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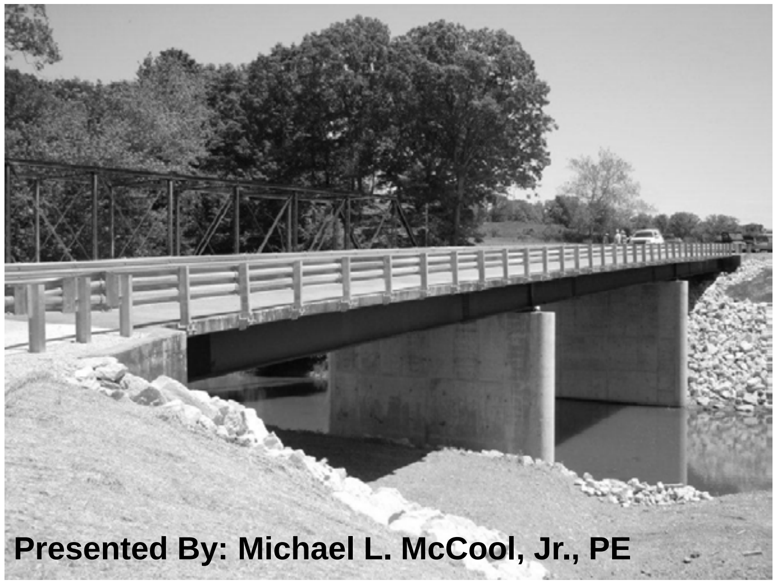
Construction Loading Example



Presented By: Michael L. McCool, Jr., PE

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Construction Loading Example

INDOT Design Policy

INDIANA DEPARTMENT OF TRANSPORTATION
Driving Indiana's Economic Growth

Design Memorandum No. 10-18
Policy Change

July 9, 2010

TO: **All Design, Operations, and District Personnel, and Consultants**

FROM: */s/ Anthony L. Uremovich*
Anthony L. Uremovich
Design Resources Engineer
Production Management Division

SUBJECT **Bridge Construction-Loads Considerations**

ADDS *Indiana Design Manual* **Section 60-3.10**

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.

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Construction Loading Example

IDM – Part 4, Chapter 403, Load Analysis & Application

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**

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Construction Loading Example

IDM – Part 4, Chapter 403, Load Analysis & Application

CONSTRUCTION LOADING

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

Deck Falsework Loads:	Designed for 15 lb/ft^2 for permanent metal stay-in-place deck forms, removable deck forms, and 2-ft exterior walkway.
Construction Live Load:	Designed for 20 lb/ft^2 extending 2 ft past the edge of coping and 75 lb/ft vertical force applied at a distance of 6 in. outside the face of coping over a 30-ft length of the deck centered with the finishing machine.
Finishing-Machine Load:	4500 lb distributed over 10 ft along the coping.
Wind Load:	Designed for 70 mph horizontal wind ~~loading of 50 lb/ft^2 in accordance with AASHTO *Guide Design Specifications for Bridge Temporary Works* (1995), Figure 2.1~~.

CONSTRUCTION-LOADINGS INFORMATION TO BE SHOWN ON GENERAL PLAN

Figure 403-4A

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Construction Loading Example

Construction Loads

Loads during construction are:

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

- **DC1 – Concrete = 150 lbs/ft^3**
- **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**

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Construction Loading Example

Construction Loads

Loads during construction are:

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**

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Construction Loading Example

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)

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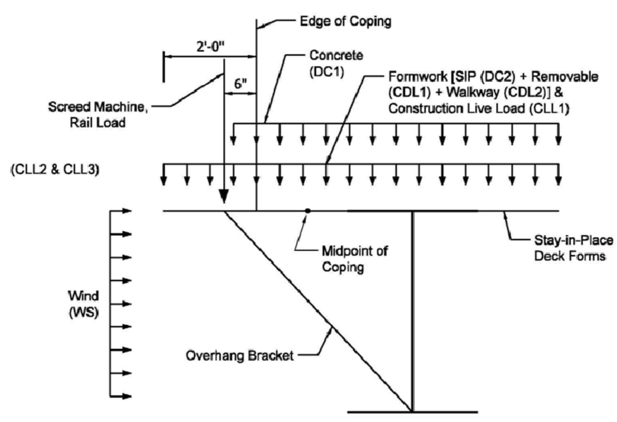
Construction Loading Example

IDM – Part 4, Chapter 403, Load Analysis & Application



CONSTRUCTION LOADS

Figure 403-4B

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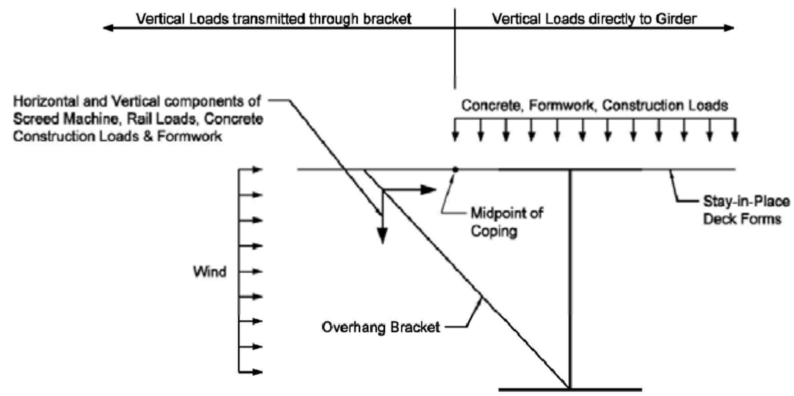
Construction Loading Example

IDM – Part 4, Chapter 403, Load Analysis & Application



CONSTRUCTION LOADS

Figure 403-4C

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Construction Loading Example

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)

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Construction Loading Example

IDM – Part 4, Chapter 407, Structural Steel

407-6.0 I-SECTIONS IN FLEXURE

<u>407-6.07 Constructability</u>

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.

