Construction Loading Example

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INDOT Design Policy

INDIANA DEPARTMENT OF TRANSPORTATION
Driving Indiana's Economic Growth

Design Memorandum No. 10-10
Policy Change

July 9, 2010

TO: All Design, Operations, and District Personnel, and Contractors
FROM: Anthony L. Ursinovich
       Design Resources Engineer
       Production Management Division

SUBJECT: Bridge Construction Loads Considerations

AUDS Indiana Design Manual Section 6.3.10

EFFECTIVE: October 1, 2010 Stage 3 Submission

Construction loadings shall be evaluated in accordance with AASHTO LRFD Article 3.4.2.
Article 3.4.2.1 addresses evaluation at the Strength Limit State. Article 3.4.2.2 addresses the
evaluation of deflections at the Service Limit State.
403-4.0 CONSTRUCTION LOADINGS

403-4.01 General Requirements

403-4.02 Application of Construction Loading

1. Component Loads, DC
2. Construction Dead Loads, CDL
3. Construction Live Loads, CLL
4. Wind Load, WS

CONSTRUCTION LOADINGS

The exterior girders have been checked for strength, deflection, and overturning using the construction loads shown below. Cantilever overhang bracings were assumed for support of the deck overhang past the edge of the exterior girders. The finishing machine was assumed to be supported 6 in. outside the vertical coping form. The top overhang bracings were assumed to be located 6 in. past the edge of the vertical coping form. The bottom overhang bracings were assumed to be hinged against the intersection of the girder bottom flange and webs.

Deck Falsework Loads: Designed for 15 lb/ft² for permanent metal stay-in-place deck forms, removable deck forms, and 2 ft exterior sidewalk.

Construction Live Load: Designed for 20 lb/ft² extending 2 ft past the edge of coping and 75 lb/ft² vertical force applied at a distance of 6 in. outside the face of coping over a 30-ft length of the deck, supported with the finishing machine.

Finishing Machine Load: 4500 lb distributed over 10 ft along the coping.

Wind Load: Designed for 70 mph horizontal wind velocity of 100 mph.

CONSTRUCTION LOADINGS INFORMATION TO BE SHOWN ON GENERAL PLAN

Figure 403-4A
Construction Loads

Loads during construction are:

DC = Dead Load from Bridge Members, Formwork, Deck, etc.

DC1 – Concrete = 150 lbs/ft³
DC2 – Stay-in-place Formwork = 15 psf

DW = N/A for Non-Composite Construction

CDL = Construction Equipment loads such as screed rails, overhang forms, temp railing, walkway

CDL1 – Removable Coping Deck Forms = 15 psf
CDL2 – Temporary Walkway = 15 psf – applied over a 2'-0" wide platform on outside of coping

CLL = Construction Live Load such as Screed Machine and Workers

CLL1 – Construction Live Load = 20 psf extended the entire bridge width plus two feet outside of bridge coping over 30 feet longitudinal length centered on Screed Machine Load

CLL2 – Screed Machine = 4500 lbs over 10 feet longitudinal length applied 6 in outside of bridge coping.

CLL3 – Vertical Railing and Walkway Load = 75 plf applied 6 in outside of bridge coping over 30 feet longitudinal length centered on Screed Machine Load
Construction Loads

Loads during construction are:

WS = Wind Load on exposed height of the Structure (negligible for interior girders)

WS - Calculated per AASHTO 3.8.1.1 (use 70 mph per AASHTO Temporary works manual Fig 2.1)

WCEL = Wind Load on screed machine (negligible)
Load Factors

[AASHTO 3.4.2.1 and 3.4.2.2] - Load Combinations

STRENGTH I - 1.25*(DC + DW) + 1.5*(CDL + CLL)
STRENGTH III - 1.25*(DC + DW) + 1.5*(CDL) + 1.25(WS)
STRENGTH IV - 1.5*(DC + DW) + 1.5*(CDL)
STRENGTH V - 1.25*(DC+DW)+1.5*(CDL)+1.35*(CLL)+0.4*(WS)
SERVICE I - 1.0*(DC+DW)+1.0*(CDL)+1.0*(CLL) +0.3*(WS)
SERVICE II - 1.0*(DC+DW)+1.0*(CDL)+1.3*(CLL)
407-6.0 I-SECTIONS IN FLEXURE

407-6.07 Constructability

LRFD 6.10.3 and its commentary provide additional information regarding constructability of a steel I-girder bridge.

See Chapter 403 for additional guidance for construction loading.

407-8.0 CONNECTIONS AND SPLICES

407-8.01 Bolted Connections

2. Design. A bolted connection should be designed as slip-critical at the Service II Limit state and for construction loading, except for secondary bracing.

