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Bridge Girder Design Report

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Design:      Pre-tensioned Prestressed Concrete Girder
Analysis:    Line Girder - Simplified Analysis using Transverse Distribution Method

Design Code: AASHTO LRFD Bridge Design Specifications
             Sixth Edition with 2013 Interim Revisions

Bridge:      Bridge 2
Girder Line: 11
Girder:      Girder group 1 > Right exterior
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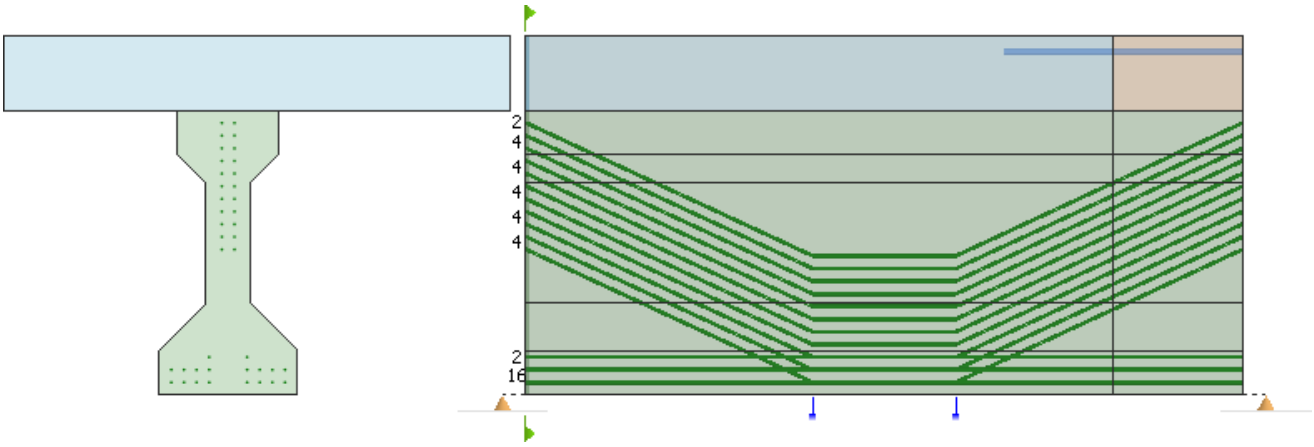
Overall Performance Ratio = 1.05

Contents

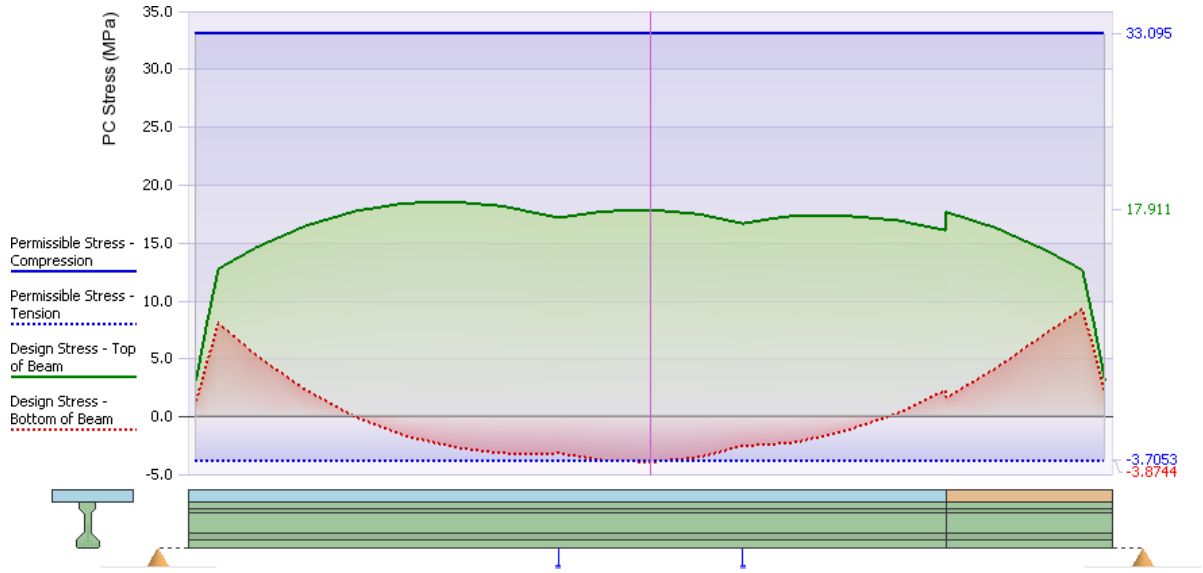
Girder Design Summary

Descending Performance Ratios

Span	Girder	Performance	Analysis Type	Limit State	Loadcase
S1	L1	1.05	Live Load Bending	Service I/III	Max +ve
		0.96	Prestress Transfer	Service I/III	-
		0.81	Erection Stage	Service I/III	-
		0.74	Live Load Bending	Strength	Max +ve
		0.69	Construction Stage	Service I/III	-
		0.53	Live Load Bending	Strength	Max -ve
		0.52	Live Load Bending	Service I/III	Max -ve
		0.52	Shear	Strength	-



Girder Design Calculations: Live Load Bending



Effects ignored within 0.2m from each beam end.

Performance ratio = -3.87 / -3.71 = 1.05

Section details:

Ref 1 "Section 1"
at 0.5 x span = 0.5 x 23.1136 = 11.5568 m from left end of beam

Design Code:

AASHTO LRFD Bridge Design Specifications
Sixth Edition with 2013 Interim Revisions

Analysis:

Live Load Bending Moments
Transient Load BM 1 : [Max +ve]
Limit State - Service I
& Service III
for Normal environment conditions [A5.9.4.2.2b]

Approximate Methods of Analysis are used - Article 4.6.2
Live Load Distribution Factor for +ve Moment = 0.94124 lanes/beam
Live Load Distribution Factor for -ve Moment = 0.94124 lanes/beam
Live Load Distribution Factor for Shear = 0.94124 lanes/beam
Live Load Distribution Factor for Fatigue = 0.78437 lanes/beam

ACTUAL STRESSES IN PRECAST BEAM

40 tendons are fully bonded at this section
0 tendons are fully debonded at this section
0 tendons are harped at this section

INITIAL PRESTRESS

height mm	No of tendons	f_{pu} MPa	area mm²	% of f_{pu}	initial force kN
50.8	8	1861.58	98.71	75.0	1102.542
50.8	2	1861.58	98.71	75.0	275.17634
101.6	8	1861.58	98.71	75.0	1102.542
101.6	2	1861.58	98.71	75.0	275.17634
152.4	2	1861.58	98.71	75.0	275.6355
152.4	2	1861.58	98.71	75.0	275.17634
203.2	2	1861.58	98.71	75.0	275.17634
254.0	2	1861.58	98.71	75.0	275.17634
304.8	2	1861.58	98.71	75.0	275.17634
355.6	2	1861.58	98.71	75.0	275.17634
406.4	2	1861.58	98.71	75.0	275.17634
457.2	2	1861.58	98.71	75.0	275.17634
508.0	2	1861.58	98.71	75.0	275.17634
558.8	2	1861.58	98.71	75.0	275.17634
TOTAL	40				5507.6592

Transverse Eccentricity

Tendon layout is symmetrical about the vertical centroidal axis.

INITIAL RELAXATION - Article 5.9.5.4.4b

Data has the time from stressing to transfer set to zero, indicating that initial relaxation is not required to be calculated here.

				relax.		After relaxation	
height mm	No of tendons	f_{pj}	f_{py} MPa	loss	area mm²	force kN	moment kN.m
50.8	8	1396.19	1675.43	0.0	98.71	1102.542	56.009134
50.8	2	1393.86	1675.43	0.0	98.71	275.17634	13.978958
101.6	8	1396.19	1675.43	0.0	98.71	1102.542	112.01827
101.6	2	1393.86	1675.43	0.0	98.71	275.17634	27.957916
152.4	2	1396.19	1675.43	0.0	98.71	275.6355	42.006851
152.4	2	1393.86	1675.43	0.0	98.71	275.17634	41.936874
203.2	2	1393.86	1675.43	0.0	98.71	275.17634	55.915832
254.0	2	1393.86	1675.43	0.0	98.71	275.17634	69.89479
304.8	2	1393.86	1675.43	0.0	98.71	275.17634	83.873748
355.6	2	1393.86	1675.43	0.0	98.71	275.17634	97.852705
406.4	2	1393.86	1675.43	0.0	98.71	275.17634	111.83166
457.2	2	1393.86	1675.43	0.0	98.71	275.17634	125.81062
508.0	2	1393.86	1675.43	0.0	98.71	275.17634	139.78958
558.8	2	1393.86	1675.43	0.0	98.71	275.17634	153.76854
TOTAL	40					5507.6592	1132.6455

Moment about the centroid of the precast beam:

M_r = 1132.6455-(5507.6592*0.514946)
= -1703.501 kN.m

Corresponding stresses:

top stress = 5507.66/360.967+-1703.5/ 8.31E7
= 15.258068+-20.49937
= -5.2413 MPa

bottom stress = 5507.66/360.967+-1703.5/-1.014E8
= 15.258068+16.807569
= 32.0656 MPa

Self weight moment:

c.s.a. = 3.61E5 mm²
density = 23.5631 kN/m³
self weight = 3.61E5*23.5631
= 8.50551 kN/m
beam length = 23.1136 m
distance = 11.5568 m
M_{sw} = 0.5*8.50551*11.5568*(23.1136-11.5568)
= 567.998 kN.m

Corresponding stresses:

top stress = 567.998/8.31E7
= 6.83511 MPa
bottom stress = 567.998/-1.014E8
= -5.6041 MPa

ELASTIC SHORTENING LOSSES - Article 5.9.5.2.3a

concrete stresses at mid-span:
stress at top of precast beam = 1.59381 MPa
stress at bottom of precast beam = 26.4615 MPa
depth of precast beam = 1143.0 mm

height mm	No of tendons	conc stress MPa	E_p/E_{ci}	tendon force kN	tendon moment kN.m
50.8	10	25.35626	6.084443	152.28851	7.7362564
101.6	10	24.25103	6.084443	145.65055	14.798096
152.4	4	23.1458	6.084443	55.605035	8.4742074
203.2	2	22.04057	6.084443	26.474925	5.3797048
254.0	2	20.93534	6.084443	25.147333	6.3874226
304.8	2	19.83011	6.084443	23.819741	7.2602569
355.6	2	18.72488	6.084443	22.492148	7.9982079
406.4	2	17.61965	6.084443	21.164556	8.6012755
457.2	2	16.51442	6.084443	19.836963	9.0694597
508.0	2	15.40919	6.084443	18.509371	9.4027605
558.8	2	14.30395	6.084443	17.181779	9.6011779
TOTAL	40			528.17091	94.708826

Moment about the centroid of the precast beam:
M_{ed} = 94.708826-(528.17091*0.514946)
= -177.2706 kN.m

hence top stress = 1.5938-528.171/360.967--177.271/ 8.31E7
= 1.5938- 1.463211--2.133216
= 2.26381 MPa
bottom stress = 26.461-528.171/360.967--177.271/-1.014E8
= 26.461- 1.463211-1.7490381
= 23.2492 MPa

After a further 2 iterations of the above process, the top and bottom stresses are as follows:
top stress = 2.18992 MPa
bottom stress = 23.579 MPa

REFINED ESTIMATES OF TIME-DEPENDENT LOSSES - Article 5.9.5.4

Elastic modulus of prestressing steel: E_p = 197.0 kN/mm²
Total effective tendon area: A_{ps} = 3944.8 mm²
Elastic modulus of concrete at transfer: E_{ci} = 32.378 kN/mm²
Percentage relative humidity: H = 70.0 %
Humidity factor for creep: k_{hc} = 1.56-0.008H = 1.0
Humidity factor for shrinkage: k_{hs} = 2.00-0.014H = 1.02
Age at the end of curing: t_c = 3.0 day
Age at transfer: t_i = 4.0 day
Age at in-situ casting: t_d = 60.0 day
Final age: t_f = 120.0 day
Comp. strength of conc. at 1st loading: f'_{ci} = 41.37 MPa

Factor for the effect of concrete strength: $k_f = \frac{35.0}{7+f'_{ci}} = \frac{35.0}{7+41.4} = 0.7236$

Time factor for creep at final time: $k_{tdc,f,i} = \frac{t_f - t_i}{61 - 0.58 * f'_{ci} + t_f - t_i}$

$= \frac{120.0 - 4.0}{61 - 0.58 * 41.4 + 120.0 - 4.0}$

$= 0.7581$

Time fac. for shrinkage at final time: $k_{tds,f,i} = \frac{t_f - t_c}{61 - 0.58 * f'_{ci} + t_f - t_c}$

$= \frac{120.0 - 3.0}{61 - 0.58 * 41.4 + 120.0 - 3.0}$

$= 0.7597$

Losses: Time of Transfer to Time of Deck Placement - Article 5.9.5.4.2

Gross area of section: $A_g = 3.61E5\ mm^2$

Perimeter of section: $p = 3503.7\ mm$

Volume to surface ratio: $V/S = A_g/p = 103.02\ mm$

Factor for the effect of the volume: $k_s = 1.45 - 0.0051 * (V/S) = 0.9245$

Creep coefficient at final time:

$\psi_b(t_f, t_i) = 1.9 * k_s . k_{hc} . k_f . k_{tdc,f,i} . t_i^{-0.118}$

$= 1.9 * 0.9245 * 1.0 * 0.7236 * 0.7581 * 4.0^{-0.118}$

$= 0.8182$

Inertia of the gross concrete section: $I_g = 5.22E10\ mm^4$

Eccentricity of prestressing force: $e_{pg} = -306.91\ mm$

Transformed section coefficient:

$$K_{id} = \frac{1}{1 + \frac{E_p}{E_{ci}}.\frac{A_{ps}}{A_g}\left[1+\frac{A_g.e_{pg}^2}{I_g}\right].[1+0.7*\psi_b(t_f,t_i)]}$$

$$= \frac{1}{1 + \frac{197.0}{32.378}*\frac{3944.8}{3.61E5}\left[1+\frac{3.61E5*-306.9^2}{5.2E10}\right]*(1+0.7*0.8182)}$$

$$= 0.85272$$

Time factor for creep at deck placement:

$$k_{tdc,d,i} = \frac{t_d - t_i}{61 - 0.58*f'_{ci} + t_d - t_i}$$

$$= \frac{60.0-4.0}{61-0.58*41.4+60.0-4.0}$$

$$= 0.602$$

Time factor for shrinkage at deck placement:

$$k_{tds,d,i} = \frac{t_d - t_c}{61 - 0.58*f'_{ci} + t_d - t_c}$$

$$= \frac{60.0-3.0}{61-0.58*41.4+60.0-3.0}$$

$$= 0.606$$

Shrinkage of Girder Concrete - Article 5.9.5.4.2a

Concrete shrinkage strain of girder: $\varepsilon_{bid} = k_s.k_{hs}.k_f.k_{tds,d,i}*0.00048$

$= 1.0*1.02*0.71*0.60*0.00048$

$= 2.121E-4$

Loss of prestress $= \varepsilon_{bid}.E_p.K_{id}$

$= 2.12E-4*197.0*0.84963$

$= 35.495$ MPa

$= \Delta f_{pSR}$

Total shrinkage loss of force = $\Delta f_{pSR}.A_{ps}$
= 35.4945*3944.78
= 140.018 kN

Corresponding gain of moment = 140.018*0.20803
(about y = 0) = 29.1282 kN.m

Moment about the centroid of the composite beam:
M_{sh} = 29.1282-(140.018*0.51494)
= -42.974 kN.m

Corresponding stresses:
top stress = 140.018/360967+-42.9735/8.31E7
= 0.3878972+-0.517129
= -0.129232 MPa

bottom stress = 140.018/360967+-42.9735/-1.014E8
= 0.3878972+0.4239978
= 0.811895 MPa

Creep of Girder Concrete - Article 5.9.5.4.2b

Creep coefficient at deck placement:
$\psi_b(t_d,t_i) = 1.9k_s.k_{hc}.k_f.k_{tdc,d,i}.t_i^{-0.118}$
$= 1.9*1.0*1.0*0.7142*0.6021*4.0^{-0.118}$
= 0.6938

Concrete stress at the center of gravity of prestressing tendons:
concrete stresses at transfer:
at top of precast beam = 1.75172 MPa
at bottom of precast beam = 26.332 MPa
at center of gravity of prestress: f_{cgp} = 21.8583 MPa

Loss of prestress = $\frac{E_p}{E_{ci}}.f_{cgp}.\psi_b(t_d,t_i).K_{id}$
$= \frac{197.0}{32.3777}*21.858*0.6938*0.8576$
= 79.1425 MPa
= Δf_{pCR}

Total creep loss of force = $\Delta f_{pCR}.A_{ps}$
= 79.1425*3944.78
= 312.2 kN

Corresponding loss of moment = 312.2*0.20803
= 64.9475 kN.m
(about y = 0)

Moment about the centroid of the composite beam:
M_{cr} = 64.9475-(312.2*0.51494)
= -95.819 kN.m

Corresponding stresses:
top stress = 312.2/3.61E5+-95.819/8.31002E7
= 0.86489+-1.153
= -0.2881 MPa

bottom stress = 312.2/3.61E5+-95.819/-1.0135E8
= 0.86489+0.94539
= 1.81029 MPa

Relaxation of Prestressing Strands - Article 5.9.5.4.2c

Stress in tendons after transfer: f_{pt} = 1275.83 MPa
Yield strength of prestressing steel: f_{py} = 1675.43 MPa
Time between tensioning and deck placement: $t = t_s - t_i$ = 60.0- 4.0 = 56.0day
Factor for relaxation steel type: K'_L = 45.0 (low relaxation)

$$\text{Loss of prestress} = \frac{f_{pt}}{K'_L}.\frac{\log(24t)}{\log(24t_i)}.\left[\frac{f_{pt}}{f_{py}} - 0.55\right].\left[1- \frac{3(\Delta f_{pSR}+\Delta f_{pCR})}{f_{pt}}\right].K_{id}$$

$$= \frac{1275.8}{45.0}*\frac{\log(24*56.0)}{\log(24* 4.0)}*\left[\frac{1275.8}{1675.4}-0.55\right]\left[1- \frac{3*(35.495+79.142)}{1275.8}\right]*0.85$$

$$= 5.87309 \text{ MPa}$$

$$= \Delta f_{pR1}$$

Total relaxation loss of force = $\Delta f_{pR1}.A_{ps}$
= 5.8731*3944.8
= 23.168069 kN