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Construction Loading Example

IDM – Part 4, Chapter 407, Structural Steel

407-8.0 CONNECTIONS AND SPLICES

<u>407-8.01 Bolted Connections</u>

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

<u>407-8.03 Splices</u>

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

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Construction Loading Example

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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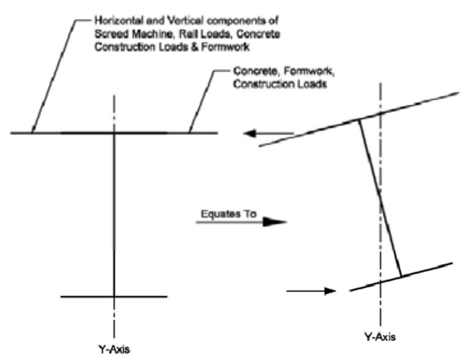
Construction Loading Example

Limit States

6 - Lateral Girder Rotation Check (Service I)



BEAM ROTATION

Figure 403-4D

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Construction Loading Example

Limit States

7 - Slip Critical Bolt Check (Service II)

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Construction Loading Example

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

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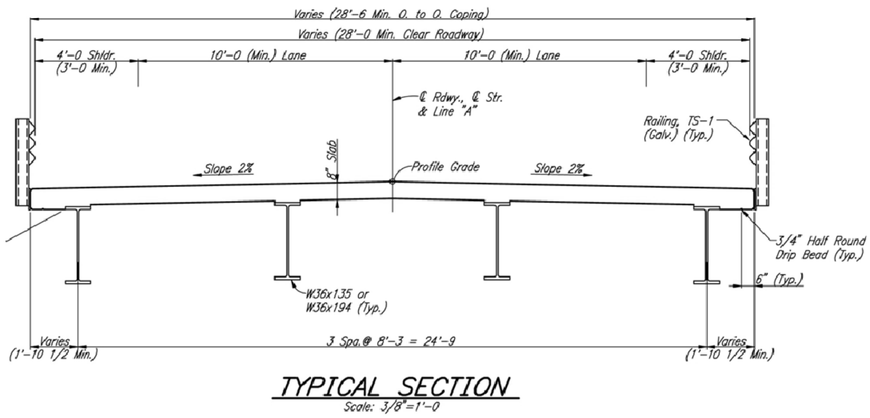
Construction Loading Example

Bridge Typical Section



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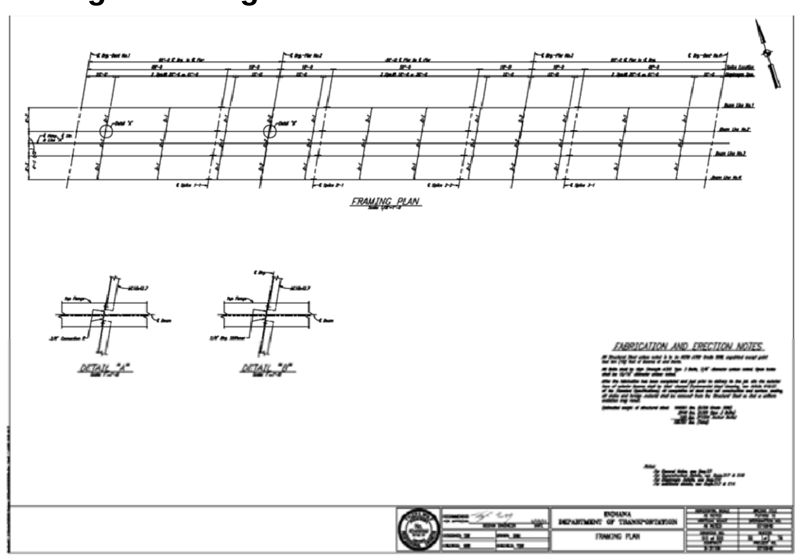
Construction Loading Example

Bridge Framing Plan



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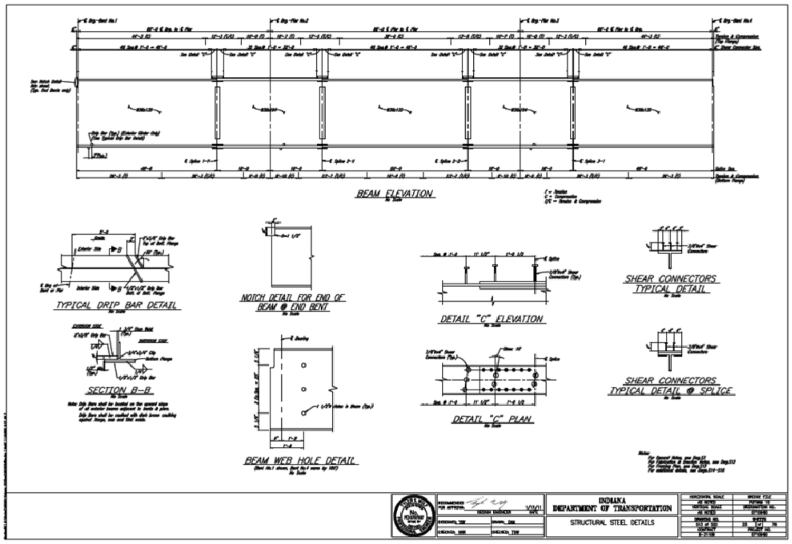
Construction Loading Example

Bridge Beam Elevation



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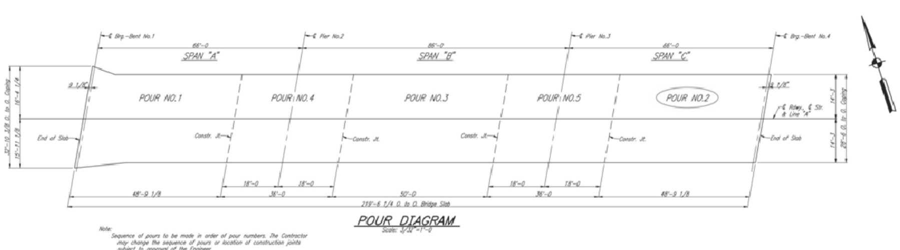
Construction Loading Example

Deck Pour Sequencing



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Construction Loading Example

Final Design Computations

INDEX (cont'd)

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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**

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Construction Loading Example

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

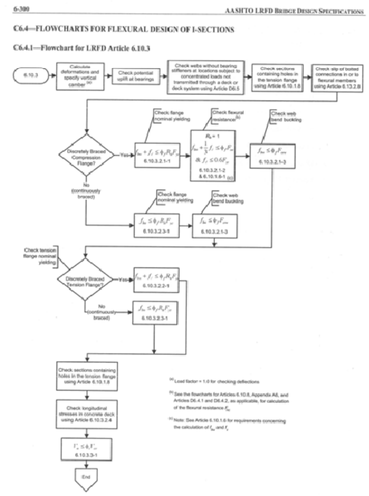

Figure C6.4.1-1—Flowchart for LRFD Article 6.10.3—Constructibility

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Construction Loading Example

Construction Load Code Checks, Interior Beams

Input - Construction Loading

INPUT

Thickness of Slab, t_s (inch) =	8	
Thickness of Fillet, t_{fillet} (inch) =	1.87	assumed average
Width of Fillet, b_{fillet} (feet) =	1.00	
Beam Spacing, s (feet) =	8	
No. of Beams, n =	4	
Out to Out Coping Width, OC (feet) =	28.5	
Weight of Permanent Deck Forms, W_{df} (psf) =	15	