407-8.03 Splices

7. Design. A bolted splice shall be slip-critical under Service II and construction loads and shall be designed in accordance with LRFD 6.13.2.2 for the Strength Limit state.
Limit States

Seven Limit State Checks

1 - Yielding Limit State Check (6.10.3.2.1-1)

2 - Lateral Torsional Buckling and Flange Local Buckling Check (6.10.3.2.1-2)

3 - Web Bend Buckling Check (6.10.3.2.1-3)

4 - Flange Lateral Bending Check (6.10.1.6-1)

5 - Discretely Braced Flange in Tension Check (6.10.3.2.2-1)

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Limit States

6 - Lateral Girder Rotation Check (Service I)

![Diagram showing beam rotation](Figure 403-4D)
Construction Loading Example

Limit States

7 - Slip Critical Bolt Check (Service II)

Design Example - Steel Beam Bridge

Bridge Geometry
- Three Spans @ 66’ – 86’ – 66’
- Skew = 10 degrees

Bridge Typical Section
- Clear Roadway = 28’-0”
- Beam Spacing = 3 @ 8’-3”
- Slab = 8”
- Overhang = 1’-10 ½”

Beam Details
- W 36x135 (Positive Moment Regions)
- W 36x194 (Negative Moment Regions)
- Grade 50W Steel
Construction Loading Example

Final Design Computations

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<th>PAGE</th>
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</thead>
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</tr>
<tr>
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</tr>
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<td>367-377</td>
</tr>
</tbody>
</table>

Construction Loading Example

Construction Load Code Checks, Interior Beams

Determine Controlling Strength Limit State
- Run Continuous Beam Analysis Program
- Investigate all 5 Pours
- Run for Strength I and IV
- By Inspection Strength III and V will not control, No wind on interior
- Determine which Pour and Strength Combination Controls
Construction Load Code Checks, Interior Beams

AASHTO Code Checks

- Follow AASHTO Figure C 6.4.1-1 flow chart
- Utilize Merlin-Dash Program for Code Checks
- Merlin-Dash Performs most code checks for Strength I only
- Modify Input Loads for code checks for Strength IV

**Input - Construction Loading**

<table>
<thead>
<tr>
<th>INPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness of Slab, t, (inch) = 8</td>
</tr>
<tr>
<td>Thickness of Fillet, f, (inch) = 1.67 assumed average</td>
</tr>
<tr>
<td>Width of Fillet, b, (feet) = 1.00</td>
</tr>
<tr>
<td>Beam Spacing, s, (feet) = 8</td>
</tr>
<tr>
<td>No. of Beams, n = 4</td>
</tr>
<tr>
<td>Out to Out Coping Width, OC, (feet) = 28.5</td>
</tr>
<tr>
<td>Weight of Permanent Deck Forms, Wp, (psf) = 15</td>
</tr>
</tbody>
</table>

DC = Dead Load from Bridge Members, Form work, Deck, etc.
DW = N/A for Non- Composite Construction
CDL = Construction Equipment loads such as screed rails, overhang forms, temp railind, walkway
CLL = Construction Live Load such as Screed Machine and Workers
WL = Wind Load on exposed height of the Structure (negligible for interior girders)
WCEL = Wind Load on screed machine (negligible)
### Construction Loading Example

#### Construction Load Code Checks, Interior Beams

**Applied Construction Loading**

<table>
<thead>
<tr>
<th><strong>OUTPUT</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NON-COMPOSITE DEAD LOADS (PER GIRDER)</strong></td>
<td></td>
</tr>
<tr>
<td>Slab: ((b/2)^2(1/12)^2) (\times) (150 pcf)</td>
<td>800 pif</td>
</tr>
<tr>
<td>Fillet: ((b/2)^2(1/12)^2) (\times) (150 pcf)</td>
<td>23 pif</td>
</tr>
<tr>
<td>Deck Forms: ((b/2)^2(1/12)^2) (\times) (W,)</td>
<td>120 pif</td>
</tr>
</tbody>
</table>

**NON-COMPOSITE CONSTRUCTION LIVE LOADS**

\[ \text{DISTR CONSTR LL; CLL: (CC+2\times2)^2(20 PSF) / n} = 163 \text{ pif over 30' of deck length} \]

---

### Construction Loading Example

#### Construction Load Code Checks, Interior Beams

**Applied Construction Loading**

**INPUT FOR MERLIN-DASH - STRENGTH I - 1.25(DC + DW) + 1.5(CDL + CLL)**

| **Slab Loads (Data Type: 10012)** |  |
| DC1 = Deck Forms = | 0.12 | klf over full str length |
| Slab = | 0.8 | klf |
| Fillet = | 0.023 | klf |
| DC1 = Slab and Fillet = | 0.82 | klf |

| **Arbitrary Uniform Loads (Data Type: 11012)** |  |
| Constr. Live Load = CLL = | 0.16 | klf over 30' of str length * |
| Constr. Live Load = CLL(1.5/1.25) = | 0.20 | klf for Merlin-Dash input |

* Apply loads to maximize moments and shear for positive and negative
Construction Load Code Checks, Interior Beams

Applied Construction Loading

INPUT FOR MERLIN-DASH - STRENGTH IV - 1.5(DC + DW) + 1.5(CDL)

| Slab Loads (Data Type: 10012) | DC1 = Deck Forms = 0.12 klf over full str length |
| DC1 = Deck Forma*(1.5/1.25) = 0.14 klf for Merlin-Dash Input |
| Arbitrary Uniform Loads (Data Type: 11012) | Slab = 0.8 klf |
| Fillet = 0.023 klf |
| DC1 = Slab and Fillet = 0.82 klf |
| DC1 = Slab and Fillet* (1.5/1.25) = 0.99 klf for Merlin-Dash Input |