Corresponding loss of moment = 23.168*0.2080
= 4.8196938 kN.m
(about y = 0)

Moment about the centroid of the composite beam:
M_{rx} = 4.81969-(23.1681*0.5149)
= -7.1106 kN.m

Corresponding stresses:
top stress = 23.1681/360967+-7.11061/ 8.31E7
= 0.0641833+-0.085567
= -0.0213834 MPa

bottom stress = 23.1681/360967+-7.11061/-1.014E8
= 0.0641833+0.0701567
= 0.13434 MPa

Erection of beam Loading

Bending moment from erection loadcase at current span location:
$M_{Applied}$ = 674.56207 kN.m
Corresponding stresses:
top stress = 674.56207/8.31E7
= 8.11746 MPa
bottom stress = 674.56207/-1.014E8
= -6.6556 MPa

Remove the dead load applied for transfer calculations
M_{sw} = -568.0 kN.m
Corresponding stresses:
top stress = -568.0/8.31E7
= -6.8351 MPa
bottom stress = -568.0/-1.014E8
= 5.60415 MPa

Construction stage 1A Loading

$M_{Applied}$ = 1017.5579 kN.m
Corresponding stresses:
top stress = 1017.5579/8.31E7
= 12.245 MPa
bottom stress = 1017.5579/-1.014E8
= -10.04 MPa

Construction stage 1B Loading

$M_{Applied}$ = 89.601562 kN.m
Corresponding stresses:
top stress = 89.601562/8.31E7
= 1.07824 MPa
bottom stress = 89.601562/-1.014E8
= -0.8840 MPa

Losses: Time of Deck Placement to Final Time - Article 5.9.5.4.3

Gross composite section area: A_c = 9.72E5 mm²
Perimeter of section: p = 7365.6 mm
Volume to surface ratio: $V/S = A_c/p$ = 131.99 mm
Factor for the effect of the volume: k_s = 1.45-0.0051*(V/S) = 0.7768
Creep coefficient at final time:

$$\psi_b(t_f,t_i) = 1.9*k_s.k_{hc}.k_f.k_{tdc,f,i}.t_i^{-0.118}$$
$$= 1.9*0.776*1.0*0.723*0.758*4.0^{-0.118}$$
$$= 0.6875$$

Inertia of the net concrete section: I_c = 1.94E8 mm⁴
Eccentricity of prestressing force: e_{pc} = 0.7960 mm
Transformed section coefficient:

$$K_{df} = \frac{1}{1 + \frac{E_p}{E_{ci}}.\frac{A_{ps}}{A_c}\left[1+\frac{A_c.e_{pc}^2}{I_c}\right].[1+0.7*\psi_b(t_f,t_i)]}$$

$$= \frac{1}{1 + \frac{197.0}{32.378}*\frac{3944.8}{9.72E5}\left[1+\frac{9.72E5*796.07^2}{1.9E11}\right]*(1+0.7*0.6875)}$$

$$= 0.86758$$

Shrinkage of Girder Concrete - Article 5.9.5.4.3a

Concrete shrinkage strain of girder: $\varepsilon_{bdf} = k_s.k_{hs}.k_f.k_{tds,f,i}*0.00048$
= 1.0*1.02*0.71*0.76*0.00048
= 2.657E-4

Loss of prestress = $\varepsilon_{bdf}.E_p.K_{df}$
= 2.66E-4*1.97E8*0.85760
= 44.888 MPa
= Δf_{pSD}

Total shrinkage loss of force = $\Delta f_{pSD}.A_{ps}$
= 44.888*3944.78
= 177.073 kN

Corresponding gain of moment = 177.073*0.20803
(about y = 0) = 36.8369 kN.m

Moment about the centroid of the composite beam:
M_{sh} = 36.8369-(177.073*0.9603)
= -133.21 kN.m

Corresponding stresses:
top stress = 177.073/844161+-133.207/9.901E8
= 0.2097626+-0.134536
= 0.0752263 MPa

bottom stress = 177.073/844161+-133.207/-1.884E8
= 0.2097626+0.7071458
= 0.916909 MPa

Creep of Girder Concrete - Article 5.9.5.4.2b

Creep coefficient at deck placement:
$\psi_b(t_d,t_i) = 1.9k_s.k_{hc}.k_f.k_{tdc,d,i}.t_i^{-0.118}$
$= 1.9*1.0*1.0*0.7142*0.6021*4.0^{-0.118}$
= 0.6938

Creep coefficient at final time:
$\psi_b(t_f,t_d) = 1.9k_s.k_{hc}.k_f.k_{tdc,f,i}.t_d^{-0.118}$
$= 1.9*1.0*1.0*0.7142*0.6185*60.0^{-0.118}$
= 0.5178

Concrete stress at the center of gravity of prestressing tendons:
concrete stresses at transfer:
at top of precast beam = 1.75172 MPa
at bottom of precast beam = 26.332 MPa
at center of gravity of prestress: f_{cgp} = 21.8583 MPa

Change in concrete stress at centroid of prestressing strands:
concrete stress change after permanent loads:
at top of precast beam = 9.85015 MPa
at bottom of precast beam = 12.1033 MPa
Δf_{cd} = 11.6932 MPa

$$\text{Loss of prestress} = \frac{E_p}{E_{ci}} * f_{cgp} * \left[\psi_b(t_f,t_i) - \psi_b(t_d,t_i) \right] * K_{df}$$
$$+ \frac{E_p}{E_c} * \Delta f_{cd} * \psi_b(t_f,t_d) * K_{df}$$
$$= \frac{197.0}{32.3777} * 21.8583 * (0.87367 - 0.69388) * 0.84963$$
$$+ \frac{197.0}{18.6932} * 11.6932 * 0.51782 * 0.84963$$
$$= 74.5326 \text{ MPa}$$
$$= \Delta f_{pCD}$$

Total creep loss of force = $\Delta f_{pCD} * A_{ps}$
= 74.5326*3944.78
= 294.015 kN

Corresponding loss of moment = 294.015*0.20803
= 61.1644 kN.m
(about y = 0)

Moment about the centroid of the composite beam:
M_{cr} = 61.1644-(294.015*0.9603)
= -221.18 kN.m

Corresponding stresses:

top stress = 294.015/8.442E5+-221.18/9.90117E8
= 0.34829+-0.2233
= 0.12490 MPa

bottom stress = 294.015/8.442E5+-221.18/-1.8837E8
= 0.34829+1.17415
= 1.52245 MPa

Relaxation of Prestressing Strands - Article 5.9.5.4.3c

Loss of prestress = Δf_{pR1}
= 5.87309 MPa
= Δf_{pR2}

Total relaxation loss of force = $\Delta f_{pR2}.A_{ps}$
= 5.8731*3944.8
= 23.168069 kN

Corresponding loss of moment = 23.168*0.2080
= 4.8196938 kN.m
(about y = 0)

Moment about the centroid of the composite beam:
M_{rx} = 4.81969-(23.1681*0.9603)
= -17.429 kN.m

Corresponding stresses:
top stress = 23.1681/844161+-17.4286/9.901E8
= 0.0274451+-0.017603
= 0.00984252 MPa

bottom stress = 23.1681/844161+-17.4286/-1.884E8
= 0.0274451+0.0925221
= 0.119967 MPa

Shrinkage of Deck Concrete - Article 5.9.5.4.3d

Concrete shrinkage strain of girder: $\varepsilon_{ddf} = k_s.k_{hs}.k_f.k_{tds,f,i}$*0.00048
= 1.025*1.02*0.71*0.76*0.00048
= 2.724E-4

Creep coefficient at final time:
$\psi_b(t_f,t_d) = 1.9k_s.k_{hc}.k_f.k_{tdc,f,i}.t_d^{-0.118}$
$= 1.9*1.0253*1.0*0.7142*0.6185*60.0^{-0.118}$
= 0.5309

Change in concrete stress at centroid of prestressing strands:

Area of deck concrete: A_d = 6.112E5 mm²
Perimeter of section: p = 7365.55 mm
Volume to surface ratio: $V/S = A_d/p$ = 82.98 mm
Factor for the effect of the volume: k_s = 1.45-0.0051*(V/S) = 1.4333
Modulus of elasticity of deck concrete: E_{cd} = 29.5566 mm²
Eccentricity of the deck: e_d = 288.894 mm³

$$\Delta f_{cdf} = \frac{\varepsilon_{ddf}.A_d.E_{cd}}{[1+0.7\psi_b(t_f,t_d)]}\left[\frac{1}{A_c}-\frac{e_{pc}.e_d}{I_c}\right]$$

$$= \frac{2.7E\text{-}4*6.11E5*29.557*1000}{[1+0.7*0.5309]}\left[\frac{1}{8.44E5}-\frac{752.269*288.894}{1.8E11}\right]$$

$$= -0.0602 \text{ MPa}$$

$$\text{Loss of prestress} = \frac{E_p}{E_c}.\Delta f_{cdf}.K_{df}.[1+0.7\psi_b(t_f,t_d)]$$

$$= \frac{197.0}{18.6932}*-0.0602*0.85760\ *(1+0.7*0.53092)$$

$$= -0.7466 \text{ MPa}$$

$$= \Delta f_{pSS}$$

Total shrinkage gain of force = $\Delta f_{pSS}.A_{ps}$
= -0.7466*3944.78
= -2.9455 kN

Corresponding gain of moment (about y = 0) = -2.9455*0.20803
= -0.6127 kN.m

Moment about the centroid of the composite beam:
M_{sh} = -0.6127-(-2.9455*0.9603)
= 2.21584 kN.m

Corresponding stresses:
top stress = -2.94554/844161+2.21584/9.901E8
= -0.003489+0.002238
= -0.00125136 MPa

bottom stress = -2.94554/844161+2.21584/-1.884E8
= -0.003489+-0.011763
= -0.0152524 MPa

Superimposed dead load 1 Loading

$M_{Applied}$ = 148.14137 kN.m
Corresponding stresses:
top stress = 148.14137/9.9012E8
= 0.14962 MPa
bottom stress = 148.14137/-1.884E8
= -0.7864 MPa

Transient Load BM 1 : [Max +ve] Loading

$M_{applied}$ = 2250.62 kN.m for Service-I
1800.5 kN.m for Service-III

```
Corresponding stresses:
      top stress = 2250.62/9.9012E8        Service-I
                 = 2.27309 MPa
   bottom stress = 1800.5/-1.884E8         Service-III
                 = -9.5582 MPa
```

PERMISSIBLE STRESSES IN PRECAST BEAM

Compression

Article 5.9.4.2.1 for permanent & transient loads

Permissible compression stress = $0.6 * f'_c$
= 0.6*55.1581
= 33.09 MPa

Tension

Article 5.9.4.2.2
Component is subject to normal exposure conditions.

Permissible tension stress = $-0.498 * \sqrt{f'_c}$
= -0.498 * √55.1581
= -3.70451 MPa

PERMISSIBLE STRESSES FOR CAST IN PLACE CONCRETE

Compression

Article 5.9.4.2
char. strength of c.i.p. concrete = 34.4738 MPa
stress limitation factor = 0.6
permissible compression stress = $0.6*f_{cu}$
= 0.6 * 34.4738
= 20.6843 MPa

Tension

Article 5.7.3.4
Flexural tensile stresses may need to be limited by cracking considerations in accordance with article 5.7.3.4.
However, no tensile stress is present at this section.

SERVICE LIMIT STATE - STRESS SUMMARY TABLE

minimum for girder bottom extreme fibre

Concrete Stresses (MPa)						
	force	moment	Cast In Place		Precast	
	kN	kN.m	top	bottom	top	bottom
Prestress	5507.66	-1703.5			-5.2413	32.0656
Self Weight		567.998			6.83511	-5.6041
Prestress + Self Wt.					1.59381	26.4615
Elastic Def	-474.77	158.837			0.59611	-2.8825
TRANSFER	5032.88	-976.66			2.18992	23.579
Erection		106.564			1.28235	-1.0514
C.I.P. Stage 1A		1017.56			12.245	-10.04
C.I.P. Stage 1B		89.6016	0.18902	0.07154	0.0905	-0.4756
Time-Dependent Losses						
Time of Transfer to Time of Deck Placement						
Shrinkage	-140.02	42.9735			0.12923	-0.8119
Creep	-312.2	95.8186			0.28815	-1.8103
Relaxation	-23.168	7.11061			0.02138	-0.1343
Time of Deck Placement to Final Time						
Shrinkage						
Girder	-177.07	133.207	0.11517	-0.0595	-0.0752	-0.9169
Deck	27.3485	-20.573	-0.0178	0.00919	0.01162	0.14161
Creep	-294.01	221.178	0.19124	-0.0987	-0.1249	-1.5224
Relaxation	-23.168	17.4286	0.01507	-0.0078	-0.0098	-0.1199
Wearing Surface		148.141	0.31251	0.11828	0.14962	-0.7864
(Diff. Shr. 1	-27.349	20.5734	9.98E-4	0.27517	-0.0116	-0.1416)
(Diff. Shr. 2		-11.207	-0.0236	-0.0089	-0.0113	0.05949)
(Differential shrinkage is not adverse or not specified)						
TOTAL PERMANENT			0.80523	0.03301	16.1978	6.05158
(γ_{TG} = 0.5)						
Temp Grad P1	-752.44	-291.34	2.3162	-0.5968	-0.7549	0.65526
Temp Grad P2		192.707	0.40652	0.15386	0.19463	-1.023
Temp Grad R1	150.487	58.2675	-0.4632	0.11936	0.15098	-0.1310
Temp Grad R2		-38.54	-0.0813	-0.0308	-0.0389	0.20459
(Temperature restraint is not adverse or not specified)						

TRANSIENT LOADS				
Transient Load BM 1- I	2250.62	4.74783	2.27309	
- III	1800.5	1.43763		-9.5582
Transient Load BM 2- I	-385.71	-0.8136	-0.3895	
- III	-308.57	-0.2463		1.63808
TOTAL PERMANENT LOAD + TRANSIENT LOAD				
Transient Load BM 1		5.00852	1.0277	17.9106	-3.8744

SLS FLEXURE
calculated using curvature of uncracked sections

The deflections are calculated from integration of the curvatures along the beam, using the parameters detailed below:
(Note that the reported values of deflections for live loadings are exaggerated when these are derived from enveloped effects)

Elastic Modulus at Transfer, E_T = 32.3777 kN/mm²
Intermediate Term Elastic Modulus, E_I = 22.0714 kN/mm²
$E_I = E_C/(\psi(t,t_i)+1)$
where $\psi(t,t_i)$ = 0.69388 (Article 5.14.2.3.6)]
Effective Elastic Modulus for time dependant effects, E_E = 34.2214 kN/mm²
$E_E = E_S.(\psi_{tc\%} +((1-\psi_{tc\%})/ (1 + \chi.\psi)))$
ψ = creep factor = 0.87367
$\psi_{tc\%}$ = percentage of creep occurring before c.i.p. deck added
= 0.69388/0.87367 = 79.4216%
χ = ageing factor, taken as 0.8
Short Term Elastic Modulus, E_S = 37.3865 kN/mm²

Precast section height = 1143.0 mm

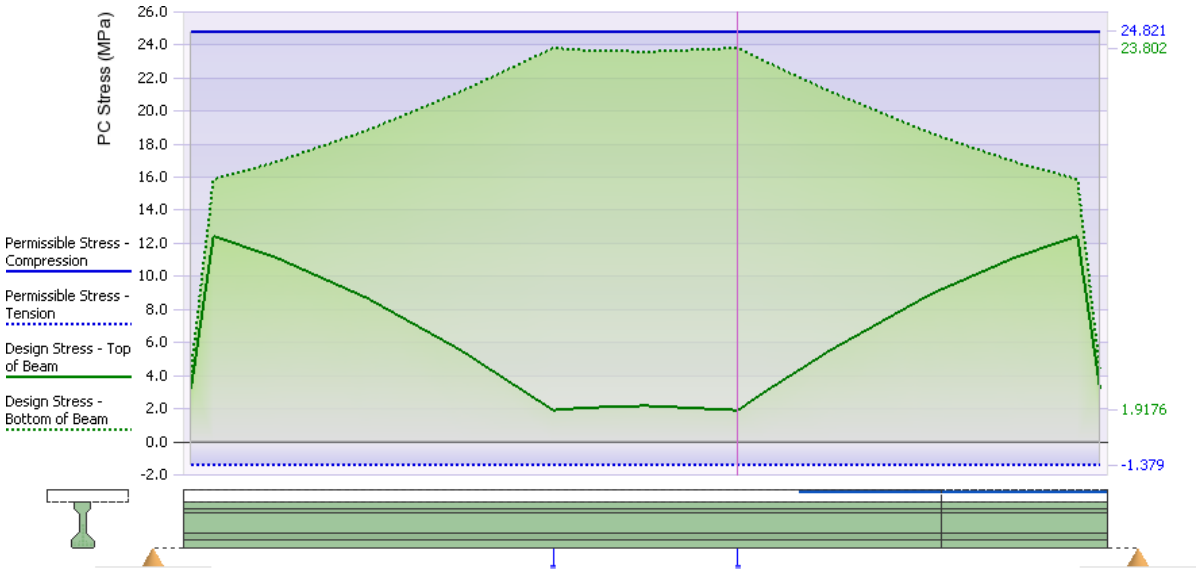
		Precast Stress (MPa)	E	Strain ($x10^{-6}$)	Curvature ($x10^{-6}$) (rad/m)	Deflection[1] (mm) Here	Max.
At Transfer	T	2.11241	E_T	65.2428	-581.78	29.9015	30.3396
	B	23.6426		730.213			
At Erection	T	3.81257	E_I	172.738	-635.78	35.7234	36.1998
	B	19.8518		899.435			
Long-term Dead	T	16.0401					
	B	6.19298					

Dead Stress Increment	T	13.9277	E_E 406.989	802.181	-48.721	-49.25
	B	-17.45	-509.9			
Total Dead Load deflection				166.4	-12.998	-13.05
Transient Load BM 1-I	T	2.28985	E_S 61.2481	335.239	-20.45	-20.541
	B	-12.036	-321.93			
Extreme in-service		-5.8429		501.639	-33.448	Cracked

The stress limit in service (-3.7134MPa) is exceeded.
[Article 5.9.4.2.2]

[1] Deflection 'Cracked' indicates tensile stress at one or more sections along the beam exceeds the stress limit.

Girder Design Calculations: Prestress Transfer



Effects ignored within 0.2m from each beam end.