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
WS = Wind Load on exposed height of the Structure (negligable for interior girders)
WCEL = Wind Load on screed machine (negligable)

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Construction Loading Example

Construction Load Code Checks, Interior Beams

Applied Construction Loading

OUTPUT

NON-COMPOSITE DEAD LOADS (PER GIRDER)

SLAB: $(s)*(t_s)*(1'/12")*(150\ pcf)$ =	800 plf
FILLET: $(b_{fillet})*(t_{fillet})*(1'/12")*(150\ pcf)$ =	23 plf
DECK FORMS: $(s-b_{fillet}+1')*(W_{df})$ =	120 plf

NON-COMPOSITE CONSTRUCTION LIVE LOADS

DISTR CONSTR LL, CLL: (OC+2*2')*(20 PSF) / n =	163 plf over 30' of deck length

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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
Arbitrary Uniform Loads (Data Type:11012)		
Slab =	0.8	klf
Fillet =	0.023	klf
DC1 = Slab and Fillet =	**0.82**	klf *
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

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Construction Loading Example

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 Forms*(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

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Construction Loading Example

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**

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Construction Loading Example

Construction Load Code Checks, Interior Beams

Dead Load Deflections

TABLE 0.0.10.1 SLAB LOAD DEFINITION

LOAD IDENTIFICATION: LOAD NO	POUR NO	DESCRIPTION	SLAB DESIGN DEPTH: INITIAL (in)	SLAB DESIGN DEPTH: FINAL (in)	POUR DAY	MODULAR RATIO: N1=3n N1	MODULAR RATIO: N2=n N2	SLAB LOAD DATA: INTENSITY (k/ft)	POSITION FROM (ft)	POSITION TO (ft)
1	1	Pour 1	0.0	7.5	1	24.0	8.0	0.94	0.00	48.00
2	2	Pour 2	0.0	7.5	7	24.0	8.0	0.94	170.00	218.00
3	3	Pour 3	0.0	7.5	14	24.0	8.0	0.94	84.00	134.00
4	4	Pour 4	0.0	7.5	21	24.0	8.0	0.94	48.00	84.00
5	5	Pour 5	0.0	7.5	28	24.0	8.0	0.94	134.00	170.00

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Construction Loading Example

Construction Load Code Checks, Interior Beams

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**

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Construction Loading Example

Construction Load Code Checks, Interior Beams

Deck – Slab Tension Check

TABLE 1.1.5.1A=MOMENTS AND ACCUMULATED STRESSES FOR POUR NO = 3 (UNFACTORED)

f < 0.43 ksi, (+) is tension

SP NO	IN NO	ID NO	D L	FROM SUPT (ft)	DEAD LOAD MOMENT (k-ft)	ACCUMULATED STRESSES, (ksi) & DEFLECTION (in.) TOP CONC.	TOP STEEL	BOT. STEEL	DEFL.
1	0	1		0.00	0.0	0.00	0.00	0.00	0.0000
1	1	1		3.30	-22.0	0.01	-2.84	2.57	-0.1940
1	2	1		6.60	-44.1	0.02	-5.30	4.76	-0.3799
1	3	1		9.90	-66.1	0.03	-7.38	6.55	-0.5506
1	4	1		13.20	-88.1	0.04	-9.07	7.97	-0.7002
1	5	1		16.50	-110.2	0.05	-10.37	9.00	-0.8241
1	6	1		19.80	-132.2	0.06	-11.29	9.64	-0.9186
1	7	1		23.10	-154.2	0.07	-11.83	9.90	-0.9813
1	8	1		26.40	-176.3	0.09	-11.98	9.77	-1.0112
1	9	1		29.70	-198.3	0.10	-11.74	9.25	-1.0081
1	10	1		33.00	-220.3	0.11	-11.12	8.35	-0.9732
1	11	1		36.30	-242.4	0.12	-10.12	7.07	-0.9088
1	12	1		39.60	-264.4	0.13	-8.73	5.40	-0.8184
1	13	1		42.90	-286.4	0.14	-6.95	3.34	-0.7066
1	14	1		46.20	-308.5	0.15	-4.79	0.90	-0.5792
1	15	2		49.50	-330.5	0.00	2.64	-2.64	-0.4443
1	16	2		52.80	-352.5	0.00	4.64	-4.65	-0.3157

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Construction Loading Example

Construction Load Code Checks, Interior Beams

Service II Loading for Slip Critical Checks

Check Slip Critical Bolts @ Service II (Construction Loads) *[AASHTO 6.10.3]*

Divide Flange Force Equally between inner & outer plates per AASHTO 6.13.6.1.4c

$P_{u\,bf}/2 = 9.7$ kips

$R_n = K_h K_s N_s P_t$ (AASHTO 6.13.2.8-1)

$K_h = 1.0$ $K_s = 0.5$ $P_t = 39.0$ kips

$R_n = 19.5$ kips

$N_{bolts\,Req'd} = P_{u\,bf}/R_n$

$N_{bolts\,Req'd} = 0.5$ Bolts < $N_{bolts\,Prov'd} =$ 14 Bolts **OK**

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

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

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

Input for Construction Loading

INPUT

Thickness of Slab, t_s (inch) =	8	
Thickness of Fillet, t_{fillet} (inch) =	1.87	assumed average
Width of Fillet, b_{fillet} (feet) =	1.00	
Beam Spacing, s (feet) =	8.25	
Overhang, oh (feet) =	1.833	
Additional Overhang Thickness, oht (in) =	2.01	
Weight of Permanent and Removable Deck Forms, W_{df} (psf) =	15	
Weight of Temporary Walkway, $W_{wlkwy-1}$ (psf) =	15	
Vertical Railing and Walkway Load, $W_{wlkwy-2}$ (plf) =	75	

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 railing, walkway
CLL = Construction Live Load such as Screed Machine and Workers
WS = Wind Load on exposed height of the Structure (negligable for interior girders)
WCEL = Wind Load on screed machine (negligable)