* Apply loads to maximize moments and shear for positive and negative

---

Construction Load Code Checks, Interior Beams

Dead Load Deflections

- AASHTO 6.10.3.5
- AASHTO Guide Specifications for Temporary Works
- Section 2.3.5 - Deflection for Falsework Members

Deflection <= L / 240 for Concrete DL only

- Use Merlin-Dash to check deflection for each Pour (1-5)
- Verify No Uplift
Construction Load Code Checks, Interior Beams

Dead Load Deflections

<table>
<thead>
<tr>
<th>LOAD POUR DESCRIPTION</th>
<th>SLAB NO</th>
<th>MODULAR RATIO</th>
<th>SLAB LOAD DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NO</td>
<td>N1</td>
<td>N2+n</td>
</tr>
<tr>
<td></td>
<td>DAY 1</td>
<td>1</td>
<td>48.00</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>24.0</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>14.0</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>24.0</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>28.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>

Deck – Slab Tension Check

- AASHTO 6.10.3.2.4
- Use Continuous Beam Analysis to determine max negative moments
- Strength IV Construction Loading controls
- Modify Merlin-Dash loads, program outputs service stresses
Construction Load Code Checks, Interior Beams

**Deck – Slab Tension Check**

TABLE 1.1.5.1A - Moments and Accumulated Stresses for Four No. = 3 (Unfactored)

<table>
<thead>
<tr>
<th>SP IN ID</th>
<th>FROM</th>
<th>MENT</th>
<th>DEAD LOAD</th>
<th>ACUMULATED</th>
<th>STRESSES, [ksi] &amp; DEFLECTION (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TOP Conc.</td>
<td>S HD STEEL</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>3.30</td>
<td>-22.9</td>
<td>0.01</td>
<td>-2.84</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>6.60</td>
<td>-44.1</td>
<td>0.02</td>
<td>-5.30</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>9.90</td>
<td>-66.1</td>
<td>0.03</td>
<td>-7.38</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>13.20</td>
<td>-88.1</td>
<td>0.04</td>
<td>-9.07</td>
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<tr>
<td>1</td>
<td>5</td>
<td>16.50</td>
<td>-110.2</td>
<td>0.05</td>
<td>-10.37</td>
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<tr>
<td>1</td>
<td>6</td>
<td>19.80</td>
<td>-132.2</td>
<td>0.06</td>
<td>-11.29</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
<td>23.10</td>
<td>-154.2</td>
<td>0.07</td>
<td>-11.83</td>
</tr>
<tr>
<td>1</td>
<td>8</td>
<td>26.40</td>
<td>-176.3</td>
<td>0.09</td>
<td>-11.90</td>
</tr>
<tr>
<td>1</td>
<td>9</td>
<td>29.70</td>
<td>-198.3</td>
<td>0.10</td>
<td>-11.74</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>33.00</td>
<td>-220.3</td>
<td>0.11</td>
<td>-11.12</td>
</tr>
<tr>
<td>1</td>
<td>11</td>
<td>36.30</td>
<td>-242.4</td>
<td>0.12</td>
<td>10.12</td>
</tr>
<tr>
<td>1</td>
<td>12</td>
<td>39.60</td>
<td>-264.4</td>
<td>0.13</td>
<td>-8.73</td>
</tr>
<tr>
<td>1</td>
<td>13</td>
<td>42.90</td>
<td>-286.4</td>
<td>0.14</td>
<td>-6.96</td>
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<tr>
<td>1</td>
<td>14</td>
<td>46.20</td>
<td>-308.5</td>
<td>0.15</td>
<td>-4.79</td>
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<tr>
<td>1</td>
<td>15</td>
<td>49.50</td>
<td>-330.5</td>
<td>0.16</td>
<td>2.64</td>
</tr>
<tr>
<td>1</td>
<td>16</td>
<td>52.80</td>
<td>-352.5</td>
<td>0.19</td>
<td>4.64</td>
</tr>
</tbody>
</table>

July 24, 2012

**Construction Loading Example for Steel Beam Bridge**

**Construction Load Code Checks, Interior Beams**

**Service II Loading for Slip Critical Checks**

Check Slip Critical Beams @ Service II (Construction Loads)

Divide Force Equally between inner & outer plates per AASHTO 6.13.4.4c

\[ P_{\text{crit}} = 9.7 \text{ kips} \]

\[ R_s = K_s \cdot R_{\text{crit}} \]

\[ R_s = 1.0 \cdot 9.7 = 9.7 \text{ kips} \]

\[ P_{\text{crit}} = 19.5 \text{ kips} \]

\[ N_{\text{max}, \text{crit}} = P_{\text{crit}} \cdot P_{\text{crit}} \]

\[ N_{\text{max}, \text{crit}} = 0.5 \text{ kips} < N_{\text{crit}} = 14 \text{ kips} \]

OK
Determine Controlling Strength Limit State

- Run Continuous Beam Analysis Program
- Investigate all 5 Pours to determine controlling loads
- Run all load cases with modified loads in Merlin-Dash to get moments
- Pour 2 and 5 control
- Example calculations shown for Pour 2 Strength V loading