Performance ratio = 23.8 / 24.8 = 0.959

Section details:

Ref 1 "Section 1"
at 0.599 x span = 0.599 x 23.1136 = 13.8636 m from left end of beam

Design Code:

AASHTO LRFD Bridge Design Specifications
Sixth Edition with 2013 Interim Revisions

Analysis:

Stresses at Transfer

ACTUAL STRESSES IN PRECAST BEAM

40 tendons are fully bonded at this section
0 tendons are fully debonded at this section
0 tendons are harped at this section

INITIAL PRESTRESS

height mm	No of tendons	f_{pu} MPa	area mm²	% of f_{pu}	initial force kN
50.8	8	1861.58	98.71	75.0	1102.542
50.8	2	1861.58	98.71	75.0	275.17634
101.6	8	1861.58	98.71	75.0	1102.542
101.6	2	1861.58	98.71	75.0	275.17634
152.4	2	1861.58	98.71	75.0	275.6355
152.4	2	1861.58	98.71	75.0	275.17634
203.2	2	1861.58	98.71	75.0	275.17634
254.0	2	1861.58	98.71	75.0	275.17634
304.8	2	1861.58	98.71	75.0	275.17634
355.6	2	1861.58	98.71	75.0	275.17634
406.4	2	1861.58	98.71	75.0	275.17634
457.2	2	1861.58	98.71	75.0	275.17634
508.0	2	1861.58	98.71	75.0	275.17634
558.8	2	1861.58	98.71	75.0	275.17634
TOTAL	40				5507.6592

Transverse Eccentricity

Tendon layout is symmetrical about the vertical centroidal axis.

INITIAL RELAXATION - Article 5.9.5.4.4b

Data has the time from stressing to transfer set to zero, indicating that initial relaxation is not required to be calculated here.

				relax.	After relaxation		
height mm	No of tendons	f_{pj}	f_{py} MPa	loss	area mm²	force kN	moment kN.m
50.8	8	1396.19	1675.43	0.0	98.71	1102.542	56.009134
50.8	2	1393.86	1675.43	0.0	98.71	275.17634	13.978958
101.6	8	1396.19	1675.43	0.0	98.71	1102.542	112.01827
101.6	2	1393.86	1675.43	0.0	98.71	275.17634	27.957916
152.4	2	1396.19	1675.43	0.0	98.71	275.6355	42.006851
152.4	2	1393.86	1675.43	0.0	98.71	275.17634	41.936874
203.2	2	1393.86	1675.43	0.0	98.71	275.17634	55.915832
254.0	2	1393.86	1675.43	0.0	98.71	275.17634	69.89479
304.8	2	1393.86	1675.43	0.0	98.71	275.17634	83.873748
355.6	2	1393.86	1675.43	0.0	98.71	275.17634	97.852705
406.4	2	1393.86	1675.43	0.0	98.71	275.17634	111.83166
457.2	2	1393.86	1675.43	0.0	98.71	275.17634	125.81062
508.0	2	1393.86	1675.43	0.0	98.71	275.17634	139.78958
558.8	2	1393.86	1675.43	0.0	98.71	275.17634	153.76854
TOTAL	40					5507.6592	1132.6455

```
Moment about the centroid of the precast beam:
           Mr = 1132.6455-(5507.6592*0.514946)
              = -1703.501 kN.m
Corresponding stresses:
      top stress = 5507.66/360.967+-1703.5/  8.31E7
                 = 15.258068+-20.49937
                 = -5.2413 MPa
   bottom stress = 5507.66/360.967+-1703.5/-1.014E8
                 = 15.258068+16.807569
                 = 32.0656 MPa


Self weight moment:
  c.s.a.      = 3.61E5 mm²
  density     = 23.5631 kN/m³
  self weight = 3.61E5*23.5631
              = 8.50551 kN/m
  beam length = 23.1136 m
  distance    = 13.8636 m
  Msw         = 0.5*8.50551*13.8636*(23.1136-13.8636)
              = 545.368 kN.m
Corresponding stresses:
  top stress     = 545.368/8.31E7
                 = 6.56278 MPa
  bottom stress  = 545.368/-1.014E8
                 = -5.3809 MPa
```

ELASTIC SHORTENING LOSSES - Article 5.9.5.2.3a

```
concrete stresses at mid-span:
          stress at top of precast beam = 1.59381 MPa
       stress at bottom of precast beam = 26.4615 MPa
                  depth of precast beam =  1143.0 mm
```

height mm	No of tendons	conc stress MPa	E_p/E_{ci}	tendon force kN	tendon moment kN.m
50.8	10	25.35626	6.084443	152.28851	7.7362564
101.6	10	24.25103	6.084443	145.65055	14.798096
152.4	4	23.1458	6.084443	55.605035	8.4742074
203.2	2	22.04057	6.084443	26.474925	5.3797048
254.0	2	20.93534	6.084443	25.147333	6.3874226
304.8	2	19.83011	6.084443	23.819741	7.2602569
355.6	2	18.72488	6.084443	22.492148	7.9982079
406.4	2	17.61965	6.084443	21.164556	8.6012755
457.2	2	16.51442	6.084443	19.836963	9.0694597
508.0	2	15.40919	6.084443	18.509371	9.4027605
558.8	2	14.30395	6.084443	17.181779	9.6011779
TOTAL	40			528.17091	94.708826

Moment about the centroid of the precast beam:

M_{ed} = 94.708826-(528.17091*0.514946)
= -177.2706 kN.m

hence top stress = 1.5938-528.171/360.967--177.271/ 8.31E7
= 1.5938- 1.463211--2.133216
= 2.26381 MPa
bottom stress = 26.461-528.171/360.967--177.271/-1.014E8
= 26.461- 1.463211-1.7490381
= 23.2492 MPa

After a further 2 iterations of the above process, the top and bottom stresses are as follows:
top stress = 2.18992 MPa
bottom stress = 23.579 MPa

PERMISSIBLE STRESSES IN PRECAST BEAM

Compression

Article 5.9.4.1.1
Permissible compression stress = 0.6 * f'_{ci}
= 0.6*41.3685
= 24.8211 MPa

Tension

Article 5.9.4.1.2
Permissible tension stress = -0.248 * $\sqrt{f'_{ci}}$
= -0.248 * √41.3685
= -1.601 MPa
but not greater than 1.38 MPa, therefore,
stress limit = -0.2 MPa

SERVICE LIMIT STATE - STRESS SUMMARY TABLE

			Concrete Stresses (MPa)			
	force	moment	Cast In Place		Precast	
	kN	kN.m	top	bottom	top	bottom
Prestress	5507.66	-1703.5			-5.2413	32.0656
Self Weight		545.368			6.56278	-5.3809
Prestress + Self Wt.					1.32148	26.6848
Elastic Def	-474.77	158.837			0.59611	-2.8825
TRANSFER	5032.88	-999.3			1.91759	23.8023

SLS FLEXURE
calculated using curvature of uncracked sections

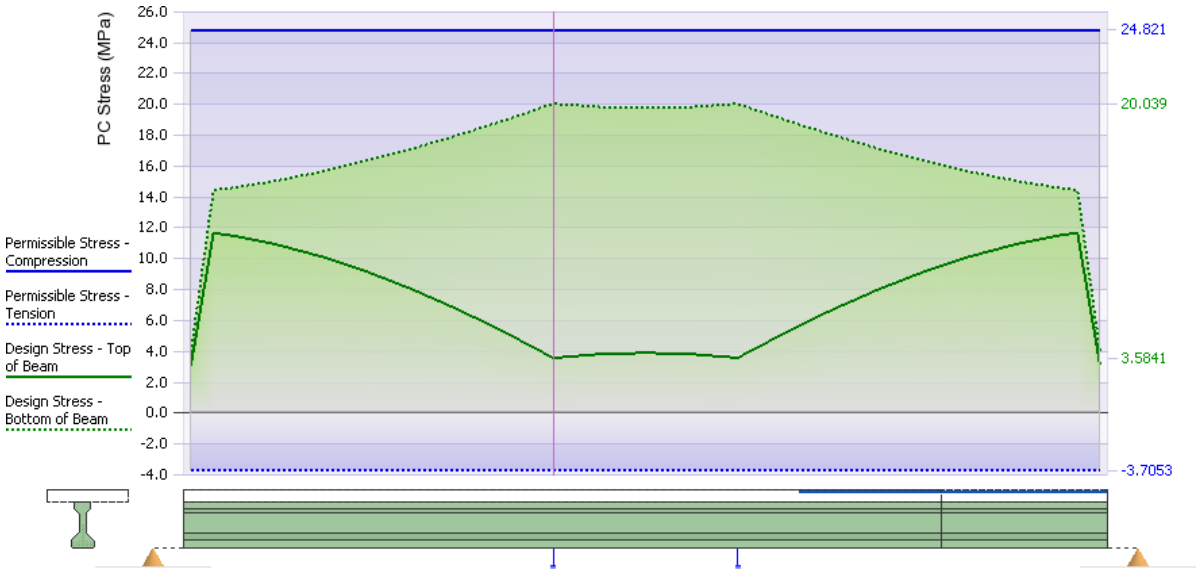
The deflections are calculated from integration of the curvatures along the beam, using the parameters detailed below:

Elastic Modulus at Transfer, E_T = 32.3777 kN/mm²

Precast section height = 1143.0 mm

		Precast Stress (MPa)	E	Strain (x10^{-6})	Curvature (x10^{-6}) (rad/m)	Deflection (mm) Here	Max.
At Transfer	T	2.18992	E_T	67.6368	-577.96	30.4682	30.4682
	B	23.579		728.25			

Girder Design Calculations: Erection Stage



Effects ignored within 0.2m from each beam end.

Performance ratio = 20.0 / 24.8 = 0.807

Section details:

Ref 1 "Section 1"
at 0.400 x span = 0.400 x 23.1136 = 9.25 m from left end of beam

Design Code:

AASHTO LRFD Bridge Design Specifications
Sixth Edition with 2013 Interim Revisions

Analysis:

Erection stage stresses
Limit State - Service I

ACTUAL STRESSES IN PRECAST BEAM

40 tendons are fully bonded at this section
0 tendons are fully debonded at this section
0 tendons are harped at this section

INITIAL PRESTRESS

height mm	No of tendons	f_{pu} MPa	area mm²	% of f_{pu}	initial force kN
50.8	8	1861.58	98.71	75.0	1102.542
50.8	2	1861.58	98.71	75.0	275.17634
101.6	8	1861.58	98.71	75.0	1102.542
101.6	2	1861.58	98.71	75.0	275.17634
152.4	2	1861.58	98.71	75.0	275.6355
152.4	2	1861.58	98.71	75.0	275.17634
203.2	2	1861.58	98.71	75.0	275.17634
254.0	2	1861.58	98.71	75.0	275.17634
304.8	2	1861.58	98.71	75.0	275.17634
355.6	2	1861.58	98.71	75.0	275.17634
406.4	2	1861.58	98.71	75.0	275.17634
457.2	2	1861.58	98.71	75.0	275.17634
508.0	2	1861.58	98.71	75.0	275.17634
558.8	2	1861.58	98.71	75.0	275.17634
TOTAL	40				5507.6592

Transverse Eccentricity

Tendon layout is symmetrical about the vertical centroidal axis.

INITIAL RELAXATION - Article 5.9.5.4.4b

Data has the time from stressing to transfer set to zero, indicating that initial relaxation is not required to be calculated here.

				relax.	After relaxation		
height mm	No of tendons	f_{pj}	f_{py} MPa	loss	area mm²	force kN	moment kN.m
50.8	8	1396.19	1675.43	0.0	98.71	1102.542	56.009134
50.8	2	1393.86	1675.43	0.0	98.71	275.17634	13.978958
101.6	8	1396.19	1675.43	0.0	98.71	1102.542	112.01827
101.6	2	1393.86	1675.43	0.0	98.71	275.17634	27.957916
152.4	2	1396.19	1675.43	0.0	98.71	275.6355	42.006851
152.4	2	1393.86	1675.43	0.0	98.71	275.17634	41.936874
203.2	2	1393.86	1675.43	0.0	98.71	275.17634	55.915832
254.0	2	1393.86	1675.43	0.0	98.71	275.17634	69.89479
304.8	2	1393.86	1675.43	0.0	98.71	275.17634	83.873748
355.6	2	1393.86	1675.43	0.0	98.71	275.17634	97.852705
406.4	2	1393.86	1675.43	0.0	98.71	275.17634	111.83166
457.2	2	1393.86	1675.43	0.0	98.71	275.17634	125.81062
508.0	2	1393.86	1675.43	0.0	98.71	275.17634	139.78958
558.8	2	1393.86	1675.43	0.0	98.71	275.17634	153.76854
TOTAL	40					5507.6592	1132.6455

Moment about the centroid of the precast beam:
M_r = 1132.6455-(5507.6592*0.514946)
= -1703.501 kN.m
Corresponding stresses:
top stress = 5507.66/360.967+-1703.5/ 8.31E7
= 15.258068+-20.49937
= -5.2413 MPa
bottom stress = 5507.66/360.967+-1703.5/-1.014E8
= 15.258068+16.807569
= 32.0656 MPa

Self weight moment:
c.s.a. = 3.61E5 mm²
density = 23.5631 kN/m³
self weight = 3.61E5*23.5631
= 8.50551 kN/m
beam length = 23.1136 m
distance = 9.25 m
M_{sw} = 0.5*8.50551*9.25*(23.1136-9.25)
= 545.368 kN.m
Corresponding stresses:
top stress = 545.368/8.31E7
= 6.56278 MPa
bottom stress = 545.368/-1.014E8
= -5.3809 MPa

ELASTIC SHORTENING LOSSES - Article 5.9.5.2.3a

concrete stresses at mid-span:
stress at top of precast beam = 1.59381 MPa
stress at bottom of precast beam = 26.4615 MPa
depth of precast beam = 1143.0 mm

height mm	No of tendons	conc stress MPa	E_p/E_{ci}	tendon force kN	tendon moment kN.m
50.8	10	25.35626	6.084443	152.28851	7.7362564
101.6	10	24.25103	6.084443	145.65055	14.798096
152.4	4	23.1458	6.084443	55.605035	8.4742074
203.2	2	22.04057	6.084443	26.474925	5.3797048
254.0	2	20.93534	6.084443	25.147333	6.3874226
304.8	2	19.83011	6.084443	23.819741	7.2602569
355.6	2	18.72488	6.084443	22.492148	7.9982079
406.4	2	17.61965	6.084443	21.164556	8.6012755
457.2	2	16.51442	6.084443	19.836963	9.0694597
508.0	2	15.40919	6.084443	18.509371	9.4027605
558.8	2	14.30395	6.084443	17.181779	9.6011779
TOTAL	40			528.17091	94.708826

Moment about the centroid of the precast beam:

M_{ed} = 94.708826-(528.17091*0.514946)
= -177.2706 kN.m

hence top stress = 1.5938-528.171/360.967--177.271/ 8.31E7
= 1.5938- 1.463211--2.133216
= 2.26381 MPa
bottom stress = 26.461-528.171/360.967--177.271/-1.014E8
= 26.461- 1.463211-1.7490381
= 23.2492 MPa

After a further 2 iterations of the above process, the top and bottom stresses are as follows:
top stress = 2.18992 MPa
bottom stress = 23.579 MPa

REFINED ESTIMATES OF TIME-DEPENDENT LOSSES - Article 5.9.5.4

Elastic modulus of prestressing steel: E_p = 197.0 kN/mm²
Total effective tendon area: A_{ps} = 3944.8 mm²
Elastic modulus of concrete at transfer: E_{ci} = 32.378 kN/mm²
Percentage relative humidity: H = 70.0 %
Humidity factor for creep: k_{hc} = 1.56-0.008H = 1.0
Humidity factor for shrinkage: k_{hs} = 2.00-0.014H = 1.02
Age at the end of curing: t_c = 3.0 day
Age at transfer: t_i = 4.0 day
Age at in-situ casting: t_d = 60.0 day
Final age: t_f = 120.0 day
Comp. strength of conc. at 1st loading: f'_{ci} = 41.37 MPa

Factor for the effect of concrete strength: $k_f = \frac{35.0}{7+f'_{ci}} = \frac{35.0}{7+41.4} = 0.7236$

Time factor for creep at final time: $k_{tdc,f,i} = \frac{t_f - t_i}{61-0.58*f'_{ci}+t_f-t_i}$

$= \frac{120.0-4.0}{61-0.58*41.4+120.0-4.0}$

$= 0.7581$

Time fac. for shrinkage at final time: $k_{tds,f,i} = \frac{t_f - t_c}{61-0.58*f'_{ci}+t_f-t_c}$

$= \frac{120.0-3.0}{61-0.58*41.4+120.0-3.0}$

$= 0.7597$

Losses: Time of Transfer to Time of Deck Placement - Article 5.9.5.4.2

Gross area of section: $A_g = 3.61E5\ mm^2$

Perimeter of section: $p = 3503.7\ mm$

Volume to surface ratio: $V/S = A_g/p = 103.02\ mm$

Factor for the effect of the volume: $k_s = 1.45-0.0051*(V/S) = 0.9245$

Creep coefficient at final time:

$$\psi_b(t_f,t_i) = 1.9*k_s.k_{hc}.k_f.k_{tdc,f,i}.t_i^{-0.118}$$
$$= 1.9*0.9245*1.0*0.7236*0.7581*4.0^{-0.118}$$
$$= 0.8182$$

Inertia of the gross concrete section: $I_g = 5.22E10\ mm^4$

Eccentricity of prestressing force: $e_{pg} = -306.91\ mm$

Transformed section coefficient:

$$K_{id} = \frac{1}{1 + \frac{E_p}{E_{ci}}.\frac{A_{ps}}{A_g}\left[1+\frac{A_g.e_{pg}^2}{I_g}\right].[1+0.7*\psi_b(t_f,t_i)]}$$

$$= \frac{1}{1 + \frac{197.0}{32.378}*\frac{3944.8}{3.61E5}\left[1+\frac{3.61E5*-306.9^2}{5.2E10}\right]*(1+0.7*0.8182)}$$

$$= 0.85272$$

Time factor for creep at deck placement:

$$k_{tdc,d,i} = \frac{t_d-t_i}{61-0.58*f'_{ci}+t_d-t_i}$$

$$= \frac{60.0-4.0}{61-0.58*41.4+60.0-4.0}$$

$$= 0.602$$

Time factor for shrinkage at deck placement:

$$k_{tds,d,i} = \frac{t_d-t_c}{61-0.58*f'_{ci}+t_d-t_c}$$

$$= \frac{60.0-3.0}{61-0.58*41.4+60.0-3.0}$$

$$= 0.606$$

Shrinkage of Girder Concrete - Article 5.9.5.4.2a

Concrete shrinkage strain of girder: $\varepsilon_{bid} = k_s.k_{hs}.k_f.k_{tds,d,i}*0.00048$
$= 1.0*1.02*0.71*0.60*0.00048$
$= 2.121E\text{-}4$