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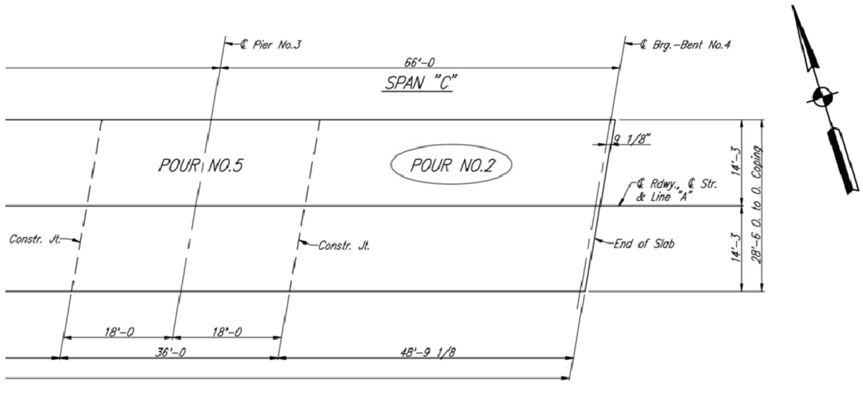
Construction Loading Example

Deck Pour Sequencing



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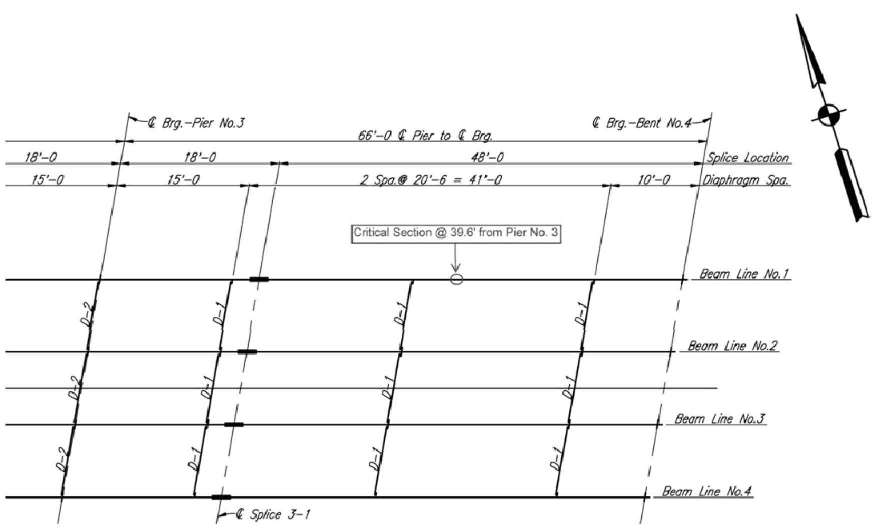
Construction Loading Example

Bridge Framing Plan



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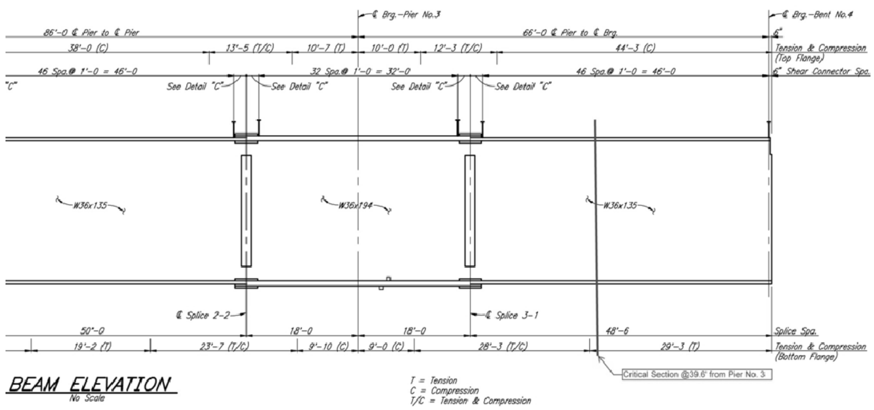
Construction Loading Example

Steel Beam Elevation



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Construction Loading Example

Construction Load Code Checks, Exterior Beams

Applied Construction Loading

OUTPUT

NON-COMPOSITE DEAD LOADS (PER GIRDER)

DC1	SLAB: $(t_s)*(1'/(2*s*12"))*(150\ pcf)*(s+oh)^2$ =	616 plf
DC1	FILLET: $(b_{mx})*(t_{fillet})*(1'/12")*(150\ pcf)$ =	23 plf
DC1	OVERHANG: (150 pcf)*(oh)*(oht)*(1/12)*(1/(2*s))*(2*s+oh) =	51 plf
DC2	DECK FORMS: $(1/2)*(s)*(W_{df})$ =	62 plf
CDL1	REMOVABLE COPING DECK FORMS: $(oh)*(W_{cf})$ =	27 plf
CDL2	TEMP SCREED RAIL AND WALKWAY: $(W_{wkwy-1}*2')$ =	30 plf

NON-COMPOSITE CONSTRUCTION LIVE LOADS

CLL1	DISTR CONSTR LL: (s/2+oh+2')*(20 psf) =	159.2 plf over 30' of deck length
CLL2	FINISHING MACHINE LL : (4500 lbs / 10') =	450 plf for 10 feet
CLL3	VERTICAL RAILING AND WALKWAY LOAD : (W_{wkwy-2}) =	75 plf over 30' of deck length

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

Applied Construction Loading – Strength V

INPUT FOR MERLIN-DASH - STRENGTH V - 1.25(DC+DW)+1.5(CDL)+1.35(CLL)+0.4(WS)+ (WCEL)

Slab Loads (Data Type:10012)		
DC1 = Deck Forms =	**0.06**	klf over full str length
Arbitrary Uniform Loads (Data Type:11012)		
Slab =	0.62	klf
Fillet =	0.02	klf
Overhang =	0.05	klf
DC1 = Slab and Fillet =	**0.69**	klf *
Arbitrary Uniform Loads (Data Type:11012)		
Removable Coping Deck Forms = CDL1* 1.5/1.25 =	0.03	
Temp Screed rail and Walkway = CDL2*1.5/1.25 =	0.04	
Constr. Dead Load = CDL =	**0.07**	klf over full str length
Distr Constr. Live Load = CLL1*(1.35/1.25) =	**0.17**	klf over 30' of str length *
Screed Constr. Live Load = CLL2*(1.35/1.25) =	**0.49**	klf over 10' of str length *
Vertical Railing 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

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

Input Properties

Construction Loading **X = 39.6**

Input
Analyzed Section

b_{fc} =	12.00 in	D =	34.92 in	b_{ft} =	12.00 in	E =	29000 ksi
t_{fc} =	0.79 in	t_w =	0.6000 in	t_{ft} =	0.790 in	t_{slab} =	8.00 in
F_{yc} =	50 ksi	F_{yw} =	50 ksi	F_{yt} =	50 ksi	Haunch =	1.37 in