Input for Construction Loading

<table>
<thead>
<tr>
<th>INPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness of Slab, t, (inch) = 8</td>
</tr>
<tr>
<td>Thickness of Flange, t_f, (inch) = 1.87</td>
</tr>
<tr>
<td>Assumed average</td>
</tr>
<tr>
<td>Width of Flange, b_f, (feet) = 1.00</td>
</tr>
<tr>
<td>Beam Spacing, s, (feet) = 8.25</td>
</tr>
<tr>
<td>Overhang, oh, (feet) = 1.03</td>
</tr>
<tr>
<td>Additional Overhang Thickness, oh, (in) = 2.01</td>
</tr>
<tr>
<td>Weight of Permanent and Removable Deck Forms, W_p, (psf) = 15</td>
</tr>
<tr>
<td>Weight of Temporary Walkway, W_walkway, (psf) = 15</td>
</tr>
<tr>
<td>Vertical Railing and Walkway Load, W_rail, (psf) = 75</td>
</tr>
</tbody>
</table>

DC = Dead Load from Bridge Members, Formwork, Deck, etc.
DNV = N/A for New-Composite Construction
CFL = Construction Equipment loads such as screed rails, overhang forms, temp railing, walkway
CLL = Construction Live Load such as Screed Machine and Workers
WS = Wind Load on elevated height of the Structure (negligible for interior girders)
WCEL = Wind Load on screed machine (negligible)
Construction Loading Example

Deck Pour Sequencing

Bridge Framing Plan
Construction Loading Example

Steel Beam Elevation

Construction Load Code Checks, Exterior Beams

Applied Construction Loading

OUTPUT

NON-COMPOSITE DEAD LOADS [PER GRIDER]

| DC1  | GLAB: (8)(1)(1/12)''(150 psf)''(a-c)^2 | 616 psf |
| DC1  | FILLET: 6in. (1/12)''(150 psf) | 23 psf |
| DC1  | OVERHANG: (150 psf)''(1/12)Y(1/12)Y(1/12)''(2a)''(c)''(a)'' | 51 psf |
| DC2  | DECK FORMS: (1/2)''(c)''(W_c) | 62 psf |
| CCL1 | REMOVABLE COPING DECK FORMS: 6in.(W_c) | 27 psf |
| CCL2 | TEMP SCREED RAIL AND WALKWAY: (W_c)''(7) | 30 psf |

NON-COMPOSITE CONSTRUCTION LIVE LOADS

| CLL1 | DISTR CONSTR LL: (a+2c+2)''(20 psf) | 159.2 psf over 30'' of deck length |
| CLL2 | FINISHING MACHINE LL: (.4500 lbs / 16) | 450 psf for 10 foot |
| CLL3 | VERTICAL RAILING AND WALKWAY LOAD: (W_c)''(a)'' | 75 psf over 30'' of deck length |
Construction Load Code Checks, Exterior Beams

Applied Construction Loading – Strength V

INPUT FOR MERLIN-DASH - STRENGTH V = 1.25(DC+Dm)+1.5(CDL)+1.35(ACL)+0.4(WGL) 

DC1 = Deck Forms = 0.06 klf over full str length

Arbitrary Uniform Loads (Date Type 11012)
- Slab = 0.62 klf
- Fillet = 0.02 klf
- Overhang = 0.05 klf
- DC1 = Slab and Fillet = 0.69 klf *

Removable Curing Deck Forms = CDL1*1.5/1.25 = 0.03
Temp Screw rail and Walkway = CDL2*1.5/1.25 = 0.04
Constl. Dead Load = CDL = 0.07 klf over full str length

Dir Construct. Line Load = CLL1(1.35/1.25) = 0.17 klf over 30 of str length *
Screw Construct. Line Load = CLL2(1.35/1.25) = 0.48 klf over 10 of str length *
Vertical Rail and Walkway Load = CLL3(1.35/1.25) = 0.08 klf over 30 of str length *

* Apply loads to maximize moments for positive and negative

---

Construction Load Code Checks, Exterior Beams

Input Properties

Construction Loading X = 39.6

<table>
<thead>
<tr>
<th>Input</th>
<th>Analyzed Section</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D = 34.90 in</td>
</tr>
<tr>
<td></td>
<td>f_p = 50 ksi</td>
</tr>
<tr>
<td>Unbraced Length (L_u) = 20.50 ft</td>
<td>V = 6.20</td>
</tr>
<tr>
<td>Location of Critical Section = 39.60 ft</td>
<td>T = 0.23</td>
</tr>
<tr>
<td>Span Length (L) = 66.00 ft</td>
<td>Vertical Clearance = 23.00 ft</td>
</tr>
<tr>
<td>Bridge Simple or Cont = Cont</td>
<td>Wind Pressure (P*) = 25 psf</td>
</tr>
<tr>
<td>Overhang Width (S_str) = 1.8750 ft</td>
<td>Number of Beams = 4</td>
</tr>
</tbody>
</table>

---
Construction Loading Example

Construction Load Code Checks, Exterior Beams

Input from Merlin-Dash

Moments

Strength I
Factored Vertical Moment at Critical = 621.9 kft
Moment at Ll. Bracing Point (Ml) = 600.2 kft
Moment at Rt. Bracing Point (Mr) = 602.2 kft
M at Mid. of Unbraced Length (Ms) = 676.9 kft

Strength II
Factored Vertical M at Critical = 434.5 kft
M at Ll. Bracing Point (Ml) = 422.9 kft
M at Rt. Bracing Point (Mr) = 467.9 kft
M at Mid. of Unbraced Len. (Ms) = 411.2 kft