Loss of prestress = $\varepsilon_{bid}.E_p.K_{id}$
$= 2.12E\text{-}4*197.0*0.84963$
$= 35.495$ MPa
$= \Delta f_{pSR}$

Total shrinkage loss of force = $\Delta f_{pSR}.A_{ps}$
$= 35.4945*3944.78$
$= 140.018$ kN

Corresponding gain of moment (about $y = 0$) = $140.018*0.20803$
$= 29.1282$ kN.m

Moment about the centroid of the composite beam:
$M_{sh} = 29.1282\text{-}(140.018*0.51494)$
$= -42.974$ kN.m

Corresponding stresses:
top stress = $140.018/360967+\text{-}42.9735/8.31E7$
$= 0.3878972+\text{-}0.517129$
$= -0.129232$ MPa

bottom stress = $140.018/360967+\text{-}42.9735/\text{-}1.014E8$
$= 0.3878972+0.4239978$
$= 0.811895$ MPa

Creep of Girder Concrete - Article 5.9.5.4.2b

Creep coefficient at deck placement:
$\psi_b(t_d,t_i) = 1.9k_s.k_{hc}.k_f.k_{tdc,d,i}.t_i^{-0.118}$
$= 1.9*1.0*1.0*0.7142*0.6021*4.0^{-0.118}$
$= 0.6938$

Concrete stress at the center of gravity of prestressing tendons:
concrete stresses at transfer:
at top of precast beam = 1.75172 MPa
at bottom of precast beam = 26.332 MPa
at center of gravity of prestress: $f_{cgp} = 21.8583$ MPa

$$\text{Loss of prestress} = \frac{E_p}{E_{ci}}.f_{cgp}.\Psi_b(t_d,t_i).K_{id}$$
$$= \frac{197.0}{32.3777}*21.858*0.6938*0.8576$$
$$= 79.1425 \text{ MPa}$$
$$= \Delta f_{pCR}$$

Total creep loss of force = $\Delta f_{pCR}.A_{ps}$
= 79.1425*3944.78
= 312.2 kN

Corresponding loss of moment = 312.2*0.20803
= 64.9475 kN.m
(about y = 0)

Moment about the centroid of the composite beam:
M_{cr} = 64.9475-(312.2*0.51494)
= -95.819 kN.m

Corresponding stresses:
top stress = 312.2/3.61E5+-95.819/8.31002E7
= 0.86489+-1.153
= -0.2881 MPa

bottom stress = 312.2/3.61E5+-95.819/-1.0135E8
= 0.86489+0.94539
= 1.81029 MPa

Relaxation of Prestressing Strands - Article 5.9.5.4.2c

Stress in tendons after transfer: f_{pt} = 1275.83 MPa
Yield strength of prestressing steel: f_{py} = 1675.43 MPa
Time between tensioning and deck placement: $t = t_s - t_i$ = 60.0- 4.0 = 56.0day
Factor for relaxation steel type: K'_L = 45.0 (low relaxation)

$$\text{Loss of prestress} = \frac{f_{pt}}{K'_L}.\frac{\log(24t)}{\log(24t_i)}.\left[\frac{f_{pt}}{f_{py}} - 0.55\right].\left[1- \frac{3(\Delta f_{pSR}+\Delta f_{pCR})}{f_{pt}}\right].K_{id}$$

$$= \frac{1275.8}{45.0}*\frac{\log(24*56.0)}{\log(24* 4.0)}*\left[\frac{1275.8}{1675.4}-0.55\right]\left[1- \frac{3*(35.495+79.142)}{1275.8}\right]*0.85$$

$$= 5.87309 \text{ MPa}$$

$$= \Delta f_{pR1}$$

Total relaxation loss of force = $\Delta f_{pR1}.A_{ps}$
= 5.8731*3944.8
= 23.168069 kN

Corresponding loss of moment = 23.168*0.2080
= 4.8196938 kN.m
(about y = 0)

Moment about the centroid of the composite beam:
M_{rx} = 4.81969-(23.1681*0.5149)
= -7.1106 kN.m

Corresponding stresses:
top stress = 23.1681/360967+-7.11061/ 8.31E7
= 0.0641833+-0.085567
= -0.0213834 MPa

bottom stress = 23.1681/360967+-7.11061/-1.014E8
= 0.0641833+0.0701567
= 0.13434 MPa

Erection of beam Loading

Bending moment from erection loadcase at current span location:
$M_{Applied}$ = 647.3922 kN.m
Corresponding stresses:
top stress = 647.3922/8.31E7
= 7.7905 MPa
bottom stress = 647.3922/-1.014E8
= -6.3875 MPa

Remove the dead load applied for transfer calculations
M_{sw} = -545.37 kN.m
Corresponding stresses:
top stress = -545.37/8.31E7
= -6.5628 MPa
bottom stress = -545.37/-1.014E8
= 5.38086 MPa

PERMISSIBLE STRESSES IN PRECAST BEAM

Compression

Article 5.9.4.2.1 for permament loads

Permissible compression stress = 0.45 * f'_c
= 0.45 * 55.1581
= 24.8211 MPa

Tension

Article 5.9.4.2.2

Permissible tension stress = -0.5 * $\sqrt{f'_c}$
= -0.5 * √55.1581
= -3.70451 MPa

SERVICE LIMIT STATE - STRESS SUMMARY TABLE

			Concrete Stresses (MPa)			
	force	moment	Cast In Place		Precast	
	kN	kN.m	top	bottom	top	bottom
Prestress	5507.66	-1703.5			-5.2413	32.0656
Self Weight		545.368			6.56278	-5.3809
Prestress + Self Wt.					1.32148	26.6848
Elastic Def	-474.77	158.837			0.59611	-2.8825
TRANSFER	5032.88	-999.3			1.91759	23.8023
Erection		102.024			1.22773	-1.0066
TOTAL PERMANENT					3.14532	22.7957

SLS FLEXURE
calculated using curvature of uncracked sections

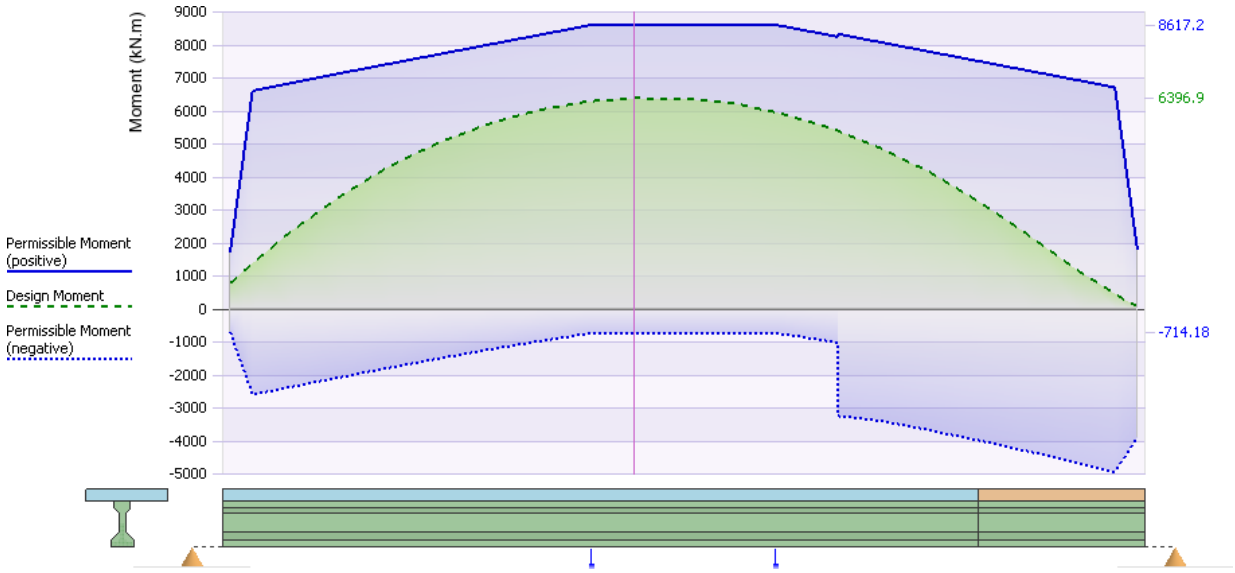
The deflections are calculated from integration of the curvatures along the beam, using the parameters detailed below:

Elastic Modulus at Transfer, E_T = 32.3777 kN/mm²
Intermediate Term Elastic Modulus, E_I = 22.0714 kN/mm²
$E_I = E_C/(\psi(t,t_i)+1)$
where $\psi(t,t_i)$ = 0.69388 (Article 5.14.2.3.6)]

Precast section height = 1143.0 mm

		Precast Stress (MPa)	E	Strain ($x10^{-6}$)	Curvature ($x10^{-6}$) (rad/m)	Deflection (mm) Here	Max.
At Transfer	T	1.92514	E_T	59.4591	-591.01	28.7861	30.3361
	B	23.7969		734.979			
At Erection	T	3.59084	E_I	162.692	-651.82	34.4532	36.1437
	B	20.0348		907.726			

Girder Design Calculations: Live Load Bending



Effects ignored within 0.2m from each beam end.

Performance ratio = 6397 / 8617 = 0.742

Section details:

Ref 1 "Section 1"
at 0.446 x span = 0.446 x 23.1136 = 10.3261 m from left end of beam

Design Code:

AASHTO LRFD Bridge Design Specifications
Sixth Edition with 2013 Interim Revisions

Analysis:

Live Load Bending Moments
Transient Load BM 1 : [Max +ve]
Limit State - Strength I

Approximate Methods of Analysis are used - Article 4.6.2
Live Load Distribution Factor for +ve Moment = 0.94124 lanes/beam
Live Load Distribution Factor for -ve Moment = 0.94124 lanes/beam
Live Load Distribution Factor for Shear = 0.94124 lanes/beam
Live Load Distribution Factor for Fatigue = 0.78437 lanes/beam

Strength Limit State Stress/Strain summary for section with NEGATIVE moment

height of neutral axis = 228.627 mm
depth in compression = 228.627 mm

Resistance Factor (φ) from Article 5.5.4.2.1

Type of force effect is:
Non-tension-controlled and non-compression-controlled
Compression-controlled strain limit in the extreme tension steel (5.7.2.1)

$$\varepsilon_{cl} = -0.002$$

Tension-controlled strain limit in the extreme tension steel (5.7.2.1)

$$\varepsilon_{tl} = -0.005$$

Net tensile strain in extreme steel at nominal resistance

$$\varepsilon_t = -0.00433$$

prestressed section:

$$0.75 <= \varphi = 0.75 + 0.25\left[\frac{eps_t - eps_{cl}}{eps_{tl} - eps_{cl}}\right] <= 1.0 \quad \text{(Eq.: 5.5.4.2.1-1)}$$

$$0.75 + 0.25\left[\frac{-0.0043 - -0.002}{-0.005 - -0.002}\right]$$

$$= 0.94433$$

$$\varphi = 0.94433$$

Location		strain	stress MPa	height mm
Precast beam	- *top*	-0.011998	0.0	1143.0
	- *bottom*	0.003	46.8843	0.0
C.I.P. stage 1	- *top*	-0.015935	0.0	1443.0
	- *bottom*	-0.011998	0.0	1143.0
Tendon	- *top*	-0.011013	-1674.9	558.8
	- *bottom*	-0.004054	-798.58	50.8

Ultimate Strength capacity of section = -756.287*0.94433
= -714.185 kN.m

Strength Limit State Stress/Strain summary for section with POSITIVE moment

height of neutral axis = 1293.47 mm
depth in compression = 149.53 mm

Resistance Factor (φ) from Article 5.5.4.2.1

Type of force effect is:
Tension-controlled prestressed concrete:
φ = 1.00

Location		strain	stress MPa	height mm
Precast beam	- *top*	-0.003019	0.0	1143.0
	- *bottom*	-0.025951	0.0	0.0
C.I.P. stage 1	- *top*	0.003	29.3027	1443.0
	- *bottom*	-0.003019	0.0	1143.0
Tendon	- *top*	-0.02142	-1860.0	558.8
	- *bottom*	-0.031319	-1860.0	50.8

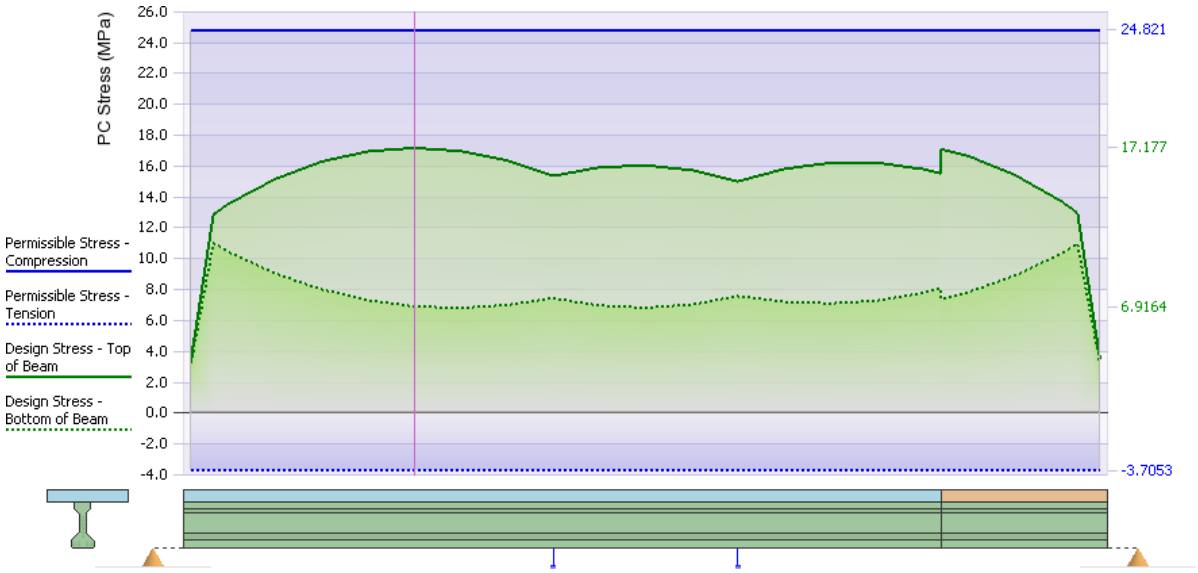
Ultimate Strength capacity of section = 8617.17*1
= 8617.17 kN.m

SUMMARY OF APPLIED LOADINGS

	BENDING MOMENT kN.m	AXIAL kN
Erection loading before composite	= 832.97427	0.0
Erection loading to stage 1A	= 1266.3321	0.0
Erection loading to stage 1B	= 100.08702	0.0
Wearing Surface loading	= 229.84975	0.0
Differential Shrinkage / Creep is	not adverse	
Transient loading	= 3967.636	0.0
TOTAL	6396.8791	0.0

Note:
The following effects are not considered (article 3.4.1) -
differential settlement
temperature gradient

Girder Design Calculations: Construction Stage



Effects ignored within 0.2m from each beam end.

Performance ratio = 17.2 / 24.8 = 0.692

Section details:

Ref 1 "Section 1"
at 0.25 x span = 0.25 x 23.1136 = 5.77841 m from left end of beam

Design Code:

AASHTO LRFD Bridge Design Specifications
Sixth Edition with 2013 Interim Revisions

Analysis:

Construction stage stresses
Limit State - Service I

ACTUAL STRESSES IN PRECAST BEAM

40 tendons are fully bonded at this section
0 tendons are fully debonded at this section
22 tendons are harped at this section

INITIAL PRESTRESS

height mm	No of tendons	f_{pu} MPa	area mm²	% of f_{pu}	initial force kN
50.8	8	1861.58	98.71	75.0	1102.542
251.1	2	1861.58	98.71	75.0	275.17634
101.6	8	1861.58	98.71	75.0	1102.542
301.9	2	1861.58	98.71	75.0	275.17634
152.4	2	1861.58	98.71	75.0	275.6355
352.7	2	1861.58	98.71	75.0	275.17634
403.5	2	1861.58	98.71	75.0	275.17634
454.3	2	1861.58	98.71	75.0	275.17634
505.1	2	1861.58	98.71	75.0	275.17634
555.9	2	1861.58	98.71	75.0	275.17634
606.7	2	1861.58	98.71	75.0	275.17634
657.5	2	1861.58	98.71	75.0	275.17634
708.3	2	1861.58	98.71	75.0	275.17634
759.1	2	1861.58	98.71	75.0	275.17634
TOTAL	40				5507.6592

Transverse Eccentricity

Tendon layout is symmetrical about the vertical centroidal axis.