Unbraced Length (L_b) =	20.50 ft	v_0 =	8.20	*[AASHTO T.3.8.1.1-1]*
Location of Critical Section =	39.60 ft	Z_0 =	0.23	*[AASHTO T.3.8.1.1-1]*
Span Length (L) =	66.00 ft	Vertical Clearance =	23.00 ft	
Bridge Simple or Cont. =	Cont.	Wind Pressure (P_B) =	25 psf	
Overhang Width (S_{ovr}) =	1.8750 ft	Number of Beams =	4	

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

Input from Merlin-Dash

Moments

Strength I *[M-Dash T.2.2.5.4]*
Factored Vertical Moment at Critical = 621.9 k-ft
Moment at Lt. Bracing Point (M_a) = 600.2 k-ft
Moment at Rt. Bracing Point (M_b) = 362.2 k-ft
M at Mid. of Unbraced Length (M_b) = 579.6 k-ft

Strength III
Factored Vertical M at Critical = 434.5 k-ft
M at Lt. Bracing Point (M_a) = 422.9 k-ft
M at Rt. Bracing Point (M_b) = 197.9 k-ft
M at Mid. of Unbraced Len. (M_b) = 411.2 k-ft

Strength IV
Factored Vertical M at Critical = 523.1 k-ft
M at Lt. Bracing Point (M_a) = 509.0 k-ft
M at Rt. Bracing Point (M_b) = 327.4 k-ft
M at Mid. of Unbraced Len. (M_b) = 495.6 k-ft

Strength V
Factored Vertical M at Critical = 603.3 k-ft
M at Lt. Bracing Point (M_a) = 582.6 k-ft
M at Rt. Bracing Point (M_b) = 353.2 k-ft
M at Mid. of Unbraced Len. (M_b) = 563.0 k-ft

[M-Dash T.2.2.4.1]
S_{xc} for Lt. Section = 438.3 in^3
S_{xc} for Rt. Section = 438.3 in^3
S_{xc} for Mid. Section = 438.3 in^3

Dist. To Section Change Point = (From Small Moment)

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

Beam Properties

Beam Height = 0.79+34.92+0.79 = 36.50 in

	A (in^2)	Y (in) (from top)	AY (in^3)	d (in)	I (in^4)	Ad^2 (in^4)
Top Flange	9.48	0.40	3.7	17.86	0.5	3022.2
Web	20.95	18.25	382.4	0.00	2129.1	0.0
Bot. Flange	9.48	36.11	342.3	17.86	0.5	3022.2
	39.91		728.39		2130.1	6044.5

$y_{bar} = \sum AY/\sum A =$ 728.39/39.91 = 18.25 in

I = 2,130.1+6,044.5 = 8174.5 in^4

$S_{fc} = bh^2/6 =$ 0.79*12.00^2/6 = 18.96 in^3

$S_{xc} = I/y =$ 8,174.5/18.25 = 447.9 in^3

$S_{xt} = I/y =$ 8,174.5/(36.50-18.25) = 447.9 in^3

$S_{ft} = bh^2/6 =$ 0.79*12.00^2/6 = 18.96 in^3

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

Flange Compressive Stress – f_{bu}

Determine f_{bu}

Strength I

$f_{bu\text{-}comp}$ = M*12/S_{xc} = 621.9*12/447.9 = 16.66 ksi

$f_{bu\text{-}tens}$ = M*12/S_{xt} = 621.9*12/447.9 = 16.66 ksi

Strength III

$f_{bu\text{-}comp}$ = M*12/S_{xc} = 434.5*12/447.9 = 11.64 ksi

$f_{bu\text{-}tens}$ = M*12/S_{xt} = 434.5*12/447.9 = 11.64 ksi

Strength IV

$f_{bu\text{-}comp}$ = M*12/S_{xc} = 523.1*12/447.9 = 14.01 ksi

$f_{bu\text{-}tens}$ = M*12/S_{xt} = 523.1*12/447.9 = 14.01 ksi

Strength V

$f_{bu\text{-}comp}$ = M*12/S_{xc} = 603.3*12/447.9 = 16.16 ksi

$f_{bu\text{-}tens}$ = M*12/S_{xt} = 603.3*12/447.9 = 16.16 ksi

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

First-order versus Second-order analysis

Determine if geometry satisfies provisions of [AASHTO 6.10.1.6]:

$L_b \leq$ 1.2*L_p*[C_b*R_b/(f_{bu}/F_{yc})]$^{0.5}$ *(AASHTO 6.10.1.6-2)*

L_p:

L_p = 1.0r_t*(E/F_{yc})$^{0.5}$ *(AASHTO 6.10.8.2.3-4)*

where: r_t = b_{fc}/[12*(h/d+1/3*$D_c t_w D^2$/(b_{fc}*t_{fc}*h*d))]$^{0.5}$ *(AASHTO C6.10.8.2.3-1)*

where: D_c = 18.25-0.79 = 17.46 in

h = 0.79/2+34.92+0.79/2 = 35.71 in

r_t = 12.00/[12*(35.71/36.50+1/3*17.46*0.60*34.92^2/(12.00*0.79*35.71*36.50))]^0.5

r_t = 3.01 in

L_p = 1.0*3.01*(29,000/50)^0.5

= **72.53 in**

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

First-order versus Second-order analysis

R_b:

* Section is not composite yet [AASHTO 6.10.1.10.2]
* No longitudinal Stiffeners are provided

$2D_c/t_w \le \lambda_{rw}$ (AASHTO 6.10.1.10.2-2)

$\lambda_{rw} = 5.7*(E/F_{yc})^{0.5}$ (AASHTO 6.10.1.10.2-4)

= 5.7*(29,000/50)^0.5

= 137.3

$2D_c/t_w$ = 2*17.46/0.60 = 58.2 < 137.3

$R_b = 1-[(a_{wc})/(1200+300*a_{wc})][(2D_c/t_w)-\lambda_{rw}]\le 1.0$ (AASHTO 6.10.1.10.2-3)

$a_{wc} = 2D_ct_w/b_{fc}t_{fc}$ (AASHTO 6.10.1.10.2-5)

= 2*17.46*0.60/12.00/0.79

= 2.21

R_b = 58.2 < 137.3 - Use Rb = 1.00

= **1.00**

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

First-order versus Second-order analysis

Strength V

C_b:

$C_b = 1.75-1.05(f_1/f_2)+0.3(f_1/f_2)^2 \le 2.3$ (AASHTO 6.10.8.2.3-7)

where: f_2 = 582.6*12/438.3

= 15.95 ksi **<------ Controls** f_2 = 15.95 ksi

or = 353.2*12/438.3

= 9.67 ksi

$f_1 = 2f_{mid} - f_2 \ge f_0$ (AASHTO 6.10.8.2.3-11)

where: f_{mid} = 563.0*12/438.3

= 15.41 ksi (adjusted for sign)

f_0 = 9.67 ksi (adjusted for sign)

f_1 = 14.88 ksi **<----- Controls for f1**

f_{mid}/f_2 = 15.41/15.95 = 0.97

0.97<=1.0, Equation 6.10.8.2.3-7 is valid

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

First-order versus Second-order analysis

C_b = 1.75-1.05*(14.88/15.95)+0.3*(14.88/15.95)^2
= 1.03 **<------ Controls**
or = 2.30

C_b = **1.03**

Lb:

$L_b \le$ $1.2*L_p*[C_b*R_b/(f_{bu}/F_{yc})]^{0.5}$ *(AASHTO 6.10.1.6-2)*
= 1.2*72.5*[1.03*1.00/(16.16/50)]^0.5/12
= 13.0 ft < 20.50 ft

Use Amplification Factor from AASHTO 6.10.1.6

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

First-order versus Second-order analysis

Amplification Factor

Strength V
Amplification Factor (A): Accounts for second order effects from lateral bending stress.

$A = 0.85/(1-f_{bu}/F_{cr}) \ge 1.0$ *(AASHTO 6.10.1.6-4)*

F_{cr}:

$F_{cr} = C_b*3.14^2*E/(L_b/r_t)^2*[1+0.078*J/(S_{xc}*h)*(L_b/r_t)^2]^{0.5}$ **(AASHTO A6.3.3-8)*

*Eqn. can only be used when web is compact or non compact

where: C_b = 1.03
E = 29000 ksi
L_b = 20.50' * 12 = 246.0 in
r_t = 3.01 in
S_{xc} = 447.92 in^3 h = 35.71 in

$J = Dt_w^3/3+b_{fc}t_{fc}^3/3(1-0.63t_{fc}/b_{fc})+b_{ft}t_{ft}^3/3(1-0.63t_{ft}/b_{ft})$ *(AASHTO A6.3.3-9)*
= 34.92*0.60^3/3+12.00*0.79^3/3*(1-0.63*0.79/12.00)+12.00*0.79^3/3*(1-0.63*0.79/12.00)
= 6.29 in^4

F_{cr} = 48.58 ksi

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

First-order versus Second-order analysis

Amplification Factor

Or use AASHTO 6.10.8.2.3-8

$F_{cr} = C_b * R_b * 3.14^2 * E/(L_b/r_t)^2 =$ 1.03*1.00*3.14^2*29,000/(20.50*12/3.01)^2
= 44.26 ksi

F_{cr} = **48.58 ksi**

A = 0.85/(1-16.16/48.58)
= **1.27**

Bracing Length exceeds allowable range, Amplification Factor = 1.27

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

Flange Lateral Bending Stress – f_ℓ

Determine f_l - Flange Lateral Bending Stress

Wind *[AASHTO 6.10.3.2.1]*

Calculate Wind Load *[AASHTO 4.6.2.7]*

Wind Pressure

$P_D = P_B * V_{dz}^2/10000$ *(AASHTO 3.8.1.2.1-1)*

P_B = 25.0 psf *(AASHTO T.3.8.1.2.1-1)*

$V_{DZ} = 2.5 * v_o * v_{30}/v_b * \ln(z/z_o)$ *(AASHTO 3.8.1.1-1)*

v_{30} = 70 mph — Use 70 mph per AASHTO Guide Design Specs *[AASHTO 3.8.1.1]*

v_b = 100 mph — for Bridge Temporary Works *[AASHTO 3.8.1.1]*

z = 23.0+(36.50+1.37+8.00)/12
= 26.82 ft < 30.0 ft

V_{DZ} = 70.0 mph
= 70.0 mph

P_D = 25.0/1000*70.0^2/10000
= 0.012 ksf

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

Flange Lateral Bending Stress – f_ℓ

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

$M_w = wL_b^2/10 + w*x/2/N_b*(L-x)*\alpha$ *(AASHTO C4.6.2.7.1-3)*

h_{exp} = (36.50+1.37+8.00)/12 = 3.82 ft

w = 0.012*3.82

= 0.05 k/ft < 0.30 k/ft *70²/100² = 0.15 k/ft Use 0.15 k/ft *[AASHTO 3.8.1.2.1]*

Proportion wind load using lever rule onto top and bottom flange

w_c = 0.15*(3.82/2-0.79/2/12)/(0.79/2+34.92+0.79/2)*12

0.09 k/ft

α = 0.8 for continuous bridges

M_{wc} = 0.09*20.50^2/10+0.09*39.60/2/4*(66.0-39.60)*0.8

= 13.6 k-ft

$f_{\ell\text{-wind}} = M_{wc}/S_c*12$

= 13.6*12/19.0

= **8.61 ksi**

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

Flange Lateral Bending Stress – f_ℓ

<u>**Construction Loads**</u>

Based on AASHTO C6.10.1.6, Flanges act elastically

Geometry of overhang

x = 1.875+0.5 = 2.4 ft

y = 2.9 ft

Horizontal Component = 2.4/2.9

Concrete - DC1

$\gamma_{conc.}$ = 150 pcf (For wet concrete)

$F_{\ell\text{-DC1}}$ = [8.00+(1.37+0.79)]/12*(150/1000)*1.88/2*(2.4/2.9) = 0.10 k/ft

$M_{\ell\text{-DC1}} = F_\ell L_b^2/12$ = 0.10*20.50^2/12 *(AASHTO C6.10.3.4-2)*

= 3.40 k-ft

$f_{\ell\text{-DC1}} = M_{\ell\text{-DC1}}/S_c*12$ = 3.40*12/19.0

= **2.15 ksi**

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

Flange Lateral Bending Stress – f_ℓ

Exterior Forms - CDL1

w = 15 psf

$F_{l\text{-}CDL1}$ = 1.88/2*15 psf (2.4/2.9)/1000 = 0.01 k/ft

$M_{l\text{-}CDL1} = F_l L_b^2/12$ = 0.01*20.50^2/12 *(AASHTO C6.10.3.4-2)*

= 0.40 k-ft

$f_{l\text{-}CDL1} = M_{l\text{-}CDL1}/S_c$*12 = 0.40*12/19.0

= **0.25 ksi**

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

Flange Lateral Bending Stress – f_ℓ

Construction Loads - CLL1

Constr. Loads = 20 psf (Distributed over 30', centered on screed machine)

$F_{l\text{-}CLL}$ = 20/1000*1.88/2*(2.4/2.9)

= 0.02 k/ft

$M_{l\text{-}CLL} = F_{l\text{-}CLL} L_b^2/12$ = 0.02*20.50^2/12 (Assume bracing length < 30') *(AASHTO C6.10.3.4-2)*