Strength IV
Factored Vertical M at Critical = 523.1 kft
M at Ll. Bracing Point (Ml) = 509.0 kft
M at Rt. Bracing Point (Mr) = 537.4 kft
M at Mid. of Unbraced Len. (Ms) = 495.6 kft

Strength V
Factored Vertical M at Critical = 603.3 kft
M at Ll. Bracing Point (Ml) = 582.6 kft
M at Rt. Bracing Point (Mr) = 563.2 kft
M at Mid. of Unbraced Len. (Ms) = 563.0 kft

Beam Properties

Beam Height = 0.73 + 0.92 + 0.79 = 36.50 in

<table>
<thead>
<tr>
<th>Flange</th>
<th>A (in²)</th>
<th>Y (in)</th>
<th>I (in⁴)</th>
<th>h (in)</th>
<th>A(h²) (in⁶)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Flange</td>
<td>9.48</td>
<td>0.40</td>
<td>3.7</td>
<td>17.86</td>
<td>0.6</td>
</tr>
<tr>
<td>Web</td>
<td>20.05</td>
<td>18.25</td>
<td>382.4</td>
<td>0.00</td>
<td>2129.1</td>
</tr>
<tr>
<td>Bottom Flange</td>
<td>9.48</td>
<td>36.11</td>
<td>342.3</td>
<td>17.86</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Ww = ΣAY/A = 728.39/0.91 = 817.45 in³
l = 2.130.1 + 16.044.5
Sw = bh²/6 = 0.79*12.00/36 = 16.96 in³

Concrete:

Wc = Wy - Ww = 0.79*12.00/36 = 16.96 in³

Wc = Wy - Ww = 0.79*12.00/36 = 16.96 in³
Construction Load Code Checks, Exterior Beams

Flange Compressive Stress – $f_{bu}$

Determine $f_{bu}$

**Strength I**

$M_{scomp} = M_{tu,LE} = 621.9kips/ft \times 12447.9 = 621.9kips/ft \times 12447.9$

$f_{bwww} = M_{tu,LE} = 621.9kips/ft \times 12447.9$

$f_{sw comp} = 16.65$ kips

**Strength III**

$M_{scomp} = M_{tu,LE} = 434.5kips/ft \times 12447.9 = 434.5kips/ft \times 12447.9$

$f_{bwww} = M_{tu,LE} = 434.5kips/ft \times 12447.9$

$f_{sw comp} = 11.04$ kips

**Strength IV**

$M_{scomp} = M_{tu,LE} = 523.1kips/ft \times 12447.9 = 523.1kips/ft \times 12447.9$

$f_{bwww} = M_{tu,LE} = 523.1kips/ft \times 12447.9$

$f_{sw comp} = 14.01$ kips

**Strength V**

$M_{scomp} = M_{tu,LE} = 603.9kips/ft \times 12447.9 = 603.9kips/ft \times 12447.9$

$f_{bwww} = M_{tu,LE} = 603.9kips/ft \times 12447.9$

$f_{sw comp} = 16.16$ kips

First-order versus Second-order analysis

Determine if geometry satisfies provisions of [AASHTO 6.10.1.6]:

\[ L_p = \frac{1.2L^2}{2} \left( C_{v} f_y \frac{h}{f_{u,LE}} \right)^{0.5} \]

\[ L_p = \frac{1.0(125)}{2} \left( \frac{C_{v} f_y}{f_{u,LE}} \right)^{0.5} \]

where:

\[ C_{v} = 0.95 \left( 12^{0.95} \right) \]

\[ f_y = 50kips/ft \]

\[ f_{u,LE} = 60kips/ft \]

\[ h = 0.75h + 4.85 + 0.75a = 35.71 \text{ in} \]

\[ \eta_1 = 40 \text{ in} \]

\[ \eta_2 = 50 \text{ in} \]

\[ \eta_3 = 50 \text{ in} \]

\[ L_p = 1.0 \left( \frac{1.0(125)}{2} \right)^{0.5} \]

\[ = 72.5 \text{ in} \]
Construction Loading Example

Construction Load Code Checks, Exterior Beams

First-order versus Second-order analysis

\[ R_e = \text{Section is not composite yet} \]
\[ * \text{No longitudinal stiffeners are provided} \]
\[ 2D_aL_e = \lambda \omega \]  
\[ \lambda = \frac{6.74E}{G_d} \cdot \lambda_k \]  
\[ \lambda_k = \frac{5.74}{20.00(5000)} \cdot 0.5 \]  
\[ = 137.3 \]
\[ 2D_aL_e = 2 \cdot 17.46(0.86) = 58.2 < 137.3 \]
\[ R_b = 1\left(\frac{[\omega]_e}{(1000-300)[\omega]_e}\right)\left(\frac{L_e}{\lambda \omega}\right)^{1.0} \]  
\[ \omega_e = 20 \mu_f N_d \]  
\[ = 2 \cdot 17.46(0.0312) \cdot 0.01 \]  
\[ = 2.21 \]
\[ R_b = 58.2 + 137.3 \cdot \text{Use } R_b = 1.00 \]
\[ = 1.00 \]

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Construction Load Code Checks, Exterior Beams