INITIAL RELAXATION - Article 5.9.5.4.4b

Data has the time from stressing to transfer set to zero, indicating that initial relaxation is not required to be calculated here.

				relax.	After relaxation		
height mm	No of tendons	f_{pj}	f_{py} MPa	loss	area mm²	force kN	moment kN.m
50.8	8	1396.19	1675.43	0.0	98.71	1102.542	56.009134
251.1	2	1393.86	1675.43	0.0	98.71	275.17634	69.096658
101.6	8	1396.19	1675.43	0.0	98.71	1102.542	112.01827
301.9	2	1393.86	1675.43	0.0	98.71	275.17634	83.075615
152.4	2	1396.19	1675.43	0.0	98.71	275.6355	42.006851
352.7	2	1393.86	1675.43	0.0	98.71	275.17634	97.054573
403.5	2	1393.86	1675.43	0.0	98.71	275.17634	111.03353
454.3	2	1393.86	1675.43	0.0	98.71	275.17634	125.01249
505.1	2	1393.86	1675.43	0.0	98.71	275.17634	138.99145
555.9	2	1393.86	1675.43	0.0	98.71	275.17634	152.97041
606.7	2	1393.86	1675.43	0.0	98.71	275.17634	166.94936
657.5	2	1393.86	1675.43	0.0	98.71	275.17634	180.92832
708.3	2	1393.86	1675.43	0.0	98.71	275.17634	194.90728
759.1	2	1393.86	1675.43	0.0	98.71	275.17634	208.88624
TOTAL	40					5507.6592	1738.9402

```
Moment about the centroid of the precast beam:
           Mr = 1738.9402-(5507.6592*0.514946)
              = -1097.206 kN.m
Corresponding stresses:
      top stress = 5507.66/360.967+-1097.21/  8.31E7
                 = 15.258068+-13.20342
                 = 2.05465 MPa
   bottom stress = 5507.66/360.967+-1097.21/-1.014E8
                 = 15.258068+ 10.82557
                 = 26.0836 MPa


Self weight moment:
  c.s.a.      = 3.61E5 mm²
  density     = 23.5631 kN/m³
  self weight = 3.61E5*23.5631
              = 8.50551 kN/m
  beam length = 23.1136 m
  distance    = 5.77841 m
  Msw         = 0.5*8.50551*5.77841*(23.1136-5.77841)
              = 425.999 kN.m
Corresponding stresses:
  top stress     = 425.999/8.31E7
                 = 5.12633 MPa
  bottom stress  = 425.999/-1.014E8
                 = -4.2031 MPa
```

ELASTIC SHORTENING LOSSES - Article 5.9.5.2.3a

```
concrete stresses at mid-span:
          stress at top of precast beam = 8.88976 MPa
       stress at bottom of precast beam = 20.4795 MPa
                 depth of precast beam =  1143.0 mm
```

height mm	No of tendons	conc stress MPa	E_p/E_{ci}	tendon force kN	tendon moment kN.m
50.8	8	19.96439	6.084443	95.924161	4.8729474
251.1	2	17.9334	6.084443	21.541438	5.4090455
101.6	8	19.44929	6.084443	93.449231	9.4944419
301.9	2	17.4183	6.084443	20.922705	6.3165555
152.4	2	18.93419	6.084443	22.743576	3.4661209
352.7	2	16.9032	6.084443	20.303973	7.1612023
403.5	2	16.3881	6.084443	19.685241	7.9429859
454.3	2	15.87301	6.084443	19.066508	8.6619063
505.1	2	15.35791	6.084443	18.447776	9.3179635
555.9	2	14.84281	6.084443	17.829044	9.9111575
606.7	2	14.32771	6.084443	17.210311	10.441488
657.5	2	13.81261	6.084443	16.591579	10.908956
708.3	2	13.29751	6.084443	15.972847	11.31356
759.1	2	12.78241	6.084443	15.354114	11.655301
TOTAL	40			415.0425	116.87363

Moment about the centroid of the precast beam:

M_{ed} = 116.87363-(415.0425*0.514946)
= -96.85078 kN.m

hence top stress = 8.8898-415.043/360.967--96.8508/ 8.31E7
= 8.8898-1.1498073- -1.16547
= 8.90542 MPa
bottom stress = 20.479-415.043/360.967--96.8508/-1.014E8
= 20.479-1.1498073-0.9555770
= 18.3741 MPa

After a further 2 iterations of the above process, the top and bottom stresses are as follows:
top stress = 8.8897 MPa
bottom stress = 18.5542 MPa

REFINED ESTIMATES OF TIME-DEPENDENT LOSSES - Article 5.9.5.4

Elastic modulus of prestressing steel: E_p = 197.0 kN/mm²
Total effective tendon area: A_{ps} = 3944.8 mm²
Elastic modulus of concrete at transfer: E_{ci} = 32.378 kN/mm²
Percentage relative humidity: H = 70.0 %
Humidity factor for creep: k_{hc} = 1.56-0.008H = 1.0
Humidity factor for shrinkage: k_{hs} = 2.00-0.014H = 1.02
Age at the end of curing: t_c = 3.0 day
Age at transfer: t_i = 4.0 day
Age at in-situ casting: t_d = 60.0 day
Final age: t_f = 120.0 day
Comp. strength of conc. at 1st loading: f'_{ci} = 41.37 MPa

Factor for the effect of concrete strength: $k_f = \frac{35.0}{7+f'_{ci}} = \frac{35.0}{7+41.4} = 0.7236$

Time factor for creep at final time: $k_{tdc,f,i} = \frac{t_f - t_i}{61 - 0.58 * f'_{ci} + t_f - t_i}$

$= \frac{120.0 - 4.0}{61 - 0.58 * 41.4 + 120.0 - 4.0}$

$= 0.7581$

Time fac. for shrinkage at final time: $k_{tds,f,i} = \frac{t_f - t_c}{61 - 0.58 * f'_{ci} + t_f - t_c}$

$= \frac{120.0 - 3.0}{61 - 0.58 * 41.4 + 120.0 - 3.0}$

$= 0.7597$

Losses: Time of Transfer to Time of Deck Placement - Article 5.9.5.4.2

Gross area of section: $A_g = 3.61E5\ mm^2$

Perimeter of section: $p = 3503.7\ mm$

Volume to surface ratio: $V/S = A_g/p = 103.02\ mm$

Factor for the effect of the volume: $k_s = 1.45 - 0.0051 * (V/S) = 0.9245$

Creep coefficient at final time:

$\psi_b(t_f, t_i) = 1.9 * k_s . k_{hc} . k_f . k_{tdc,f,i} . t_i^{-0.118}$

$= 1.9 * 0.9245 * 1.0 * 0.7236 * 0.7581 * 4.0^{-0.118}$

$= 0.8182$

Inertia of the gross concrete section: $I_g = 5.22E10\ mm^4$

Eccentricity of prestressing force: $e_{pg} = -196.91\ mm$

Transformed section coefficient:

$$K_{id} = \frac{1}{1 + \frac{E_p}{E_{ci}}.\frac{A_{ps}}{A_g}\left[1+\frac{A_g.e_{pg}^2}{I_g}\right].[1+0.7*\psi_b(t_f,t_i)]}$$

$$= \frac{1}{1 + \frac{197.0}{32.378}*\frac{3944.8}{3.61E5}\left[1+\frac{3.61E5*-196.9^2}{5.2E10}\right]*(1+0.7*0.8182)}$$

$$= 0.88290$$

Time factor for creep at deck placement:

$$k_{tdc,d,i} = \frac{t_d - t_i}{61 - 0.58*f'_{ci} + t_d - t_i}$$

$$= \frac{60.0-4.0}{61-0.58*41.4+60.0-4.0}$$

$$= 0.602$$

Time factor for shrinkage at deck placement:

$$k_{tds,d,i} = \frac{t_d - t_c}{61 - 0.58*f'_{ci} + t_d - t_c}$$

$$= \frac{60.0-3.0}{61-0.58*41.4+60.0-3.0}$$

$$= 0.606$$

Shrinkage of Girder Concrete - Article 5.9.5.4.2a

Concrete shrinkage strain of girder: $\varepsilon_{bid} = k_s.k_{hs}.k_f.k_{tds,d,i}*0.00048$

$= 1.0*1.02*0.71*0.60*0.00048$

$= 2.121E-4$

Loss of prestress $= \varepsilon_{bid}.E_p.K_{id}$

$= 2.12E-4*197.0*0.88036$

$= 36.778$ MPa

$= \Delta f_{pSR}$

Total shrinkage loss of force = $\Delta f_{pSR}.A_{ps}$
= 36.7781*3944.78
= 145.081 kN

Corresponding gain of moment = 145.081*0.31804
(about y = 0) = 46.1417 kN.m

Moment about the centroid of the composite beam:
M_{sh} = 46.1417-(145.081*0.51494)
= -28.567 kN.m

Corresponding stresses:
top stress = 145.081/360967+-28.5674/8.31E7
= 0.4019245+-0.343770
= 0.0581537 MPa

bottom stress = 145.081/360967+-28.5674/-1.014E8
= 0.4019245+0.2818600
= 0.683785 MPa

Creep of Girder Concrete - Article 5.9.5.4.2b

Creep coefficient at deck placement:
$\psi_b(t_d,t_i) = 1.9k_s.k_{hc}.k_f.k_{tdc,d,i}.t_i^{-0.118}$
$= 1.9*1.0*1.0*0.7142*0.6021*4.0^{-0.118}$
= 0.6938

Concrete stress at the center of gravity of prestressing tendons:
concrete stresses at transfer:
at top of precast beam = 9.04277 MPa
at bottom of precast beam = 20.354 MPa
at center of gravity of prestress: f_{cgp} = 17.2067 MPa

Loss of prestress = $\frac{E_p}{E_{ci}}.f_{cgp}.\psi_b(t_d,t_i).K_{id}$
$= \frac{197.0}{32.3777}*17.207*0.6938*0.8821$
= 64.0856 MPa
= Δf_{pCR}

Total creep loss of force = $\Delta f_{pCR}.A_{ps}$
= 64.0856*3944.78
= 252.804 kN

Corresponding loss of moment = 252.804*0.31804
= 80.4017 kN.m
(about y = 0)

Moment about the centroid of the composite beam:
M_{cr} = 80.4017-(252.804*0.51494)
= -49.779 kN.m

Corresponding stresses:
top stress = 252.804/3.61E5+-49.779/8.31002E7
= 0.70035+-0.5990
= 0.10133 MPa

bottom stress = 252.804/3.61E5+-49.779/-1.0135E8
= 0.70035+0.49114
= 1.19149 MPa

Relaxation of Prestressing Strands - Article 5.9.5.4.2c

Stress in tendons after transfer: f_{pt} = 1299.38 MPa
Yield strength of prestressing steel: f_{py} = 1675.43 MPa
Time between tensioning and deck placement: $t = t_s - t_i$ = 60.0- 4.0 = 56.0day
Factor for relaxation steel type: K'_L = 45.0 (low relaxation)

$$\text{Loss of prestress} = \frac{f_{pt}}{K'_L}.\frac{\log(24t)}{\log(24t_i)}.\left[\frac{f_{pt}}{f_{py}} - 0.55\right].\left[1- \frac{3(\Delta f_{pSR}+\Delta f_{pCR})}{f_{pt}}\right].K_{id}$$

$$= \frac{1299.4}{45.0}*\frac{\log(24*56.0)}{\log(24* 4.0)}*\left[\frac{1299.4}{1675.4}-0.55\right]\left[1- \frac{3*(36.778+64.086)}{1299.4}\right]*0.88$$

$$= 6.94164 \text{ MPa}$$

$$= \Delta f_{pR1}$$

Total relaxation loss of force = $\Delta f_{pR1}.A_{ps}$
= 6.9416*3944.8
= 27.383265 kN

Corresponding loss of moment = 27.383*0.3180
= 8.7089704 kN.m
(about y = 0)

Moment about the centroid of the composite beam:
M_{rx} = 8.70897-(27.3833*0.5149)
= -5.3919 kN.m

Corresponding stresses:
top stress = 27.3833/360967+-5.39193/ 8.31E7
= 0.0758609+-0.064885
= 0.0109762 MPa

bottom stress = 27.3833/360967+-5.39193/-1.014E8
= 0.0758609+0.0531994
= 0.12906 MPa

Erection of beam Loading

Bending moment from erection loadcase at current span location:
$M_{Applied}$ = 505.89017 kN.m
Corresponding stresses:
top stress = 505.89017/8.31E7
= 6.08772 MPa
bottom stress = 505.89017/-1.014E8
= -4.9914 MPa

Remove the dead load applied for transfer calculations
M_{sw} = -426.0 kN.m
Corresponding stresses:
top stress = -426.0/8.31E7
= -5.1263 MPa
bottom stress = -426.0/-1.014E8
= 4.20311 MPa

Construction stage 1A Loading

$M_{Applied}$ = 783.32263 kN.m
Corresponding stresses:
top stress = 783.32263/8.31E7
= 9.42625 MPa
bottom stress = 783.32263/-1.014E8
= -7.7286 MPa

Construction stage 1B Loading

$M_{Applied}$ = 44.810547 kN.m
Corresponding stresses:
top stress = 44.810547/8.31E7
= 0.53923 MPa
bottom stress = 44.810547/-1.014E8
= -0.4421 MPa

Losses: Time of Deck Placement to Final Time - Article 5.9.5.4.3

Gross composite section area: A_c = 9.72E5 mm²
Perimeter of section: p = 7365.6 mm
Volume to surface ratio: $V/S = A_c/p$ = 131.99 mm
Factor for the effect of the volume: k_s = 1.45-0.0051*(V/S) = 0.7768
Creep coefficient at final time:

$$\psi_b(t_f,t_i) = 1.9*k_s.k_{hc}.k_f.k_{tdc,f,i}.t_i^{-0.118}$$
$$= 1.9*0.776*1.0*0.723*0.758*4.0^{-0.118}$$
$$= 0.6875$$

Inertia of the net concrete section: I_c = 1.94E8 mm⁴
Eccentricity of prestressing force: e_{pc} = 0.6860 mm
Transformed section coefficient:

$$K_{df} = \frac{1}{1 + \frac{E_p}{E_{ci}}.\frac{A_{ps}}{A_c}\left[1+\frac{A_c.e_{pc}^2}{I_c}\right].[1+0.7*\psi_b(t_f,t_i)]}$$

$$= \frac{1}{1 + \frac{197.0}{32.378}*\frac{3944.8}{9.72E5}\left[1+\frac{9.72E5*686.07^2}{1.9E11}\right]*(1+0.7*0.6875)}$$

$$= 0.89066$$

Shrinkage of Girder Concrete - Article 5.9.5.4.3a

Concrete shrinkage strain of girder: $\varepsilon_{bdf} = k_s.k_{hs}.k_f.k_{tds,f,i}*0.00048$
= 1.0*1.02*0.71*0.76*0.00048
= 2.657E-4

Loss of prestress = $\varepsilon_{bdf}.E_p.K_{df}$
= 2.66E-4*1.97E8*0.88217
= 46.1743 MPa
= Δf_{pSD}

Total shrinkage loss of force = $\Delta f_{pSD}.A_{ps}$
= 46.1743*3944.78
= 182.147 kN

Corresponding gain of moment = 182.147*0.31804
(about y = 0) = 57.9302 kN.m

Moment about the centroid of the composite beam:
M_{sh} = 57.9302-(182.147*0.9603)
= -116.99 kN.m

Corresponding stresses:
top stress = 182.147/844161+-116.986/9.901E8
= 0.2157735+-0.118153
= 0.0976197 MPa

bottom stress = 182.147/844161+-116.986/-1.884E8
= 0.2157735+0.6210367
= 0.83681 MPa

Creep of Girder Concrete - Article 5.9.5.4.2b

Creep coefficient at deck placement:
$\psi_b(t_d,t_i) = 1.9k_s.k_{hc}.k_f.k_{tdc,d,i}.t_i^{-0.118}$
$= 1.9*1.0*1.0*0.7142*0.6021*4.0^{-0.118}$
= 0.6938

Creep coefficient at final time:
$\psi_b(t_f,t_d) = 1.9k_s.k_{hc}.k_f.k_{tdc,f,i}.t_d^{-0.118}$
$= 1.9*1.0*1.0*0.7142*0.6185*60.0^{-0.118}$
= 0.5178

Concrete stress at the center of gravity of prestressing tendons:
concrete stresses at transfer:
at top of precast beam = 9.04277 MPa
at bottom of precast beam = 20.354 MPa
at center of gravity of prestress: f_{cgp} = 17.2067 MPa

Change in concrete stress at centroid of prestressing strands:
concrete stress change after permanent loads:
at top of precast beam = 12.1466 MPa
at bottom of precast beam = 11.3949 MPa
Δf_{cd} = 11.604 MPa

$$\text{Loss of prestress} = \frac{E_p}{E_{ci}} * f_{cgp} * \left[\psi_b(t_f,t_i) - \psi_b(t_d,t_i) \right] * K_{df}$$
$$+ \frac{E_p}{E_c} * \Delta f_{cd} * \psi_b(t_f,t_d) * K_{df}$$
$$= \frac{197.0}{32.3777} * 17.2067 * (0.87367 - 0.69388) * 0.88036$$
$$+ \frac{197.0}{18.6932} * 11.604 * 0.51782 * 0.88036$$
$$= 72.3196 \text{ MPa}$$
$$= \Delta f_{pCD}$$

Total creep loss of force = $\Delta f_{pCD} * A_{ps}$
= 72.3196*3944.78
= 285.285 kN

Corresponding loss of moment = 285.285*0.31804
= 90.7321 kN.m
(about y = 0)

Moment about the centroid of the composite beam:
M_{cr} = 90.7321-(285.285*0.9603)
= -183.23 kN.m

Corresponding stresses:

top stress = 285.285/8.442E5+-183.23/9.90117E8
= 0.33795+-0.1850
= 0.15289 MPa

bottom stress = 285.285/8.442E5+-183.23/-1.8837E8
= 0.33795+0.97268
= 1.31064 MPa

Relaxation of Prestressing Strands - Article 5.9.5.4.3c

Loss of prestress = Δf_{pR1}
= 6.94164 MPa
= Δf_{pR2}

Total relaxation loss of force = $\Delta f_{pR2}.A_{ps}$
= 6.9416*3944.8
= 27.383265 kN

Corresponding loss of moment = 27.383*0.3180
= 8.7089704 kN.m
(about y = 0)

Moment about the centroid of the composite beam:
M_{rx} = 8.70897-(27.3833*0.9603)
= -17.587 kN.m

Corresponding stresses:
top stress = 27.3833/844161+-17.5872/9.901E8
= 0.0324385+-0.017763
= 0.0146757 MPa

bottom stress = 27.3833/844161+-17.5872/-1.884E8
= 0.0324385+ 0.093364
= 0.125802 MPa

Shrinkage of Deck Concrete - Article 5.9.5.4.3d

Concrete shrinkage strain of girder: $\varepsilon_{ddf} = k_s.k_{hs}.k_f.k_{tds,f,i}$*0.00048
= 1.025*1.02*0.71*0.76*0.00048
= 2.724E-4

Creep coefficient at final time:
$\psi_b(t_f,t_d) = 1.9k_s.k_{hc}.k_f.k_{tdc,f,i}.t_d^{-0.118}$
$= 1.9*1.0253*1.0*0.7142*0.6185*60.0^{-0.118}$
= 0.5309

Change in concrete stress at centroid of prestressing strands:

Area of deck concrete: A_d = 6.112E5 mm²
Perimeter of section: p = 7365.55 mm
Volume to surface ratio: $V/S = A_d/p$ = 82.98 mm
Factor for the effect of the volume: k_s = 1.45-0.0051*(V/S) = 1.4333
Modulus of elasticity of deck concrete: E_{cd} = 29.5566 mm²
Eccentricity of the deck: e_d = 288.894 mm³

$$\Delta f_{cdf} = \frac{\varepsilon_{ddf}.A_d.E_{cd}}{[1+0.7\psi_b(t_f,t_d)]}\left[\frac{1}{A_c}-\frac{e_{pc}.e_d}{I_c}\right]$$

$$= \frac{2.7E\text{-}4*6.11E5*29.557*1000}{[1+0.7*0.5309]}\left[\frac{1}{8.44E5}-\frac{642.261*288.894}{1.8E11}\right]$$

$$= 0.57008 \text{ MPa}$$

$$\text{Loss of prestress} = \frac{E_p}{E_c}.\Delta f_{cdf}.K_{df}.[1+0.7\psi_b(t_f,t_d)]$$

$$= \frac{197.0}{18.6932}*0.57008*0.88217\ *(1+0.7*0.53092)$$

$$= 7.26975 \text{ MPa}$$

$$= \Delta f_{pSS}$$

Total shrinkage gain of force = $\Delta f_{pSS}.A_{ps}$
= 7.26975*3944.78
= 28.6776 kN

Corresponding gain of moment (about y = 0) = 28.6776*0.31804
= 9.12061 kN.m

Moment about the centroid of the composite beam:
M_{sh} = 9.12061-(28.6776*0.9603)
= -18.418 kN.m

Corresponding stresses:
top stress = 28.6776/844161+-18.4185/9.901E8
= 0.0339717+-0.018602
= 0.0153694 MPa

bottom stress = 28.6776/844161+-18.4185/-1.884E8
= 0.0339717+0.097777
= 0.131749 MPa

PERMISSIBLE STRESSES IN PRECAST BEAM

Compression

Article 5.9.4.2.1 for permament loads
Permissible compression stress = 0.45 * f'_c
= 0.45 * 55.1581
= 24.8211 MPa

Tension

Article 5.9.4.2

Permissible tension stress = $-0.5 * \sqrt{f'_c}$
= $-0.5 * \sqrt{55.1581}$
= -3.70451 MPa

PERMISSIBLE STRESSES FOR CAST IN PLACE CONCRETE

Compression

Article 5.9.4.2

char. strength of c.i.p. concrete = 34.4738 MPa
stress limitation factor = 0.6
permissible compression stress = $0.6 * f_{cu}$
= 0.6 * 34.4738
= 20.6843 MPa

Tension

Article 5.7.3.4

Flexural tensile stresses may need to be limited by cracking considerations in accordance with article 5.7.3.4.