= 0.54 k-ft

$f_{l\text{-}CLL} = M_{l\text{-}CLL}/S_c$*12

= 0.54*12/19.0

= **0.34 ksi**

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

Flange Lateral Bending Stress – f_ℓ

Finishing Machine - CLL2

Screed = 450 plf (Distributed over 10')

$F_{l\text{-}CLL2}$ = 450/1000*(2.4/2.9)
= 0.37 k/ft

$M_{l\text{-}CLL2} = F_{l\text{-}CLL2} {}^* L_b^2/12{}^*[1-6{}^*(a/L_b)^2+4{}^*(a/L_b)^3]$

Assumes Lb > 10' (otherwise b = Lb) and that critical point in question is at center of bracing

a = 5.3 ft b = 10.0 ft

= 0.37*20.5^2/12*[1-6*(5.25/20.50)^2+4*(5.25/20.50)^3]
= 8.66 k-ft

$f_{l\text{-}CLL2} = M_{l\text{-}CLL2}/S_c{}^*12$
= 8.66*12/19.0
= **5.48 ksi**

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

Flange Lateral Bending Stress – f_ℓ

Screed Rail and Walkway - CLL3

w = 75 plf (From AASHTO Guide Design Specs for Bridges ('95) 2.2.3.1)

$F_{l\text{-}CLL3}$ = 75 plf (2.4/2.9)/1000 = 0.06 k/ft

$M_{l\text{-}CLL3} = F_l L_b^2/12$ = 0.06*20.50^2/12 *(AASHTO C6.10.3.4-2)*
= 2.14 k-ft

$f_{l\text{-}CLL3} = M_{l\text{-}CLL3}/S_c{}^*12$ = 2.14*12/19.0
= **1.36 ksi**

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

Flange Lateral Bending Stress – f_ℓ

f_{l1} - First order Analysis

[AASHTO 3.4.2, T.3.4.1-1 & T.3.4.1-2]

Strength V = γ_p(DC+DW) + 1.5(CDL) + 1.35(CLL) + 0.4(WS) where γ_p = 1.25

f_{l1}^V = 1.25*2.15 + 1.5*(0.25) + 1.35*(0.34+5.48+1.36) + 0.4*8.61

= **16.21 ksi**

f_{bu} = **16.16 ksi**

f_l - Approximate Second Order Analysis (AASHTO 6.10.1.6-4)

f_L = A*f_{l1}

(AASHTO 6.10.1.6-1)

f_L^V = 1.27 * 16.21 = **20.65 ksi** < 0.6*F_{yc} = 0.6*50.0 = **30.00 ksi** ok

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

[6.10.3.2.1] Check Flange Nominal Yielding

CHECK 6.10.3.2.1 - FIRST EQUATION

$f_{bu} + f_l \leq \varphi_f R_h F_{yc}$ (AASHTO 6.10.3.2.1-1)

φ_f = 1.0 [AASHTO 6.4.2]

R_h = [12+β*(3*ρ-ρ^3)]/(12+2*β) (AASHTO 6.10.1.10.1-1)

β = 2*$D_n t_w / A_{fn}$ (AASHTO 6.10.1.10.1-2)

D_n = 17.46 in (Top Fl.)

or = 34.92-17.46 = 17.46 in (Bot. Fl)

A_{fn} = 9.48 in²

β = 2*17.46*0.60/9.48

= 2.21

ρ = 50/50 = 1.0 <----- **Controls**

or = 1.0

R_h = [12+2.21*(3*1.0-1.0^3)]/(12+2*2.21)

= 1.00

$\varphi_f R_h F_{yc}$ = 1.0*1.0*50

= **50.0 ksi**

Strength V

$f_{bu} + f_l$ = 16.16+20.65 = **36.8 ksi** < **50.0 ksi** **ok** (AASHTO 6.10.3.2.1-1)

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

[6.10.3.2.1] Check Flexural Resistance

CHECK 6.10.3.2.1 - SECOND EQUATION - STRENGTH V

$f_{bu} + 1/3f_l \leq \varphi_f F_{nc}$ *(AASHTO 6.10.3.2.1-2)*

$\varphi_f = 1.0$ *[AASHTO 5.4.2]*

Use the lesser of the F_{nc} values found from [AASHTO 6.10.8.2.2-1] and [6.10.8.2.3-1]

AASHTO 6.10.8.2.2-1

$F_{nc} = R_bR_hF_{yc}$ <-------**Controls** *(AASHTO 6.10.8.2.2-1)*

or $= [1-(1-F_{yr}/R_h/F_{yc})(\lambda_f-\lambda_{pf})/(\lambda_{rf}-\lambda_{pf})]R_bR_hF_{yc}$ *(AASHTO 6.10.8.2.2-2)*

where: F_{yr} = 0.7*50 = 35 ksi <-------**Controls**

or = F_{yw} = 50 ksi

or = 0.5*50 = 25 ksi

$\lambda_f = b_{fc}/2t_{fc}$ *(AASHTO 6.10.8.2.2-3)*

= 12.00/2/0.79 = 7.6

$\lambda_{pf} = 0.38*(E/F_{yc})^{0.5}$ *(AASHTO 6.10.8.2.2-4)*

0.38*(29,000/50)^0.5 = 9.2

$\lambda_{rf} = 0.56*(E/F_{yr})^{0.5}$ *(AASHTO 6.10.8.2.2-5)*

0.56*(29,000/35)^0.5 = 16.1

9.2 > 7.6 : Use Eqn. 6.10.8.2.2-1

F_{nc} = 1.0*1.0*50 *(AASHTO 6.10.8.2.2-1)*

= **50.00 ksi**

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

[6.10.3.2.1] Check Flexural Resistance

AASHTO 6.10.8.2.3-1

L_b = 20.50 ft

L_p = 6.04 ft

$L_r = \pi r_t(E/F_{yr})^{0.5}$ *(AASHTO 6.10.8.2.3-5)*

= 3.14*3.01/12*(29,000/35)^0.5 = 22.70 ft

$F_{nc} = R_bR_hF_{yc}$ *(AASHTO 6.10.8.2.3-1)*

or $= C_b[1-(1-F_{yr}/R_h/F_{yc})(L_b-L_p)/(L_r-L_p)]R_bR_hF_{yc}$ <-------**Controls (Lp<Lb<Lr)** *(6.10.8.2.3-2)*

or $= F_{cr} = C_b*R_b*3.14^2*E/(L_b/r_t)^2$ *(AASHTO 6.10.8.2.3-3)*

F_{nc} = 1.03[1-(1-35/1.0/50)*(20.50-6.04)/(22.70-6.04)]*1.0*1.0*50

= 38.15 ksi < $R_bR_hF_{yc}$ = 1.0*1.0*50 = 50.0 ksi

F_{nc} = **38.15 ksi**

Use a F_{nc} Value of 38.15 ksi

$\varphi_f F_{nc}$ = 1.00*38.15

= 38.1 ksi

$f_{bu} + 1/3*f_l$ = 16.16+ 1/3*20.65 = **23.0 ksi** < **38.1 ksi** **ok** *(AASHTO 6.10.3.2.1-2)*