First-order versus Second-order analysis

\[ C_s = 1.75*1.05*(14.89/15.59)+0.3*(14.89/15.59)^2 \]
\[ = 1.93 \]
\[ \text{or} \]
\[ C_s = 2.30 \]

\[ C_s = 1.60 \] — Controls

\[ L_b = 1.2*(P_{cs}+P_{fu}+P_{fu}^{\text{cr}}) \]
\[ \text{where: } P_{cs} = 1.2*P_{cr} \]
\[ (\text{AASHTO 8.10.1.8-2}) \]
\[ = 12.0*(1.03*1.00*16.1690)*0.5412 \]
\[ = 13.0 \text{ ft} \times 20.50 \text{ ft} \]

Use Amplification Factor from AASHTO 6.10.1.6
Construction Load Code Checks, Exterior Beams

First-order versus Second-order analysis

Amplification Factor

Or use AASHTO 6.10.8.2.5-6

\[ F_w = C_o \times \frac{P_o}{E_{fl}} \times \frac{A}{I} \times \frac{1}{(1 + 1.4 \times 10^{-6} \times L/2 \times 20,000 \times (20.6^2 \times 12/3 \times 0.1)^2)} \]

\[ F_w = 44.26 \text{ ksi} \]

\[ A = 0.65/(-1.16 \times 10^4(48.58)) \]

\[ A = 1.27 \]

Bracing Length exceeds allowable range, Amplification Factor = 1.27

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Construction Load Code Checks, Exterior Beams

Flange Lateral Bending Stress \( f_l \)

Determine \( f_l \) - Flange Lateral Bending Stress

**Wind**

Calculate Wind Load

Wind Pressure

\[ P_w = P_0 \times (V_{pk})^2 / 10,000 \]

\[ P_0 = 25.0 \text{ psi} \]

\[ V_{pk} = 2.6 \times \left( \frac{100 \times 50}{10,000} \right) \]

**V**

\[ V_{10} = 70 \text{ mph} \]

\[ V_{25} = 100 \text{ mph} \]

Use 70 mph per AASHTO Guide Design Speeds

**V** = 70 mph for Bridge Temporary Work

\[ \frac{V_{pk}}{V_{pk}} \times \frac{100}{10,000} \]

\[ V_{pk} = 25.0/100 \times 70.0 \times 0.02 \times 10,000 \]

\[ V_{pk} = 9.0 \text{ ksi} \]
Construction Loading Example for Steel Beam Bridge

Construction Load Code Checks, Exterior Beams

Flange Lateral Bending Stress – $f_l$

Wind transmitted to supports by 3rd load path - bending of flanges

$$M_{w} = \frac{w}{10} + \frac{w}{2} \cdot 2 \cdot \frac{h_{l}}{l} \cdot \sqrt{2} = 3.82 \text{ ft}$$

$$w = 0.012 \text{ kft}$$

For continuous bridges:

$$M_{w} = 0.06 \cdot 0.5 \cdot 0.5 = 0.015 \text{ kft}$$

$$f_{l} = \frac{M_{w}}{I} \cdot 12$$

$$f_{l} = 13.6 \cdot 12 = 163.2 \text{ ksi}$$

Concrete - DCI

$$F_{con} = 150 \text{ pcf}$$

$$M_{con} = F_{con} \cdot \frac{h_{l}}{2} = 0.10 \cdot 20.5 \cdot \frac{12}{2} = 3.40 \text{ kft}$$

$$f_{con} = \frac{M_{con}}{I} \cdot 12 = 3.40 \cdot 12 = 40.8 \text{ ksi}$$
Construction Load Code Checks, Exterior Beams

Flange Lateral Bending Stress – $f_l$

Exterior Forms - CDL1

$w = 10 \text{ psf}$

$F_{CDL1} = 1.80/2 \times 15 \text{ psf} (2.42 \times 1000) = 0.01 \text{ klf}$

$N_{CDL1} = F_{CDL1} L^2/12 = 0.01 \times 20 \times 50 \times 12 / 12 = 0.40 \text{ klf}$

$f_{CDL1} = N_{CDL1} S_{fl}/L^2 = 0.40/12 \times 10 = 0.26 \text{ ksi}$
Construction Load Code Checks, Exterior Beams

Flange Lateral Bending Stress – $f_f$

**Finishing Machine - CLL2**

$F_{C2,LL2} = 450/1000 \times (2.442) = 0.36 \text{ kips}$

$M_{C2,LL2} = F_{C2,LL2} \times d_2 \times \left(1 - \frac{a}{L_p}\right) \times b$ (Assumes $L_p = 50\%$ of span)

$= 0.37 \times 20.5 \times 2/12 \times (1 - 1) \times 15.0 = 1.04 \text{ kips}$

$f_f = \frac{M_{C2,LL2}}{W_{f,2}} = \frac{1.04}{850} = 0.0012 = 1.2 \text{ kips/ft}$

**Screed Rail and Walkway - CLL3**

$w = \frac{75}{2.44} = 0.03 \text{ kips/ft}$

$F_{S3,LL3} = 75 \text{ psf} \times (2.442) / 1000 = 0.00 \text{ kips}$

$M_{S3,LL3} = F_{S3,LL3} \times d_2 \times \left(1 - \frac{a}{L_p}\right) \times b$ (AAH710 26.14.2.4.1)