SERVICE LIMIT STATE - STRESS SUMMARY TABLE

			Concrete Stresses (MPa)			
	force	moment	Cast In Place		Precast	
	kN	kN.m	top	bottom	top	bottom
Prestress	5507.66	-1097.2			2.05465	26.0836
Self Weight		425.999			5.12633	-4.2031
Prestress + Self Wt.					7.18098	21.8805
Elastic Def	-381.88	87.9095			-6.1E-5	-1.9253
TRANSFER	5125.78	-583.3			7.18092	19.9552

Erection		79.8913			0.96138	-0.7882
C.I.P. Stage 1A		783.323			9.42625	-7.7286
C.I.P. Stage 1B		44.8105	0.09453	0.03578	0.04526	-0.2378
Time-Dependent Losses						
Time of Transfer to Time of Deck Placement						
Shrinkage	-145.08	28.5674			-0.0582	-0.6837
Creep	-252.8	49.7786			-0.1013	-1.1915
Relaxation	-27.383	5.39193			-0.011	-0.1290
Time of Deck Placement to Final Time						
Shrinkage						
Girder	-182.15	116.986	0.07621	-0.0772	-0.0976	-0.8368
Deck	-1.4094	0.90517	5.9E-4	-6.0E-4	-7.6E-4	-0.0065
Creep	-285.29	183.227	0.11935	-0.1208	-0.1529	-1.3106
Relaxation	-27.383	17.5872	0.01146	-0.0116	-0.0147	-0.1258
TOTAL PERMANENT			0.20760	-0.2102	17.1774	6.9164

SLS FLEXURE
calculated using curvature of uncracked sections

The deflections are calculated from integration of the curvatures along the beam, using the parameters detailed below:

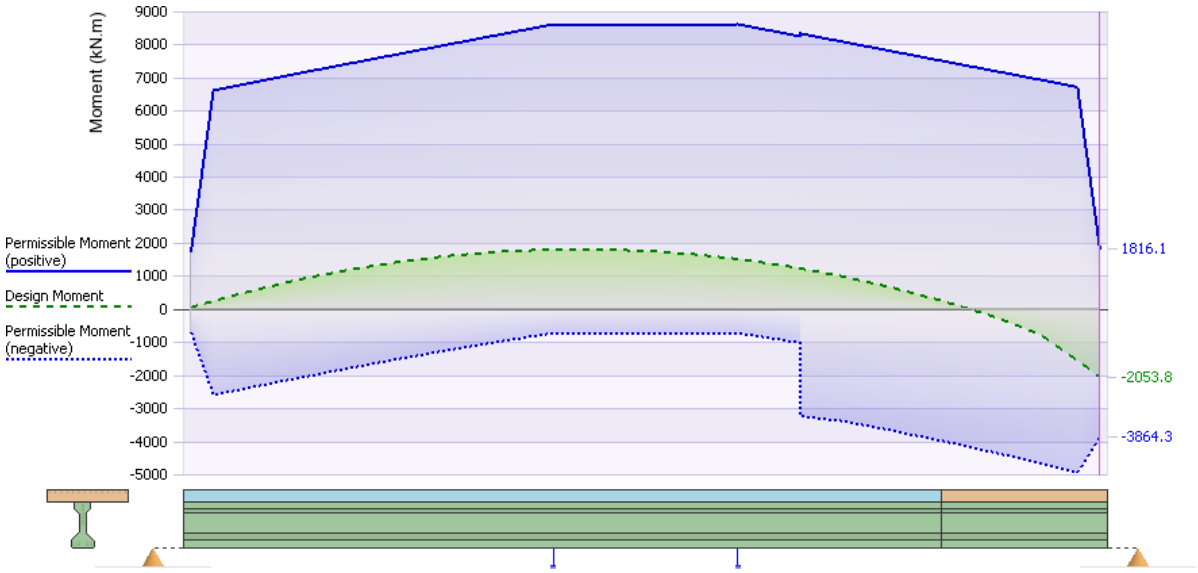
Elastic Modulus at Transfer, E_T = 32.3777 kN/mm²
Intermediate Term Elastic Modulus, E_I = 22.0714 kN/mm²
$E_I = E_C/(\psi(t,t_i)+1)$
where $\psi(t,t_i)$ = 0.69388 (Article 5.14.2.3.6)]
Short Term Elastic Modulus, E_S = 37.3865 kN/mm²

Precast section height = 1143.0 mm

		Precast Stress (MPa)	E	Precast Strain (x10^{-6})	Curvature (x10^{-6}) (rad/m)	Deflection (mm) Here	Max.
At Transfer	T	8.6673	E_T	267.694	-275.14	17.427	30.3361
	B	18.8497		582.183			
At Erection	T	9.14173	E_I	414.188	-286.39	22.0707	36.1437
	B	16.3666		741.527			
From in situ 1A	T	8.06855	E_S	215.814	343.624	-20.148	-31.482

	$_{B}$	-6.6155	-176.95			
From in situ 1B	^{T}	0.03621	E_S 0.96841	5.30056	-0.6323	-1.2659
	$_{B}$	-0.1903	-5.0901			

Girder Design Calculations: Live Load Bending



Effects ignored within 0.2m from each beam end.

Performance ratio = -2054 / -3864 = 0.531

Section details:

Ref 2 "Section 2"
at 0.991 x span = 0.991 x 23.1136 = 22.9136 m from left end of beam

Design Code:

AASHTO LRFD Bridge Design Specifications
Sixth Edition with 2013 Interim Revisions

Analysis:

Live Load Bending Moments
Transient Load BM 2 : [Max -ve]
Limit State - Strength I

Approximate Methods of Analysis are used - Article 4.6.2
Live Load Distribution Factor for +ve Moment = 0.94124 lanes/beam
Live Load Distribution Factor for -ve Moment = 0.94124 lanes/beam
Live Load Distribution Factor for Shear = 0.94124 lanes/beam
Live Load Distribution Factor for Fatigue = 0.78437 lanes/beam

Strength Limit State Stress/Strain summary for section with NEGATIVE moment

height of neutral axis = 144.439 mm
depth in compression = 144.439 mm

Resistance Factor (φ) from Article 5.5.4.2.1

Type of force effect is:
Tension-controlled reinforced concrete:
φ = 0.90

Location		strain	stress MPa	height mm
Precast beam	- *top*	-0.02074	0.0	1143.0
	- *bottom*	0.003	46.8843	0.0
C.I.P. stage 1	- *top*	-0.026971	0.0	1443.0
	- *bottom*	-0.02074	0.0	1143.0
Reinforcement	- *top*	-0.025671	-420.0	1380.4
	- *bottom*	-0.025671	-420.0	1380.4

Ultimate Strength capacity of section = -3877.05*0.9
= -3489.35 kN.m

Strength Limit State Stress/Strain summary for section with POSITIVE moment

height of neutral axis = 1401.03 mm
depth in compression = 41.9696 mm

Resistance Factor (φ) from Article 5.5.4.2.1

Type of force effect is:
Compression-controlled sections:
with spirals or ties, φ = 0.75

Location		strain	stress MPa	height mm
Precast beam	- *top*	-0.018444	0.0	1143.0
	- *bottom*	-0.100146	0.0	0.0
C.I.P. stage 1	- *top*	0.003	29.3027	1443.0
	- *bottom*	-0.018444	0.0	1143.0
Reinforcement	- *top*	-0.001475	-294.93	1380.4
	- *bottom*	-0.001475	-294.93	1380.4

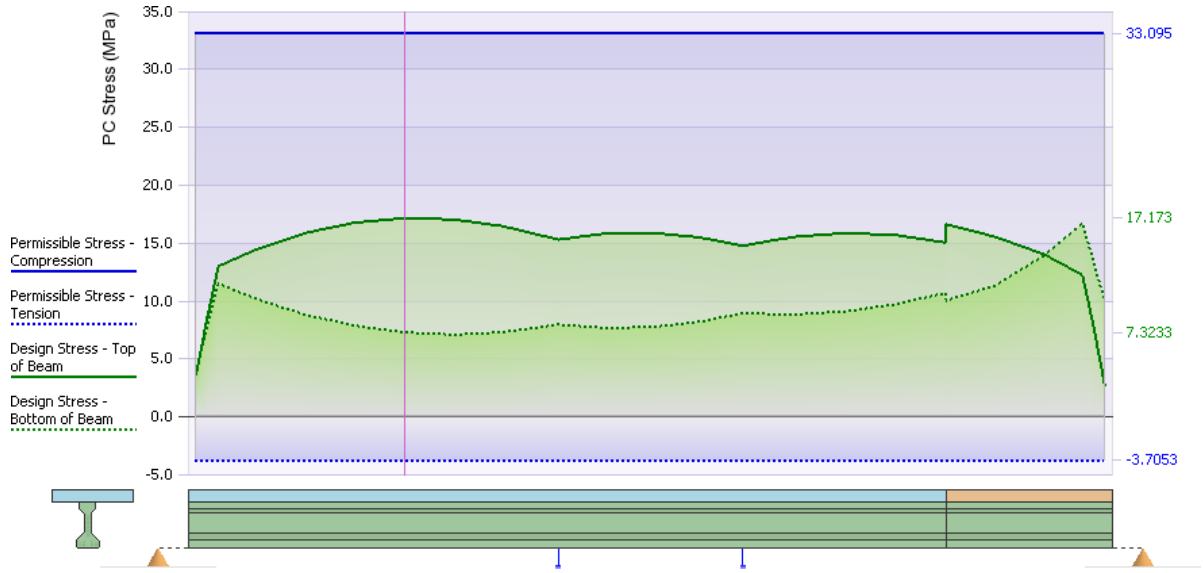
Ultimate Strength capacity of section = 69.7806*0.75
= 52.3354 kN.m

SUMMARY OF APPLIED LOADINGS

	BENDING MOMENT kN.m	AXIAL kN
Erection loading before composite	= 27.732897	0.0
Erection loading to stage 1A	= 30.68843	0.0
Erection loading to stage 1B	= 15.010684	0.0
Wearing Surface loading	= -161.854	0.0
Differential Shrinkage / Creep	= -10.79364	0.0
Transient loading	= -1965.399	0.0
TOTAL	-2064.615	0.0

Note:
The following effects are not considered (article 3.4.1) -
differential settlement
temperature gradient

Girder Design Calculations: Live Load Bending



Effects ignored within 0.2m from each beam end.

Performance ratio = 17.2 / 33.1 = 0.519

Section details:

Ref 1 "Section 1"
at 0.233 x span = 0.233 x 23.1136 = 5.40341 m from left end of beam

Design Code:

AASHTO LRFD Bridge Design Specifications
Sixth Edition with 2013 Interim Revisions

Analysis:

Live Load Bending Moments
Transient Load BM 2 : [Max -ve]
Limit State - Service I
& Service III
for Normal environment conditions [A5.9.4.2.2b]

Approximate Methods of Analysis are used - Article 4.6.2
Live Load Distribution Factor for +ve Moment = 0.94124 lanes/beam
Live Load Distribution Factor for -ve Moment = 0.94124 lanes/beam
Live Load Distribution Factor for Shear = 0.94124 lanes/beam
Live Load Distribution Factor for Fatigue = 0.78437 lanes/beam

ACTUAL STRESSES IN PRECAST BEAM

40 tendons are fully bonded at this section
0 tendons are fully debonded at this section
22 tendons are harped at this section

INITIAL PRESTRESS

height mm	No of tendons	f_{pu} MPa	area mm²	% of f_{pu}	initial force kN
50.8	8	1861.58	98.71	75.0	1102.542
272.736	2	1861.58	98.71	75.0	275.17634
101.6	8	1861.58	98.71	75.0	1102.542
323.536	2	1861.58	98.71	75.0	275.17634
152.4	2	1861.58	98.71	75.0	275.6355
374.336	2	1861.58	98.71	75.0	275.17634
425.136	2	1861.58	98.71	75.0	275.17634
475.936	2	1861.58	98.71	75.0	275.17634
526.736	2	1861.58	98.71	75.0	275.17634
577.536	2	1861.58	98.71	75.0	275.17634
628.336	2	1861.58	98.71	75.0	275.17634
679.136	2	1861.58	98.71	75.0	275.17634
729.936	2	1861.58	98.71	75.0	275.17634
780.736	2	1861.58	98.71	75.0	275.17634
TOTAL	40				5507.6592

Transverse Eccentricity

Tendon layout is symmetrical about the vertical centroidal axis.

INITIAL RELAXATION - Article 5.9.5.4.4b

Data has the time from stressing to transfer set to zero, indicating that initial relaxation is not required to be calculated here.

				relax.		After relaxation	
height mm	No of tendons	f_{pj}	f_{py} MPa	loss	area mm²	force kN	moment kN.m
50.8	8	1396.19	1675.43	0.0	98.71	1102.542	56.009134
272.736	2	1393.86	1675.43	0.0	98.71	275.17634	75.050456
101.6	8	1396.19	1675.43	0.0	98.71	1102.542	112.01827
323.536	2	1393.86	1675.43	0.0	98.71	275.17634	89.029414
152.4	2	1396.19	1675.43	0.0	98.71	275.6355	42.006851
374.336	2	1393.86	1675.43	0.0	98.71	275.17634	103.00837
425.136	2	1393.86	1675.43	0.0	98.71	275.17634	116.98733
475.936	2	1393.86	1675.43	0.0	98.71	275.17634	130.96629
526.736	2	1393.86	1675.43	0.0	98.71	275.17634	144.94525
577.536	2	1393.86	1675.43	0.0	98.71	275.17634	158.9242
628.336	2	1393.86	1675.43	0.0	98.71	275.17634	172.90316
679.136	2	1393.86	1675.43	0.0	98.71	275.17634	186.88212
729.936	2	1393.86	1675.43	0.0	98.71	275.17634	200.86108
780.736	2	1393.86	1675.43	0.0	98.71	275.17634	214.84004
TOTAL	40					5507.6592	1804.432

Moment about the centroid of the precast beam:

M_r = 1804.432-(5507.6592*0.514946)
= -1031.714 kN.m

Corresponding stresses:

top stress = 5507.66/360.967+-1031.71/ 8.31E7
= 15.258068+-12.41531
= 2.84276 MPa

bottom stress = 5507.66/360.967+-1031.71/-1.014E8
= 15.258068+10.179396
= 25.4375 MPa

Self weight moment:

c.s.a. = 3.61E5 mm²
density = 23.5631 kN/m³
self weight = 3.61E5*23.5631
= 8.50551 kN/m
beam length = 23.1136 m
distance = 5.40341 m
M_{sw} = 0.5*8.50551*5.40341*(23.1136-5.40341)
= 406.97 kN.m

Corresponding stresses:

top stress = 406.97/8.31E7
= 4.89735 MPa
bottom stress = 406.97/-1.014E8
= -4.0154 MPa

ELASTIC SHORTENING LOSSES - Article 5.9.5.2.3a

concrete stresses at mid-span:
stress at top of precast beam = 9.67786 MPa
stress at bottom of precast beam = 19.8333 MPa
depth of precast beam = 1143.0 mm

height mm	No of tendons	conc stress MPa	E_p/E_{ci}	tendon force kN	tendon moment kN.m
50.8	8	19.38196	6.084443	93.125732	4.7307872
272.736	2	17.41008	6.084443	20.912829	5.7036785
101.6	8	18.93061	6.084443	90.957086	9.2412399
323.536	2	16.95873	6.084443	20.370668	6.5906416
152.4	2	18.47925	6.084443	22.19711	3.3828396
374.336	2	16.50737	6.084443	19.828506	7.422521
425.136	2	16.05602	6.084443	19.286345	8.1993168
475.936	2	15.60467	6.084443	18.744183	8.9210291
526.736	2	15.15331	6.084443	18.202022	9.5876577
577.536	2	14.70196	6.084443	17.65986	10.199203
628.336	2	14.25061	6.084443	17.117699	10.755664
679.136	2	13.79925	6.084443	16.575537	11.257042
729.936	2	13.3479	6.084443	16.033376	11.703336
780.736	2	12.89655	6.084443	15.491214	12.094547
TOTAL	40			406.50217	119.7895

Moment about the centroid of the precast beam:
M_{ed} = 119.7895-(406.50217*0.514946)
= -89.5371 kN.m

hence top stress = 9.6779-406.502/360.967--89.5371/ 8.31E7
= 9.6779-1.1261477- -1.07746
= 9.62918 MPa
bottom stress = 19.833-406.502/360.967--89.5371/-1.014E8
= 19.833-1.1261477-0.8834166
= 17.8237 MPa

After a further 2 iterations of the above process, the top and bottom stresses are as follows:
top stress = 9.61749 MPa
bottom stress = 17.993 MPa