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

[6.10.3.2.1] Check Web Bend Buckling

CHECK 6.10.3.2.1 - THIRD EQUATION

$f_{bu} \leq \varphi_f F_{crw}$ *(AASHTO 6.10.3.2.1-3)*

$\varphi_f = 1.0$ *[AASHTO 6.5.4.2]*

$F_{crw} = 0.9 \cdot E \cdot k/(D/t_w)^2 \quad \leq R_h F_{yc}$ or $F_{yw}/0.7$ *(AASHTO 6.10.1.9.1-1)*

$k = 9/(D_c/D)^2$ *(AASHTO 6.10.1.9.1-2)*

$= 9/(17.46/34.92)$^2 = 36.00

$F_{crw} = 0.9 \cdot 29{,}000 \cdot 36.00/(34.92/0.60)$^2

= 277.4 ksi

or $R_h F_{yc} = 1.00 \cdot 50$ = 50.0 ksi **<--------Controls**

or $F_{yw}/0.7 = 50/0.7$ = 71.4 ksi

$\varphi_f F_{crw} = 1.0 \cdot 50$

= 50.0 ksi

Strength V

f_{bu} = **16.16 ksi** < **50.0 ksi** **ok** *(AASHTO 6.10.3.2.1-3)*

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Construction Loading Example

Construction Load Code Checks, Exterior Beams

[6.10.3.2.2] Check Tension Flange Nominal Yielding

CHECK 6.10.3.2.2

Check provisions of [AASHTO 6.10.3.2.2] to see if tension flange satisfies requirements.

$f_{bu} + f_l \leq \varphi_f R_h F_{yt}$ *(AASHTO 6.10.3.2.2-1)*

$\varphi_f = 1.0$

$\varphi_f R_h F_{yt} = 1.00 \cdot 1.00 \cdot 50$ = **50 ksi**

Conservatively use moments from compression flange loads for tension flange.

S_{xt} = 18.96 in^3

M_{wc} =	13.60 k-ft	->	f_{wc} = 13.6*12/18.96	=	8.61 ksi
$M_{l\text{-}DC1}$ =	3.40 k-ft	->	$f_{l\text{-}DC1}$ = 3.4*12/18.96	=	2.15 ksi
$M_{l\text{-}CDL1}$ =	0.40 k-ft	->	$f_{l\text{-}CDL1}$ = 0.4*12/18.96	=	0.25 ksi
$M_{l\text{-}CLL1}$ =	0.54 k-ft	->	$f_{l\text{-}CLL1}$ = 0.5*12/18.96	=	0.34 ksi
$M_{l\text{-}CLL2}$ =	8.66 k-ft	->	$f_{l\text{-}CLL2}$ = 8.7*12/18.96	=	5.48 ksi
$M_{l\text{-}CLL3}$ =	2.14 k-ft	->	$f_{l\text{-}CLL3}$ = 2.1*12/18.96	=	1.36 ksi

Do not apply amplification factor because vertical loads cause tension

[AASHTO 3.4.2, T.3.4.1-1 & T.3.4.1-2]

Strength V = γ_p(DC+DW) + 1.5(CDL) + 1.35(CLL) + 0.4(WS) where γ_p = 1.25

f_{l1}^V = 1.25*2.15 + 1.5*(0.25) + 1.35*(0.34+5.48+1.36) + 0.4*8.61

= 16.21 ksi

f_{bu} = 16.16 ksi

$f_{bu} + f_l$ = **32.37 ksi** < **50 ksi** **ok** *(AASHTO 6.10.3.2.2-1)*

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Construction Loading Example

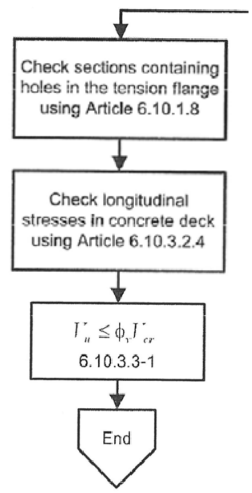
Construction Load Code Checks, Exterior Beams

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



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Construction Loading Example

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.

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Construction Loading Example

Serviceability for Rotation Checks, Exterior Beams

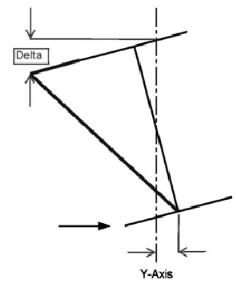
Lateral Girder Rotation Check (Service I)

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.



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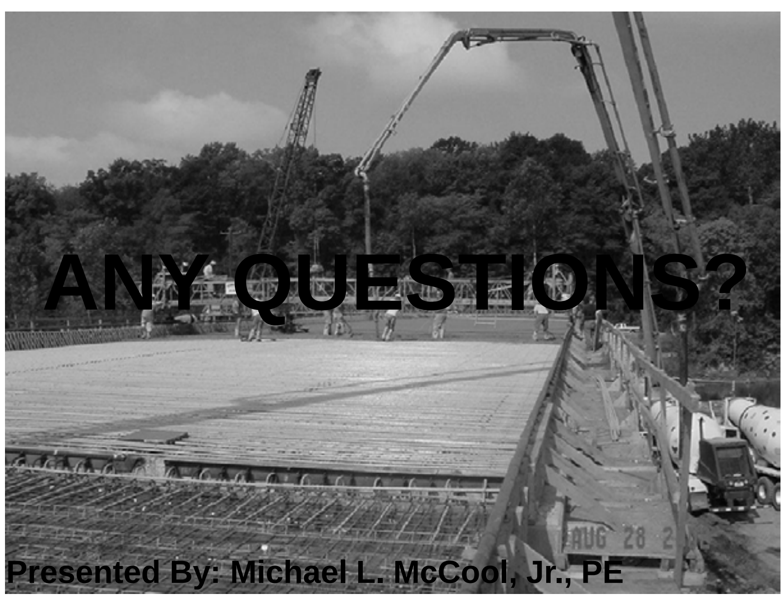
Construction Loading Example



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