$= 0.00 \times 2 - 2.14 \text{ kips/ft}$

$f_f = \frac{M_{S3,LL3}}{W_{f,2}} = \frac{2.14}{850} = 0.0025 = 2.5 \text{ kips/ft}$
Construction Load Code Checks, Exterior Beams

Flange Lateral Bending Stress – $f_l$

- $f_l$: First-Order Analysis

\[ \text{Strength} \, V = \gamma_R (DC + OW) + 1.5(\text{CL}) + 1.35(\text{LL}) + 0.4(\text{WS}) \]

where $\gamma_R = 1.25$

- $f_l^u = 1.25\times2.15 + 1.5(0.25) + 1.35(0.34+0.48+1.36) + 0.4\times8.81$

- $f_l^u = 16.21 \text{ ksi}$

- $f_l = 16.18 \text{ ksi}$

- $f_l^u = 1.27 \times 16.21 = 20.85 \text{ ksi} \quad \text{ok} \quad 0.6\times60.0 = 36.0 \text{ ksi} \quad \text{ok}$

- $f_l$: Approximate Second-Order Analysis

[6.10.3.2.1] Check Flange Nominal Yielding

\[ \phi P_{nf} = 1 \times \phi P_{nf} \]

- $\phi = 1.0$

- $P_{nf} = \left( 12 + \frac{1}{2} \right) (9.3 - \frac{1}{2}) (12 + 2.13)$

- $\beta = 2 \times \phi P_{nf} / A_{nf}$

- $C_{nf} = 17.45 \text{ in}$ (Type I)

- $\sigma_{nf} = 34.95 - 17.45 = 17.45 \text{ in dia. flt.}$

- $A_{nf} = 9.48 \text{ in}^2$

- $\beta = 2 \times 17.45 / 9.48 = 3.66$

- $\rho = 50 / 50 = 1.0$

- $\sigma_{nf} = 1.0$

- $P_{nf} = 1.0 \times 1.0 = 1.0$

- $\phi P_{nf} = 1.0 \times 36.0 \text{ ksi}$

- $P_{nf} = 50.0 \text{ ksi}$

Strength $V$

- $f_l^u = 10.10 + 20.05 = 30.15 \text{ ksi} \quad < \quad 50.0 \text{ ksi} \quad \text{ok}$
Construction Load Code Checks, Exterior Beams

[6.10.3.2.1] Check Flexural Resistance

CHECK 6.10.3.2.1 - SECOND EQUATION - STRENGTH V

\[ f_{cu} = \frac{1.35 \times \psi F_{ct}}{\nu} \text{ (AASHTO 6.10.3.2.1-2)} \]

\[ \nu = 1.0 \text{ (AASHTO 6.10.3.2.1-2)} \]

Use the lesser of the \( F_{yw} \) values found from [AASHTO 6.10.8.2.2-1] and [6.10.8.2.3-1]

AASHTO 6.10.8.2.2-1

\[ F_{yw} = \frac{N_L R_y F_{yw}}{L_y} \text{ (AASHTO 6.10.8.2.2-1)} \]

or \( 1 - (1 - F_y) F_{yw} / (\lambda_x \lambda_y \lambda_w) F_{yw} R_y F_{yw} \)

where \( F_y = 0.75 \) ksi = 55 ksi

\[ N_L = 0.65 \text{ ksi} \]

\[ \lambda_x = 12.00 \text{ ksi} \]

\[ \lambda_y = 5.6 \text{ ksi} \]

\[ \lambda_w = 0.38 \text{ ksi} \]

\[ 0.56 \times (29,000 / 3000) / 0.5 = 9.2 > 7.6 \text{ : Use Eqn. 6.10.8.2.2-1} \]

\[ F_{yw} = 1.0 \times 0.65 \]

\[ = 50.00 \text{ ksi} \text{ (AASHTO 6.10.8.2.2-1)} \]

Construction Load Code Checks, Exterior Beams

[6.10.3.2.1] Check Flexural Resistance

**AASHTO 6.10.8.2.3-1**

\[ L_y = 20.50 \text{ ft} \]

\[ L_x = 6.64 \text{ ft} \]

\[ L_w = \frac{\pi^4 E I_y}{k_y} \text{ (AASHTO 6.10.8.2.3-3)} \]

\[ = 3.15 \times 10^{-11} \times 28,000 / 3000 \times 0.5 = 22.70 \text{ ft} \]

\[ F_{yw} = R_y F_{yw} \text{ (AASHTO 6.10.8.2.3-2)} \]

or \( 1 - (1 - F_y) F_{yw} / (\lambda_x \lambda_y \lambda_w) F_{yw} R_y F_{yw} \)

\[ \nu = 1.0 \times 0.65 \text{ ksi} \]

\[ \lambda_x = 50.0 \text{ ksi} \]

\[ \lambda_y = 1.0 \text{ ksi} \]

\[ \lambda_w = 22.70 \text{ ksi} \]

\[ 0.65 \times (29,000 / 3000) / 0.5 = 10.1 > 7.6 \text{ : Use Eqn. 6.10.8.2.2-2} \]

\[ F_{yw} = 1.0 \times 0.65 \]

\[ = 38.16 \text{ ksi} \text{ (AASHTO 6.10.8.2.3-2)} \]

