Structural Analysis Models and Their Advancing Technologies

OTEI 2016
October 25th, 2016
Mary Lou Kutska, PE

Special Thanks to:
Tony Shkurti, PhD, PE, SE
Travis Konda, PhD, PE
Agenda

Introduction
  • Context
  • Structure Layout
  • Consultant Roles

Methods of Analyses
  • Line Girder
  • 3D Refined FEM

Refined Analysis Details
  • Framing & Build-up
  • Connectivity and Refined Detailing
  • Loading

Post Processing and Code Checking
  • Output Generation
  • Code Checking Macro

Conclusions
Project Context - Overview

- **Total Construction Cost** = $156 M
- **Using over 10M lbs of US-made Steel**
- **Construction Timeline** = 2015 – 2017 (24 Months)
  - Open to traffic: November 2017
  - Finishing All Work: Summer of 2018
  - Landscaping Contract 2018

Photos Courtesy of MnDOT
Project Context – Location & Need

Virginia MN, 190 miles North of Minneapolis

Taconite mine – Mesabi Iron Range

- Built in 1960 on mine land
- Easement agreement to move road
- Mining interests notified MnDOT in 2010
Construction Manager / General Contractor (CMGC)

- Integrated approach to planning, designing and construction
- Work collaboratively to develop the project scope, optimize the design, improve quality, and manage cost

Main Players:
- MnDOT – Owner
- Kiewit – General Contractor
- PTG – Prime Designer
- HNTB – Independent Peer Reviewer (I.P.R.)
**Aggressive schedule**
- EOR Design starts March Week 1
- EOR Final Steel Plans June Week 2
- Peer review turn-around 2 weeks after submitted plans
  - 30%, 60%, and 90%
Structural Layout – Alignment Options

- 3 different roadway alignments studied

   E-2 Selected

Photos Courtesy of MnDOT
CONSTRUCTION NOTES:


THE FIRST ONE OR TWO DIGITS OF EACH BAR MARK INDICATE THE BAR SIZE.

BARS MARKED WITH THE SUFFIX "T" SHALL BE EPOXY TREATED IN ACCORDANCE WITH SPEC 335.

BARS MARKED WITH THE SUFFIX "S" SHALL BE TREATED IN ACCORDANCE WITH THE PROJECT SPECIFICATIONS GOVERNING.

BRIDGE SHEET MATERIALS SHALL BE CAREFULLY PLACED TO AVOID INTERFERENCE WITH HOLES FOR ANCHOR RODS. THE BEAMS SHALL BE SET IN THE FINAL POSITION PRIOR TO TESTING AND THE BEAMS SHALL BE SET IN THE FINAL POSITION PRIOR TO GRATING ANCHOR HOLES.

BENCH MARKS AND PLAN ELEVATIONS ARE REFERENCED FROM NAVES DUNWIN, UNLESS OTHERWISE NOTED.

THE PILE LOADS SHOWN IN THE PLANS AND CORRESPONDING NOMINAL PILE RESISTANCE (MPA) ARE COMPUTED USING LIPM METHODOLOGY.

SEE BRIDGE SURVEY SHEET FOR SCHEDULE INFORMATION.

GENERAL PLAN

CONSTRUCTION NOTES:


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Methods of Analyses

3D FEM Model

Advantages

• Accurate
• Flexible – can apply any Load, BC, Framing
• Better overall global picture

Limitations

• Expensive, time-consuming
• Currently, most Code Checking modules not reliable
• Needs detailed Code Checking Macros

Line Girder Model

Advantages

• Simple, Fast, Inexpensive
• Adequate software Code Checking
• May use AASHTO defined Distribution Factors

Limitations

• Prismatic Sections
• D.F. calibrated for generic cases / parametric / limitations
• Potentially resulting in conservative designs – less economical
• Restrictions on connectivity and detailing at supports, etc.
Methods of Analyses – Combination

**Prime (PTG)**
Line Girder
- Manually input all obtained LL D.F.s in the line girder analysis
- Run all the Code Checks in the line girder software to verify sizes and to finalize design