REFINED ESTIMATES OF TIME-DEPENDENT LOSSES - Article 5.9.5.4

Elastic modulus of prestressing steel: E_p = 197.0 kN/mm²

Total effective tendon area: A_{ps} = 3944.8 mm²

Elastic modulus of concrete at transfer: E_{ci} = 32.378 kN/mm²

Percentage relative humidity: H = 70.0 %

Humidity factor for creep: $k_{hc} = 1.56-0.008H = 1.0$

Humidity factor for shrinkage: $k_{hs} = 2.00-0.014H = 1.02$

Age at the end of curing: t_c = 3.0 day

Age at transfer: t_i = 4.0 day

Age at in-situ casting: t_d = 60.0 day

Final age: t_f = 120.0 day

Comp. strength of conc. at 1st loading: f'_{ci} = 41.37 MPa

Factor for the effect of concrete strength:

$$k_f = \frac{35.0}{7+f'_{ci}} = \frac{35.0}{7+41.4} = 0.7236$$

Time factor for creep at final time:

$$k_{tdc,f,i} = \frac{t_f-t_i}{61-0.58*f'_{ci}+t_f-t_i}$$

$$= \frac{120.0-4.0}{61-0.58*41.4+120.0-4.0}$$

$$= 0.7581$$

Time fac. for shrinkage at final time:

$$k_{tds,f,i} = \frac{t_f-t_c}{61-0.58*f'_{ci}+t_f-t_c}$$

$$= \frac{120.0-3.0}{61-0.58*41.4+120.0-3.0}$$

$$= 0.7597$$

Losses: Time of Transfer to Time of Deck Placement - Article 5.9.5.4.2

Gross area of section: A_g = 3.61E5 mm²

Perimeter of section: p = 3503.7 mm

Volume to surface ratio: $V/S = A_g/p$ = 103.02 mm

Factor for the effect of the volume: $k_s = 1.45-0.0051*(V/S) = 0.9245$

Creep coefficient at final time:

$$\psi_b(t_f,t_i) = 1.9*k_s.k_{hc}.k_f.k_{tdc,f,i}.t_i^{-0.118}$$

$$= 1.9*0.9245*1.0*0.7236*0.7581*4.0^{-0.118}$$

$$= 0.8182$$

Inertia of the gross concrete section: I_g = 5.22E10 mm⁴

Eccentricity of prestressing force: e_{pg} = -185.17 mm

Transformed section coefficient:

$$K_{id} = \frac{1}{1 + \frac{E_p}{E_{ci}}.\frac{A_{ps}}{A_g}\left[1+\frac{A_g.e_{pg}^2}{I_g}\right].[1+0.7*\psi_b(t_f,t_i)]}$$

$$= \frac{1}{1 + \frac{197.0}{32.378}*\frac{3944.8}{3.61E5}\left[1+\frac{3.61E5*-185.2^2}{5.2E10}\right]*(1+0.7*0.8182)}$$

$$= 0.88544$$

Time factor for creep at deck placement:

$$k_{tdc,d,i} = \frac{t_d - t_i}{61-0.58*f'_{ci}+t_d-t_i}$$

$$= \frac{60.0-4.0}{61-0.58*41.4+60.0-4.0}$$

$$= 0.602$$

Time factor for shrinkage at deck placement:

$$k_{tds,d,i} = \frac{t_d - t_c}{61-0.58*f'_{ci}+t_d-t_c}$$

$$= \frac{60.0-3.0}{61-0.58*41.4+60.0-3.0}$$

$$= 0.606$$

Shrinkage of Girder Concrete - Article 5.9.5.4.2a

Concrete shrinkage strain of girder: $\varepsilon_{bid} = k_s.k_{hs}.k_f.k_{tds,d,i}*0.00048$
$= 1.0*1.02*0.71*0.60*0.00048$
$= 2.121E-4$

Loss of prestress $= \varepsilon_{bid}.E_p.K_{id}$
$= 2.12E-4*197.0*0.88294$
$= 36.886$ MPa
$= \Delta f_{pSR}$

Total shrinkage loss of force = $\Delta f_{pSR}.A_{ps}$
= 36.886*3944.78
= 145.507 kN

Corresponding gain of moment = 145.507*0.32977
(about y = 0) = 47.985 kN.m

Moment about the centroid of the composite beam:
M_{sh} = 47.985-(145.507*0.51494)
= -26.943 kN.m

Corresponding stresses:
top stress = 145.507/360967+-26.9434/8.31E7
= 0.4031039+-0.324228
= 0.078876 MPa

bottom stress = 145.507/360967+-26.9434/-1.014E8
= 0.4031039+0.2658366
= 0.668941 MPa

Creep of Girder Concrete - Article 5.9.5.4.2b

Creep coefficient at deck placement:
$\psi_b(t_d,t_i) = 1.9k_s.k_{hc}.k_f.k_{tdc,d,i}.t_i^{-0.118}$
$= 1.9*1.0*1.0*0.7142*0.6021*4.0^{-0.118}$
= 0.6938

Concrete stress at the center of gravity of prestressing tendons:
concrete stresses at transfer:
at top of precast beam = 9.82068 MPa
at bottom of precast beam = 19.7162 MPa
at center of gravity of prestress: f_{cgp} = 16.8612 MPa

Loss of prestress = $\frac{E_p}{E_{ci}}.f_{cgp}.\psi_b(t_d,t_i).K_{id}$
$= \frac{197.0}{32.3777}*16.861*0.6938*0.8846$
= 62.9755 MPa
= Δf_{pCR}

Total creep loss of force = $\Delta f_{pCR}.A_{ps}$
= 62.9755*3944.78
= 248.425 kN

Corresponding loss of moment = 248.425*0.32977
= 81.9248 kN.m
(about y = 0)

Moment about the centroid of the composite beam:
M_{cr} = 81.9248-(248.425*0.51494)
= -46.001 kN.m

Corresponding stresses:
top stress = 248.425/3.61E5+-46.001/8.31002E7
= 0.68822+-0.5535
= 0.13466 MPa

bottom stress = 248.425/3.61E5+-46.001/-1.0135E8
= 0.68822+0.45386
= 1.14208 MPa

Relaxation of Prestressing Strands - Article 5.9.5.4.2c

Stress in tendons after transfer: f_{pt} = 1301.17 MPa
Yield strength of prestressing steel: f_{py} = 1675.43 MPa
Time between tensioning and deck placement: $t = t_s - t_i$ = 60.0- 4.0 = 56.0day
Factor for relaxation steel type: K'_L = 45.0 (low relaxation)

$$\text{Loss of prestress} = \frac{f_{pt}}{K'_L}.\frac{\log(24t)}{\log(24t_i)}.\left[\frac{f_{pt}}{f_{py}} - 0.55\right].\left[1 - \frac{3(\Delta f_{pSR}+\Delta f_{pCR})}{f_{pt}}\right].K_{id}$$

$$= \frac{1301.2}{45.0} * \frac{\log(24*56.0)}{\log(24*4.0)} * \left[\frac{1301.2}{1675.4} - 0.55\right]\left[1 - \frac{3*(36.886+62.976)}{1301.2}\right] * 0.88$$

$$= 7.02855 \text{ MPa}$$

$$= \Delta f_{pR1}$$

Total relaxation loss of force = $\Delta f_{pR1}.A_{ps}$
= 7.0286*3944.8
= 27.726113 kN

Corresponding loss of moment = 27.726*0.3297
= 9.1434367 kN.m
(about y = 0)

Moment about the centroid of the composite beam:
M_{rx} = 9.14344-(27.7261*0.5149)
= -5.134 kN.m

Corresponding stresses:
top stress = 27.7261/360967+-5.13401/ 8.31E7
= 0.0768107+-0.061781
= 0.0150297 MPa

bottom stress = 27.7261/360967+-5.13401/-1.014E8
= 0.0768107+0.0506546
= 0.127465 MPa

Erection of beam Loading

Bending moment from erection loadcase at current span location:
$M_{Applied}$ = 481.82514 kN.m
Corresponding stresses:
top stress = 481.82514/8.31E7
= 5.79813 MPa
bottom stress = 481.82514/-1.014E8
= -4.7539 MPa

Remove the dead load applied for transfer calculations
M_{sw} = -406.97 kN.m
Corresponding stresses:
top stress = -406.97/8.31E7
= -4.8973 MPa
bottom stress = -406.97/-1.014E8
= 4.01537 MPa

Construction stage 1A Loading

$M_{Applied}$ = 746.7127 kN.m
Corresponding stresses:
top stress = 746.7127/8.31E7
= 8.98569 MPa
bottom stress = 746.7127/-1.014E8
= -7.3674 MPa

Construction stage 1B Loading

$M_{Applied}$ = 41.902235 kN.m
Corresponding stresses:
top stress = 41.902235/8.31E7
= 0.50423 MPa
bottom stress = 41.902235/-1.014E8
= -0.4134 MPa

Losses: Time of Deck Placement to Final Time - Article 5.9.5.4.3

Gross composite section area: A_c = 9.72E5 mm²
Perimeter of section: p = 7365.6 mm
Volume to surface ratio: $V/S = A_c/p$ = 131.99 mm
Factor for the effect of the volume: k_s = 1.45-0.0051*(V/S) = 0.7768
Creep coefficient at final time:

$$\psi_b(t_f,t_i) = 1.9*k_s.k_{hc}.k_f.k_{tdc,f,i}.t_i^{-0.118}$$
$$= 1.9*0.776*1.0*0.723*0.758*4.0^{-0.118}$$
$$= 0.6875$$

Inertia of the net concrete section: I_c = 1.94E8 mm⁴
Eccentricity of prestressing force: e_{pc} = 0.6743 mm
Transformed section coefficient:

$$K_{df} = \frac{1}{1 + \frac{E_p}{E_{ci}}.\frac{A_{ps}}{A_c}\left[1+\frac{A_c.e_{pc}^2}{I_c}\right].[1+0.7*\psi_b(t_f,t_i)]}$$

$$= \frac{1}{1 + \frac{197.0}{32.378}*\frac{3944.8}{9.72E5}\left[1+\frac{9.72E5*674.33^2}{1.9E11}\right]*(1+0.7*0.6875)}$$

$$= 0.89298$$

Shrinkage of Girder Concrete - Article 5.9.5.4.3a

Concrete shrinkage strain of girder: $\varepsilon_{bdf} = k_s.k_{hs}.k_f.k_{tds,f,i}*0.00048$
= 1.0*1.02*0.71*0.76*0.00048
= 2.657E-4

Loss of prestress = $\varepsilon_{bdf}.E_p.K_{df}$
= 2.66E-4*1.97E8*0.88465
= 46.3042 MPa
= Δf_{pSD}

Total shrinkage loss of force = $\Delta f_{pSD}.A_{ps}$
= 46.3042*3944.78
= 182.66 kN

Corresponding gain of moment (about y = 0) = 182.66*0.32977
= 60.2371 kN.m

Moment about the centroid of the composite beam:
M_{sh} = 60.2371-(182.66*0.9603)
= -115.17 kN.m

Corresponding stresses:
top stress = 182.66/844161+-115.171/9.901E8
= 0.2163807+-0.116321
= 0.10006 MPa

bottom stress = 182.66/844161+-115.171/-1.884E8
= 0.2163807+0.6114031
= 0.827784 MPa

Creep of Girder Concrete - Article 5.9.5.4.2b

Creep coefficient at deck placement:
$\psi_b(t_d,t_i) = 1.9k_s.k_{hc}.k_f.k_{tdc,d,i}.t_i^{-0.118}$
$= 1.9*1.0*1.0*0.7142*0.6021*4.0^{-0.118}$
= 0.6938

Creep coefficient at final time:
$\psi_b(t_f,t_d) = 1.9k_s.k_{hc}.k_f.k_{tdc,f,i}.t_d^{-0.118}$
$= 1.9*1.0*1.0*0.7142*0.6185*60.0^{-0.118}$
= 0.5178

Concrete stress at the center of gravity of prestressing tendons:
concrete stresses at transfer:
at top of precast beam = 9.82068 MPa
at bottom of precast beam = 19.7162 MPa
at center of gravity of prestress: f_{cgp} = 16.8612 MPa

Change in concrete stress at centroid of prestressing strands:
concrete stress change after permanent loads:
at top of precast beam = 12.254 MPa
at bottom of precast beam = 11.3917 MPa
Δf_{cd} = 11.6405 MPa

$$\text{Loss of prestress} = \frac{E_p}{E_{ci}} * f_{cgp} * \left[\psi_b(t_f,t_i) - \psi_b(t_d,t_i) \right] * K_{df}$$
$$+ \frac{E_p}{E_c} * \Delta f_{cd} * \psi_b(t_f,t_d) * K_{df}$$
$$= \frac{197.0}{32.3777} * 16.8612 * (0.87367 - 0.69388) * 0.88294$$
$$+ \frac{197.0}{18.6932} * 11.6405 * 0.51782 * 0.88294$$
$$= 72.3739 \text{ MPa}$$
$$= \Delta f_{pCD}$$

Total creep loss of force = $\Delta f_{pCD} * A_{ps}$
= 72.3739*3944.78
= 285.499 kN

Corresponding loss of moment = 285.499*0.32977
= 94.1512 kN.m
(about y = 0)

Moment about the centroid of the composite beam:
M_{cr} = 94.1512-(285.499*0.9603)
= -180.01 kN.m

Corresponding stresses:

top stress = 285.499/8.442E5+-180.01/9.90117E8
= 0.33820+-0.1818
= 0.15639 MPa

bottom stress = 285.499/8.442E5+-180.01/-1.8837E8
= 0.33820+0.95562
= 1.29383 MPa

Relaxation of Prestressing Strands - Article 5.9.5.4.3c

Loss of prestress = Δf_{pR1}
= 7.02855 MPa
= Δf_{pR2}

Total relaxation loss of force = $\Delta f_{pR2}.A_{ps}$
= 7.0286*3944.8
= 27.726113 kN

Corresponding loss of moment = 27.726*0.3297
= 9.1434367 kN.m
(about y = 0)

Moment about the centroid of the composite beam:
M_{rx} = 9.14344-(27.7261*0.9603)
= -17.482 kN.m

Corresponding stresses:
top stress = 27.7261/844161+-17.482/9.901E8
= 0.0328446+-0.017656
= 0.0151881 MPa

bottom stress = 27.7261/844161+-17.482/-1.884E8
= 0.0328446+0.0928054
= 0.12565 MPa

Shrinkage of Deck Concrete - Article 5.9.5.4.3d

Concrete shrinkage strain of girder: $\varepsilon_{ddf} = k_s.k_{hs}.k_f.k_{tds,f,i}$*0.00048
= 1.025*1.02*0.71*0.76*0.00048
= 2.724E-4

Creep coefficient at final time:
$\psi_b(t_f,t_d) = 1.9k_s.k_{hc}.k_f.k_{tdc,f,i}.t_d^{-0.118}$
$= 1.9*1.0253*1.0*0.7142*0.6185*60.0^{-0.118}$
= 0.5309

Change in concrete stress at centroid of prestressing strands:

Area of deck concrete: A_d = 6.112E5 mm²
Perimeter of section: p = 7365.55 mm
Volume to surface ratio: $V/S = A_d/p$ = 82.98 mm
Factor for the effect of the volume: k_s = 1.45-0.0051*(V/S) = 1.4333
Modulus of elasticity of deck concrete: E_{cd} = 29.5566 mm²
Eccentricity of the deck: e_d = 288.894 mm³

$$\Delta f_{cdf} = \frac{\varepsilon_{ddf}.A_d.E_{cd}}{[1+0.7\psi_b(t_f,t_d)]}\left[\frac{1}{A_c}-\frac{e_{pc}.e_d}{I_c}\right]$$

$$= \frac{2.7E\text{-}4*6.11E5*29.557*1000}{[1+0.7*0.5309]}\left[\frac{1}{8.44E5}-\frac{630.523*288.894}{1.8E11}\right]$$

$$= 0.63733 \text{ MPa}$$

$$\text{Loss of prestress} = \frac{E_p}{E_c}.\Delta f_{cdf}.K_{df}.[1+0.7\psi_b(t_f,t_d)]$$

$$= \frac{197.0}{18.6932}*0.63733*0.88465\ *(1+0.7*0.53092)$$

$$= 8.15021 \text{ MPa}$$
$$= \Delta f_{pSS}$$

Total shrinkage gain of force = $\Delta f_{pSS}.A_{ps}$
= 8.15021*3944.78
= 32.1508 kN

Corresponding gain of moment (about y = 0) = 32.1508*0.32977
= 10.6026 kN.m

Moment about the centroid of the composite beam:
M_{sh} = 10.6026-(32.1508*0.9603)
= -20.272 kN.m

Corresponding stresses:
top stress = 32.1508/844161+-20.2718/9.901E8
= 0.0380861+-0.020474
= 0.017612 MPa

bottom stress = 32.1508/844161+-20.2718/-1.884E8
= 0.0380861+0.1076157
= 0.145702 MPa

Superimposed dead load 1 Loading

$M_{Applied}$ = 129.34157 kN.m
Corresponding stresses:
top stress = 129.34157/9.9012E8
= 0.13063 MPa
bottom stress = 129.34157/-1.884E8
= -0.6866 MPa

Transient Load BM 2 : [Max -ve] Loading

$M_{applied}$ = -192.9 kN.m for Service-I
-154.32 kN.m for Service-III

```
Corresponding stresses:
      top stress = -192.9/9.9012E8         Service-I
                 = -0.1948 MPa
   bottom stress = -154.32/-1.884E8        Service-III
                 = 0.81922 MPa
```

PERMISSIBLE STRESSES IN PRECAST BEAM

Compression

Article 5.9.4.2.1 for permanent & transient loads

Permissible compression stress = $0.6 * f'_c$
= 0.6*55.1581
= 33.09 MPa

Tension

Article 5.9.4.2.2
Component is subject to normal exposure conditions.

Permissible tension stress = $-0.498 * \sqrt{f'_c}$
= -0.498 * √55.1581
= -3.70451 MPa

PERMISSIBLE STRESSES FOR CAST IN PLACE CONCRETE

Compression

Article 5.9.4.2
char. strength of c.i.p. concrete = 34.4738 MPa
stress limitation factor = 0.6
permissible compression stress = $0.6*f_{cu}$
= 0.6 * 34.4738
= 20.6843 MPa

Tension

Article 5.7.3.4
Flexural tensile stresses may need to be limited by cracking considerations in accordance with article 5.7.3.4.