Use \( F_{yw} \) Value of 38.16 ksi

\[ \psi F_{yw} = 1.0 \times 38.16 \]

\[ = 38.16 \text{ ksi} \]

\[ f_{yw} = 1 / 3 \times 16.16 \times 1 / 3 \times 20.65 = 23.0 \text{ ksi} < 38.1 \text{ ksi} \text{ (AASHTO 6.10.2.2-1-2)} \]
Construction Load Code Checks, Exterior Beams

[6.10.3.2.1] Check Web Bend Buckling

CHECK 6.10.3.2.1 - THIRD EQUATION

\[ f_{lw} \leq \frac{F_{lw}}{\sqrt{\gamma}} \]

\[ \gamma = 1.0 \]

\[ F_{lw} = 0.9F_{lw} \] (AASHTO 6.10.3.2.1-2)

\[ F_{lw} = 0.9F_{lw} \times D \]

\[ k = \frac{w(D)^2}{2(0.0654653)^2} = 36.60 \] (AASHTO 6.10.1.6.1-3)

or \[ F_{lw} = 0.9F_{lw} \times D \]

\[ = 277.4 \text{ ksi} \]

or \[ F_{lw} = 0.9F_{lw} \times D \]

\[ = 50.0 \text{ ksi} \]

or \[ F_{lw} = 0.9F_{lw} \times D \]

\[ = 71.4 \text{ ksi} \]

\[ \gamma F_{lw} = 1.0 \]

\[ = 50.0 \text{ ksi} \]

Strength V

\[ f_{lw} = 16.16 \text{ ksi} < 50.0 \text{ ksi} \text{ ok} \] (AASHTO 6.10.2.1-3)

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[6.10.3.2.2] Check Tension Flange Nominal Yielding

CHECK 6.10.3.2.2

Check provisions of [AASHTO 6.10.3.2.3] to see if tension flange satisfies requirements:

\[ f_{fl} = \frac{F_{fl}}{\sqrt{k}} \]

\[ \gamma = 1.0 \]

\[ F_{fl} = 1.0 \times 1.0 \times 50 = 50 \text{ ksi} \]

Conservatively use moments from compression flange loads for tension flange:

\[ M_{fl} = 10.39 \text{ k-ft} \]

\[ M_{fl} = 10.39 \text{ k-ft} \]

\[ f_{fl} = \frac{13.60}{18.61} = 8.61 \text{ ksi} \]

\[ M_{fl} = 3.40 \text{ k-ft} \]

\[ M_{fl} = 3.40 \text{ k-ft} \]

\[ f_{fl} = \frac{3.40}{12.60} = 2.57 \text{ ksi} \]

\[ M_{fl} = 0.54 \text{ k-ft} \]

\[ M_{fl} = 0.54 \text{ k-ft} \]

\[ f_{fl} = \frac{0.54}{12.60} = 0.39 \text{ ksi} \]

\[ M_{fl} = 8.68 \text{ k-ft} \]

\[ M_{fl} = 8.68 \text{ k-ft} \]

\[ f_{fl} = \frac{8.68}{12.60} = 0.69 \text{ ksi} \]

\[ M_{fl} = 2.14 \text{ k-ft} \]

\[ M_{fl} = 2.14 \text{ k-ft} \]

\[ f_{fl} = \frac{2.14}{12.60} = 0.17 \text{ ksi} \]

Do not apply amplification factor because vertical loads cause tension

\[ \gamma_{fl} = \gamma_{fl} \text{ (CC+OW) + 1.35(CLL) + 0.4(OW)} \]

\[ \gamma_{fl} = 1.25 \]

\[ \gamma_{fl} = \gamma_{fl} \text{ (CC+OW) + 1.35(CLL) + 0.4(OW)} \]

\[ \gamma_{fl} = 16.16 \text{ ksi} \]

\[ f_{fl} = \frac{32.37}{50 \text{ ksi}} \text{ ok} \] (AASHTO 6.10.2.2-3.0)
Construction Load Code Checks, Exterior Beams

Additional Checks Required

- [6.10.1.8] Check sections with holes in tension flanges
- [6.10.3.2.4] Check longitudinal stresses in concrete deck
- (6.10.3.3-1) Check shear in beams

Serviceability for Rotation Checks, Exterior Beams

Lateral Girder Rotation Check (Service I)

Check ensures while the deck is being sequentially poured, the exterior beam does not rotate, resulting in excessive overhang deflections.

The eccentric loads should be applied to the exterior beam to determine the amount of torsion each load causes.

Using the torsion, the horizontal forces in the top flange (causing deflection outward) and bottom flange (causing deflection inward) should be calculated.

Each flange is analyzed as a continuous beam over supports, where the supports are the diaphragms.
Serviceability for Rotation Checks, Exterior Beams

Lateral Girder Rotation Check (Service I)

The loads are applied to match the deck pour sequence, most likely with the concrete and screed machine starting on one end, with the other end virtually unloaded.

After the analysis, the inward deflection of the bottom flange and outward deflection of the top flange should be used to determine the rotation of the beam.

This rotation is directly related to the rotation of the coping as shown in IDM Figure 403-4D.

BLN limits the maximum delta of the coping to 0.20 inches.