**Peer (HNTB)**
3D Analyses
- Obtain applicable D.F. from the actual 3D model of the structure:
  - moment, shear, fatigue
  - One lane and two lanes loaded
Defining the Framing and Elevation

- Excel-based input
- Interactive Database Editor within CSi
- Shell elements and beam frame elements used
Detailing the Hybrid Girder

- Deck Shell Elements
- Beam Flange Elements
- Web Shell Elements
- Flange insertion points
- Beam stiffener elements
- Deck coordinates constrained to top flange
- Longitudinal joints defined at cross frames and changes in girder properties
Modeling the Diaphragms and Crossframes

- Super-elevation neglected
- Crossframe/diaphragm members modeled as single beam elements
- Implemented crossframe eccentricities as defined in plans
- Connection plate dead loads applied as miscellaneous load
Establishing the Pour Sequence

- Simplified to two pours
- Abutments and center span first followed by pours over the pier
Differentiating deck stiffness loading

**NON-COMPOSITE**
- Steel Girders
- Wet deck
- Haunch and overhang
- Non-structural wearing course
- Calculated Miscellaneous Steel
- Miscellaneous Dead Load
- Utilities

**LONG-TERM (3N)**
- Barriers and Medians
- Future Wearing Surface

**SHORT-TERM (N)**
- Braking Force
- Wind on Structure
- Wind on Live Load
- Temperature Loading
- Live Loading

*Deck stiffness reduction in negative DL moment regions.*
Comparing Model to Calculated DL

- Independent check performed on DL weights
- All miscellaneous steel loads were added to the model
  - Splice plates
  - Shear studs
  - Diaphragm connection plates
  - Bearing stiffeners
- Additional concrete loads were added to the model
  - Abutment diaphragm
  - Haunch
  - Triangular overhang
- Less than 1% difference between CSi reactions and hand calculations.

<table>
<thead>
<tr>
<th>Steel</th>
<th></th>
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<tbody>
<tr>
<td>Girder</td>
<td>8562.3 [kips]</td>
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<tr>
<td>Stiffeners</td>
<td>355.3 [kips]</td>
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<tr>
<td>Splice plate</td>
<td>193.3 [kips]</td>
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<tr>
<td>Shear studs</td>
<td>39.0 [kips]</td>
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<tr>
<td>Diaphragms*</td>
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<tr>
<td>Diaphragm connection*</td>
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<td>0.5&quot; deck</td>
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<tr>
<td>Overhang</td>
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<tr>
<td>End diaphragm</td>
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<td>Median</td>
<td>792.6 [kips]</td>
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<tr>
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<tr>
<td>12&quot; water</td>
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<tr>
<td>18&quot; Sanitary</td>
<td>283.1 [kips]</td>
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<td>Water+sanitary</td>
<td>181.2 [kips]</td>
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<tr>
<td>Total</td>
<td>679.4 [kips]</td>
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<p>| | |</p>
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<tr>
<td>Hand calc</td>
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<td>Csi DL</td>
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<td>Difference</td>
<td>22.7 [kips]</td>
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Developing the Live Load Methodology

- 7 lane total loading
- Three lane positions were explored
- Fascia girder (G1) and interior girder (G5) analyzed
- Maximizations of all lane positioning taken
- CSi limitations due not allow influence surface definitions
- HL-93, pedestrian load, inspection trucks, and permit trucks
Processing the Results

- Live load enveloping done within excel
- Strength and Service Combinations done in Macro
- Design code checks done in Macro
- Graphics developed in Macro
## 3D Analysis Scope

- Verify all D.F. from an independent 3D model of the structure
- Obtain all moments, shears from 3D for all loads
- Perform the Code Checking by using custom prepared Code Checking macros

### Live Load Distribution Factors from 3D LARSA Analysis

<table>
<thead>
<tr>
<th>Moment LLDF, Positive Moment Region</th>
<th>Exterior Girder</th>
<th>Fatigue</th>
<th>Interior Girder</th>
<th>Fatigue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span 1</td>
<td>0.782</td>
<td>0.537</td>
<td>0.639</td>
<td>0.36</td>
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<tr>
<td>Span 2</td>
<td>0.77</td>
<td>0.575</td>
<td>0.627</td>
<td>0.368</td>
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<tr>
<td>Span 3</td>
<td>0.776</td>
<td>0.549</td>
<td>0.628</td>
<td>0.342</td>
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</table>

