
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<tr>
<td>Cable-stayed</td>
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<tr>
<td>Truss</td>
<td>$12,910,050</td>
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<tr>
<td>Tied-arch</td>
<td>$12,910,050</td>
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<table>
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<tr>
<th>Annual Life Cycle Cost</th>
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<td><strong>Option</strong></td>
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<td>Truss</td>
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<td>Tied-arch</td>
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Bridge Type Study – Evaluation Criteria & Findings

- Site Constraints
  - Same for all alternates
- Overall Costs
  - Virtually the same construction & life cycle costs
- Bridge type selected based on:
  - Constructability – channel encroachment during construction (Adv – Cable stayed; others require erection towers or shoring)
  - Inspection/Maintenance considerations (Adv – Arch)
  - IDOT Experience - familiarity with particular type of construction (Adv – Arch)

Selected Bridge Type: Tied-Arch
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Proposed River Bridge – General Plan & Elevation

UNIT 1 = 805'
UNIT 2 = 590'
UNIT 3 = 720'
5 SPANS
4 SPANS

West Approach
Main Span
East Approach

56'
655'
Arch Span Features

- 590-foot span; 118-foot rise
- Floor beams & hangers spaced at 31'-4"

Arch Span Features

- Rib Bracing - Struts @ approx. 2 times the hanger spacing; No diagonal or “K” bracing; Clean/Open Structure
- Struts are offset from hangers – Simplifies connections
Arch Span Features

- Redundant hangers (2 cables) – With loss of 1 cable or when cable needs to be replaced, a single cable can support two traffic lanes on far side of the deck.

Arch Span Features

- Arch rib 3.5' x 5.0'
- Hanger 2 - 2" cables
- Concrete deck on steel stringers
- Tie girder (Gr 70W) 9' deep
- Diagonal bracing
- Floor beam 4' to 4.5' deep
- Vierendeel Strut 4.5' x 5.0'
- C Rib
- C Tie
- 118' at peak
- 53'
Arch Span Features

* Relief joints in the deck and stringers uncouple them from the arch structure

Proposed River Bridge – Piers

Approach Piers

Main Piers
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Tie Girders: I-sections……not Box-sections

Advantages:
- Very economical
- Greatly simplifies the floor beam connections
- Torsionally flexible; reduces secondary stresses and potential fatigue cracking in FB connections
- Easier to inspect & maintain
Tie Girders: I-sections......not Box-sections

Overall Torsional Stiffness:

- No loss of overall torsional stiffness of the arch system

Tie-Girders: I-sections......not Box-sections

Tie-Rib “Knuckle” Connection

Floor beam

Top Flange

Slots in Rib Plate

Bottom Flange

Tie

Rib

slots in Rib Plate
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   - Complex Analysis
   - Unique Design Loads
   - Unique Design Checks
7. Construction

Analysis & Design

- Used LARSA 4D for modeling and analysis
- Modeled as line elements, except plate elements for knuckles and the Floor Beams framing in to the knuckles
- 4,695 nodes
Analysis & Design

- Live Load – AASHTO HL-93 applied as incrementally moving load
- Variable transverse placements to maximize force effects in various members
- Analysis Data ➔ Force envelopes by member groups
- Strength checks by AASHTO LRFD
- Knuckle behavior not definitive; Stresses checked by stress contours

Unique Design Loads

- Nothing in AASHTO on loads specific to arch bridges, which are very sensitive to unbalanced load
- Used these load cases for design:
  - Dead Load
  - Live Load *
  - 10% Dead Load reduction where there is no LL

* Applied as moving loads
Stability Design of Arch Span

- No guidelines in AASHTO Design Specifications
- Used AISC’s Direct Analysis Method - commonly used for complex building structures – Most rational & transparent stability design method
- Considered geometric imperfections (L/1000 lateral offset of ribs)
- Considered 20% stiffness reduction to account for unanticipated residual stresses and local yielding
- Performed second-order analysis using LARSA 4D in both vertical and lateral directions
- Strength checks by AASHTO LRFD

Vessel Collision Design

- River traversed by Large / Heavy Barges
- Operational Classification: Critical Bridge
- VC Force computed using probability based analysis that considered:
  - Waterway depth & geometry – straight or curved
  - Type, size & frequency of Vessels
  - Vessel direction & speed
Vessel Collision Design

- Design Vessel
- VC Force

VC = 3800 Kips

Main Pier

Foundation Design

- All Vertical Piles vs. Battered Piles
- Lateral Load Resistance:
  - Battered piles - Only axial capacity
  - Vertical piles - Axial & bending capacity of piles in conjunction with soil resistance
- Soil Structure Interaction – Used “GROUP” by Ensoft for analysis

- Economical Design – less no. of piles, smaller foot-print of footing & cofferdam, easier pile installation; $2M saving
Seismic Analysis & Design

- Bridge location: SPZ “2” and Site Soil Classification “E”
- Seismic Design for 2500-year Return Period
- AASHTO provides Seismic Response Spectrum only for 1000-year return period
- Used 2500-year Response Spectrum provided by NEHRP(*) with a “2/3rd” Design Factor
  (*) NEHRP = National Earthquake Hazards Reduction Program

Seismic Analysis & Design

- A simplistic 3D elastic model of entire bridge –
  - Approach spans as continuous beams
  - Arch as two beams (parabolic – ribs + struts, straight - tie girders + deck);
    Equivalent mass and stiffness derived by vibration analysis of the full 3D arch model
  - and piers as vertical cantilevers.
- Elastic model analyzed for various modes & frequencies; Seismic forces were computed by modal superposition using Complete Quadratic Combination (CQC) method.
Aerodynamic Stability – Study by RWDI

1st Stage:
- Analytical Desktop (CFD) Study
- Vibration modes provided by exp
- Findings:
  - Provided Wind Loads for Design (*)
  - Aerodynamic Stability Not Clear
  - Testing Required to Confirm Stability
  (*) Less than AASHTO loads

Aerodynamic Stability

2nd Stage:
- Tested Sectional Model in Wind Tunnel
- Investigated stability against flutter, vortex shedding & galloping
- Findings:
  - Confirmed Aerodynamic Stability
  - Flutter - OK
  - Vortex-Shedding Excitation - OK
  - Galloping - OK
Fabrication Geometry & Pre-stressed Assembly

Fully Constructed Arch Span:

- Conforms to theoretical Roadway Profile after DL displacements
- Has Minimal Flexural Stresses due to Dead Load

** Require manipulation to fully assemble; Cambers it up; induces bending stresses that will counter bending stresses due to the Dead Loads

Fabricate to this shape **

Erection on Temporary Shoring; When assembled in unstressed condition, the girder ends at mid-span splice do not meet **
Fabrication Geometry & Pre-stressed Assembly

Fully assembled Geometry

Final geometry (Under full dead load)

Δ<sub>DL</sub>

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Arch Erection (engineered by Hanson Engineers)

Fabrication
Acknowledgements

Client: Illinois Department of Transportation, District 6
IDOT Bureau of Bridges & Structures
Springfield, IL

Geotechnical: Wang Engineering, Lombard, IL

Peer Review: Alfred Benesch Co., Chicago, IL

Wind Engr'g.: RWDI, Ontario, CN

Contractor: Halverson Construction Co., Springfield, IL

Fabricator: Industrial Steel Construction, Gary, IN
Questions?