<table>
<thead>
<tr>
<th>Moment LLDF, Negative Moment Region</th>
<th>Exterior Girder</th>
<th>Fatigue</th>
<th>Interior Girder</th>
<th>Fatigue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pier 1</td>
<td>0.852</td>
<td>0.553</td>
<td>0.695</td>
<td>0.329</td>
</tr>
<tr>
<td>Pier 2</td>
<td>0.857</td>
<td>0.573</td>
<td>0.689</td>
<td>0.33</td>
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</table>

<table>
<thead>
<tr>
<th>Shear LLDF</th>
<th>Exterior Girder</th>
<th>Fatigue</th>
<th>Interior Girder</th>
<th>Fatigue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pier 1</td>
<td>0.917</td>
<td>0.704</td>
<td>1.038</td>
<td>0.593</td>
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<tr>
<td>Pier 2</td>
<td>0.933</td>
<td>0.704</td>
<td>1.022</td>
<td>0.58</td>
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### Live Load Distribution Factors from AASHTO LRFD

<table>
<thead>
<tr>
<th>Moment LLDF, Positive Moment Region</th>
<th>Exterior Girder</th>
<th>One Lane</th>
<th>Fatigue</th>
<th>One Lane</th>
<th>Fatigue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span 1</td>
<td>0.95</td>
<td>0.788</td>
<td>0.792</td>
<td>0.467</td>
<td>0.755</td>
</tr>
<tr>
<td>Span 2</td>
<td>0.95</td>
<td>0.737</td>
<td>0.792</td>
<td>0.417</td>
<td>0.705</td>
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<tr>
<td>Span 3</td>
<td>0.95</td>
<td>0.787</td>
<td>0.792</td>
<td>0.453</td>
<td>0.754</td>
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</table>

<table>
<thead>
<tr>
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<th>One Lane</th>
<th>Fatigue</th>
<th>One Lane</th>
<th>Fatigue</th>
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</thead>
<tbody>
<tr>
<td>Pier 1</td>
<td>0.95</td>
<td>0.875</td>
<td>0.792</td>
<td>0.502</td>
<td>0.837</td>
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<tr>
<td>Pier 2</td>
<td>0.95</td>
<td>0.861</td>
<td>0.792</td>
<td>0.483</td>
<td>0.824</td>
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<table>
<thead>
<tr>
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<th>Exterior Girder</th>
<th>One Lane</th>
<th>Fatigue</th>
<th>One Lane</th>
<th>Fatigue</th>
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<tbody>
<tr>
<td>Pier 1</td>
<td>0.95</td>
<td>0.918</td>
<td>0.7917</td>
<td>0.84</td>
<td>1.082</td>
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</table>
Processing the Results – Comparing Approaches

Combined Approach worked well:

<table>
<thead>
<tr>
<th>Case</th>
<th>Lanes</th>
<th>Deflection Limit</th>
<th>Actual Deflection - Span 2</th>
<th>Check</th>
</tr>
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<tbody>
<tr>
<td>I</td>
<td>6 + No Trail</td>
<td>L/800</td>
<td>0.527</td>
<td>911</td>
</tr>
<tr>
<td>II</td>
<td>4 + Trail</td>
<td>L/1000</td>
<td>0.478</td>
<td>1004</td>
</tr>
<tr>
<td>III</td>
<td>6 + Trail</td>
<td>L/1000</td>
<td>0.500</td>
<td>959</td>
</tr>
</tbody>
</table>

We believe that the L/959 represents a small difference of about 4.3% between the two modeling approaches, and recommend that it be accepted as is.

L.L. Deflection

Code Checking

Dead Load Deflection
Key Takeaways

• Analysis must fit your time constraints
• Know your structural software limitations
• More detailed analysis results in more economic design
Questions?

OTEC 2016
October 25th, 2016
Mary Lou Kutska, PE

Special Thanks to:
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Construction Photos

Photos Courtesy of MnDOT (August 2016)
Construction Photos

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