SERVICE LIMIT STATE - STRESS SUMMARY TABLE
maximum for girder top extreme fibre

			Concrete Stresses (MPa)			
	force	moment	Cast In Place		Precast	
	kN	kN.m	top	bottom	top	bottom
Prestress	5507.66	-1031.7			2.84276	25.4375
Self Weight		406.97			4.89735	-4.0154
Prestress + Self Wt.					7.7401	21.4221
Elastic Def	-374.83	81.2753			-0.0604	-1.8403
TRANSFER	5132.83	-543.47			7.67973	19.5818

Erection		74.855			0.90078	-0.7385
C.I.P. Stage 1A		746.713			8.98569	-7.3674
C.I.P. Stage 1B		41.9022	0.0884	0.03346	0.04232	-0.2224
Time-Dependent Losses						
Time of Transfer to Time of Deck Placement						
Shrinkage	-145.51	26.9434			-0.0789	-0.6689
Creep	-248.42	46.0005			-0.1346	-1.1421
Relaxation	-27.726	5.13401			-0.015	-0.1274
Time of Deck Placement to Final Time						
Shrinkage						
Girder	-182.66	115.171	0.0719	-0.0791	-0.1000	-0.8277
Deck	-4.5741	2.88407	0.0018	-0.002	-0.0025	-0.0207
Creep	-285.5	180.014	0.11237	-0.1236	-0.1563	-1.2938
Relaxation	-27.726	17.482	0.01091	-0.012	-0.0152	-0.1256
Wearing Surface		129.342	0.27285	0.10327	0.13063	-0.6866
(Diff. Shr. 1	4.57409	-2.8841	9.98E-4	0.27517	0.00251	0.02073)
(Diff. Shr. 2		-5.601	-0.0118	-0.0045	-0.0057	0.02973)
(Differential shrinkage is not adverse or not specified						)
TOTAL PERMANENT			0.55823	-0.08	17.2364	6.36024
(γ_{TG} = 0.5)						
Temp Grad P1	-752.44	-291.34	2.3162	-0.5968	-0.7549	0.65526
Temp Grad P2		96.3319	0.20321	0.07692	0.09729	-0.5113
Temp Grad R1	150.487	58.2675	-0.4632	0.11936	0.15098	-0.1310
Temp Grad R2		-19.268	-0.0406	-0.0154	-0.0195	0.10228
(Temperature restraint is not adverse or not specified						)

TRANSIENT LOADS						
Transient Load BM 1- I		1863.99	3.93222		1.8826	
- III		1491.2		1.19066		-7.9162
Transient Load BM 2- I		-192.9	-0.4069		-0.1948	
- III		-154.32		-0.1232		0.81922
TOTAL PERMANENT LOAD + TRANSIENT LOAD						
Transient Load BM 2			2.67072	-0.0992	17.1731	7.32333

SLS FLEXURE
calculated using curvature of uncracked sections

The deflections are calculated from integration of the curvatures along the beam, using the parameters detailed below:
(Note that the reported values of deflections for live loadings are exaggerated when these are derived from enveloped effects)

Elastic Modulus at Transfer, E_T = 32.3777 kN/mm²

Intermediate Term Elastic Modulus, E_I = 22.0714 kN/mm²

$E_I = E_C/(\psi(t,t_i)+1)$

where $\psi(t,t_i)$ = 0.69388 (Article 5.14.2.3.6)]

Effective Elastic Modulus for time dependant effects, E_E = 34.2214 kN/mm²

$E_E = E_S.(\psi_{tc\%} + ((1-\psi_{tc\%})/ (1 + \chi.\psi)))$

ψ = creep factor = 0.87367

$\psi_{tc\%}$ = percentage of creep occurring before c.i.p. deck added
= 0.69388/0.87367 = 79.4216%

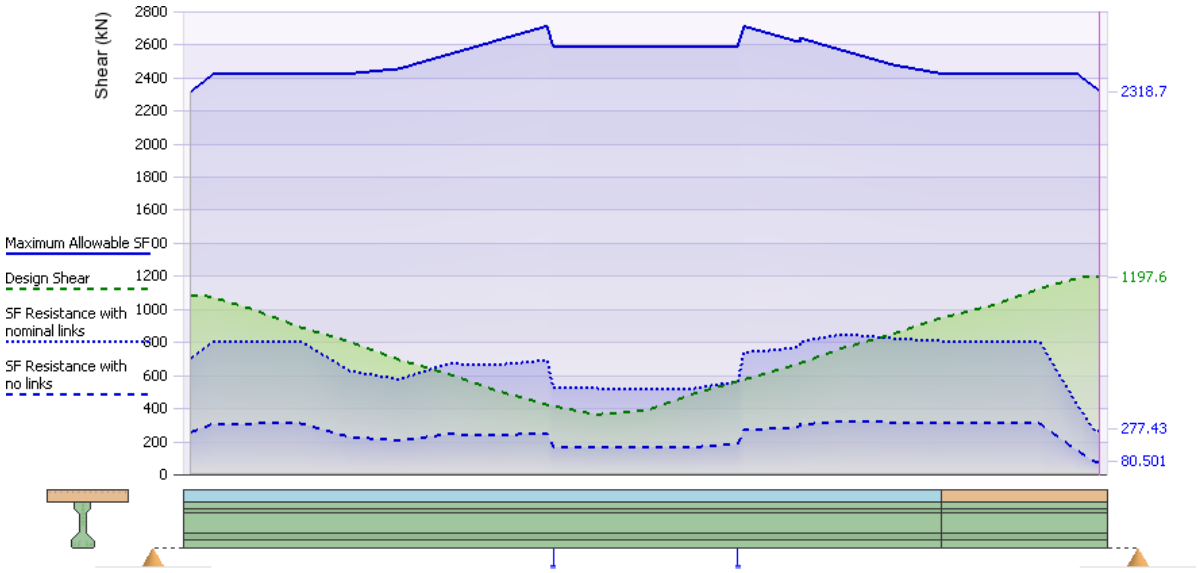
χ = ageing factor, taken as 0.8

Short Term Elastic Modulus, E_S = 37.3865 kN/mm²

Precast section height = 1143.0 mm

		Precast Stress (MPa)	E	Precast Strain (x10^{-6})	Curvature (x10^{-6}) (rad/m)	Deflection (mm) Here	Deflection (mm) Max.
At Transfer	T	9.20544	E_T	284.315	-249.49	15.9064	30.3396
	B	18.4384		569.48			
At Erection	T	9.53222	E_I	431.88	-260.0	20.4644	36.1998
	B	16.0914		729.059			
Long-term Dead	T	16.8135					
	B	6.99716					
Dead Stress Increment	T	7.6081	E_E	222.32	487.008	-29.119	-49.25
	B	-11.441		-334.33			
Total Dead Load deflection					227.01	-8.6541	-13.05
Transient Load BM 2-I	T	-0.1558	E_S	-4.1687	-22.817	2.2014	4.39981
	B	0.81918		21.9112			
Extreme in-service					204.192	-6.4527	-8.8909

Girder Design Calculations: Shear



Effects ignored within 0.2m from each beam end.

Performance ratio = 1198 / 2319 = 0.516

Section details:

Ref 2 "Section 2"
at 0.991 x span = 0.991 x 23.1136 = 22.9136 m from left end of beam

Design Code:

AASHTO LRFD Bridge Design Specifications
Sixth Edition with 2013 Interim Revisions

Analysis:

Shear Forces and associated Bending Moments
Transient Load SF + assoc. BM 1
Limit State - Strength I

Approximate Methods of Analysis are used - Article 4.6.2
Live Load Distribution Factor for +ve Moment = 0.94124 lanes/beam
Live Load Distribution Factor for -ve Moment = 0.94124 lanes/beam
Live Load Distribution Factor for Shear = 0.94124 lanes/beam
Live Load Distribution Factor for Fatigue = 0.78437 lanes/beam

SUMMARY OF APPLIED LOAD EFFECTS

	SHEAR FORCE kN	BENDING MOMENT kN.m	AXIAL LOAD kN
Erection loading before composite =	129.42331	27.732897	0.0
Erection loading to stage 1A =	144.09112	30.68843	0.0
Erection loading to stage 1B =	69.170412	15.010684	0.0
Wearing surface loading =	56.69805	-161.854	0.0
Differential Shrinkage / Creep =	0.4580671	-10.79364	0.0
Transient loading:			
Max SF + associated BM =	797.73786	-735.5756	0.0
Max BM + associated SF =	487.02182	-1965.399	0.0
TOTAL - Max SF + associated BM:	1197.5788	-834.7912	0.0
- Max BM + associated SF:	886.86278	-2064.615	0.0

Note:
The following effects are not considered (article 3.4.1) -
differential settlement
temperature gradient

The current section is closer to the support than the critical section for shear (article 5.8.3.2). The shear forces in the table are therefore the values at the critical section for shear.

Article 5.8.3
Transverse Shear Reinforcement

The '*maximum SF with associated BM*' loadcase is critical at this section.

factored shear force V_u = 1197.58 kN
factored moment M_u = -834.79 kN.m

The factored moment at this section is negative, and so the following calculations relate to the inverted section

Calculate effective shear depth, d_v - Article 5.8.2.9

overall depth of section h = 1443.0 mm
compression fibre to tension force centroid d_e = -1118.8 mm
resistance moment of section (no axial load) M_r = -5824.3 kN.m
total tension force T = 5803.48 kN
distance from resultant tension to compression = M_r/T
= 1.00358 m

$0.9*d_e$ = 0.9*-1118.8 = -1006.9 mm
$0.72*h$ = 0.72*1443.0 = 1038.96 mm
hence, effective shear depth, d_v = 1038.96 mm

Critical section for shear - Article 5.8.3.2

angle of compressive stress (see below) $\theta = 41.3479°$

$0.5*d_v.\cot(\theta) = 0.5*1038.96*1.13636$
$= 590.316$ mm

critical section for shear is larger of d_v and 0.59031
hence, critical section for shear:
from face of support = 1.03896 m
from end of the beam = 22.4692 m

Determine β and θ - Article 5.8.3.4

Shear stress on the concrete - 5.8.2.9-1

Resistance factor for shear [A5.5.4.2] $\varphi = 0.9$
Vertical component of prestress at section $V_p = 29.0241$ kN

$$v = \frac{V_u - \varphi.V_p}{\varphi.b_v.d_v} = \frac{1197.58 - 0.9*29.0241}{0.9*0.1778*1.03896} = 7.04617 \text{ MPa}$$

Factored axial force	N_u	= 0.0 kN
Area of prestress steel on tension side	A_{ps}	= 1579.36 mm²
Area of concrete on flexural tension side	A_c	= 6.118E5 mm²
Area of non-prestress steel on tension side	A_s	= 0.0 mm²
Modulus of elasticity of tendons	E_p	= 197.0 kN/mm²
Modulus of elasticity of non-prestress steel	E_s	= 0.0 kN/mm²
Modulus of elasticity of concrete	E_c	= 37.3865 kN/mm²
	f_{po}	= 0.7*f_{pu}
		= 0.7*1861.58
		= 1303.11 MPa
Factored moment (not less than $\lvert V_u - V_p \rvert d_v$)	$\lvert M_u \rvert$	= 2064.61 MPa

General procedure: (Article 5.8.3.4.2)

Strain in reinforcement:

$$\varepsilon_s = \frac{\frac{|M_u|}{d_v} + 0.5N_u + |V_u - V_p| - A_{ps}f_{po}}{E_sA_s + E_pA_{ps}} \quad \text{(Eq. 5.8.3.4.2-4)}$$

$$\varepsilon_s = \frac{\left[\frac{2064.6}{1039.0} + 0.5* \quad 0.0 + |1197.6-29.024| - 1579.4*1303.1\right]}{0.0*0.0 + 197.0*0.0016}$$

$= 0.0035$

with at least the minimum amount of shear reinforcement:

$$\beta = \frac{4.8}{(1 + 750\varepsilon_s)} = \frac{4.8}{(1 + 750*0.0035)} \qquad \text{(Eq. 5.8.3.4.2-1)}$$

$$= 1.31652$$

with no shear reinforcement:

$s_x = 1.03896$ m

maximum aggregate size: $a_g = 25.4$ mm $= 1.0$ IN

$$s_{xe} = s_x * \frac{1.38}{a_g + 0.63} = 1.039 * \frac{1.38}{1.0 + 0.63} = 0.87961 \text{ m}$$

$$= 34.6303 \text{ IN}$$

$12.0\text{IN} <= s_{xe} <= 80.0\text{IN}$

$s_{xe} = 34.6303$ IN

$$\beta = \frac{4.8}{(1 + 750\varepsilon_s)} * \frac{51}{(39 + s_{xe})} \qquad \text{(Eq. 5.8.3.4.2-2)}$$

$$= \frac{4.8}{(1 + 750*0.0035)} * \frac{51}{(39 + 34.63)}$$

$$= 0.91188$$

$$\theta = 29 + 3500\varepsilon_s \qquad \text{(Eq. 5.8.3.4.2-3)}$$

$$= 29 + 3500* 0.0035$$

$$= 41.3479$$

Nominal Shear Resistance
Article 5.8.3.3

inclination of the transverse reinforcement, α = 90.0°

nominal shear resistance $V_n = V_c + V_s + V_p$ (5.8.3.3-1)

with at least the minimum amount of shear reinforcement:

$V_c = 0.08297*\beta(\sqrt{f'_c}).b_v.d_v$ (5.8.3.3-3)
$= 0.08297*1.3165*(\sqrt{55.158})*177.8*1039.0$
$= 149.86$ kN

with no shear reinforcement:

$V_c = 0.08297*\beta(\sqrt{f'_c}).b_v.d_v$ (5.8.3.3-3)
$= 0.08297*0.9118*(\sqrt{55.158})*177.8*1039.0$
$= 103.8$ kN

$V_p = 29.024$ kN
V_s depends upon the reinforcement present.

Maximum Shear Force
Articles 5.8.2.4 and 5.8.3.3

Maximum shear with no transverse reinforcement:

$V_u > 0.5*\varphi.(V_c + V_p)$ (5.8.2.4-1)
$= 0.5*0.9*(103.803+29.0241)$
$= 59.7724$ kN
$\varphi.V_u > 0.9*59.7724$
$= 53.7952$ kN

Maximum value of shear resistance with transverse reinforcement

$V_{n,max} = 0.25 * f'_c.b_v.d_v + V_p$ (5.8.3.3-2)
$= 0.25 * 55.1581*177.8*1038.96 + 29.0241$
$= 2576.32$ kN
$\varphi.V_{n,max} = 0.9*2576.32$
$= 2318.69$ kN

Transverse Reinforcement Requirements

inclination of the transverse reinforcement, α = 90.0°
minimum yield strength of transverse rft f_y = 420.0 MPa

Minimum Transverse Reinforcement (article 5.8.2.5):

$$\frac{A_v}{s} >= \frac{0.083*\sqrt{f'_c}.b_v}{f_y}$$

$= 0.083*\sqrt{55.1581}*177.8/420.0$
$= 0.2610$ mm²/mm

Shear resistance (article 5.8.3.3) with minimum reinforcement (article 5.8.3.3):

$V_n = V_c + V_s + V_p$

$V_s = A_v/s \ . \ f_y.d_v.(\cot(\theta)+\cot(\alpha)).\sin(\alpha)$ (5.8.3.3-4)

$V_{s,min} = 0.26105* \ 420.0*1038.96*1.13636$

$= 129.449$ kN

therefore,

$V_{n,min} = 149.868 + 129.449 + 29.0241$
$= 308.341$ kN
$\varphi.V_{n,min} = 0.9*308.341$
$= 277.507$ kN

Additional transverse reinforcement for shear (article 5.8.3.3):

Vu is greater than $\varphi V_{n,min}$, therefore additional transverse reinforcement is required.

contribution to shear strength from shear rft,

$V_s = V_u/\varphi - (V_c+V_p)$
$= 1197.58/ \ 0.9-(149.868+29.0241)$
$= 1151.75$ kN

from equation 5.8.3.3-4

$A_v/s = V_s / (f_y.d_v.(\cot(\theta)+\cot(\alpha)).\sin(\alpha))$

hence, $A_v/s = 1151.75 / (\ 420.0*1038.96*1.13636)$
$= 2.32271$ mm²/mm

Link arrangement:

size	diameter mm	Maximum spacing mm 2 legs	4 legs
10	11.3	86.3539	172.708
15	16.0	173.127	346.254
20	19.5	257.155	514.309
25	25.2	429.463	858.927

Maximum spacing (article 5.8.2.7):

$0.125*f'_c$ = 0.125*55.1581
= 6.8948 MPa

$$v_u = \frac{V_u - \varphi . V_p}{\varphi . b_v . d_v} \quad \text{Eqn. 5.8.2.9-1}$$

$$= \frac{1197.58 - 0.9*29.0241}{0.9*177.8*1038.96}$$

= 7.04617 MPa

v_u >= $0.125*f'_c$

therefore, s_{max} = $0.4*d_v$ <= 0.3048
= 0.4*1038.96
= 415.584 mm

hence maximum permissible spacing = 304.8 mm

Longitudinal Reinforcement - Article 5.8.3.5

Non-prestressed reinforcing steel:
Area on flexural tensile side A_s = 0.0 mm²
tensile capacity = 0.0 kN

Prestressing steel:
Area on flexural tensile side A_{ps} = 1579.36 mm²
tensile strength f_{pu} = 1861.58 MPa
allowance for development = 0.26246
tensile capacity = 0.26246*1579.36*1861.58
= 771.683 kN

Total tensile capacity = 0.0+771.683
= 771.683 kN

Equation 5.8.3.5-1 right hand side:
$M_u/(d_v.\varphi)$ = 2064.61/(1.03896*1.0)
= 1987.19 kN
$0.5*N_u/\varphi$ = 0.5*0.0/ 0.75
= 0.0 kN
V_u/φ - $0.5*V_s$ - V_p = 1197.58/0.9 - 0.5*1151.75 - 29.0241
= 725.744
* cot(θ) = 725.744*1.13636
= 824.705 kN

where V_s is taken from equation 5.8.3.3-4 but not greater than V_u/φ
V_u/φ = 1197.58/0.9
= 1330.64 kN
A_v/s . $f_y.d_v$.cot(θ) = 0.00232*420.0*1.03896*1.13636
= 1151.75 kN

1987.19+0.0+824.705 = 2811.9 kN

which is greater than 771.683, so Equation 1 is not satisfied, therefore additional longitudinal reinforcement is required.
Area of fully developed non-prestressed reinforcing steel required on flexural tension side of member is given by:

$A_s.f_y$ = 2811.9-771.683 = 2040.22 kN

hence additional area required,

= 2040.22/420.0
= 4857.66 mm²

Summary of link requirements along the beam:

Preferred size of links: 11.3 mm Bar #: 10

dimension from left beam end m	A_v / s mm²/mm	Spacing in mm with preferred link size[1]
0.2	0.79613	251.937
0.2787	0.77705	258.123
0.48068	0.72763	275.654
0.762	0.63692	300.0
1.71136	0.53740	300.0
2.94205	0.37830	300.0
4.17273	0.53517	300.0
5.40341	0.44931	300.0
6.63409	0.26087	300.0
7.86478	0.26087	300.0
9.09546	0.26087	300.0
9.25	0.26087	300.0
10.012	0.26087	300.0
10.3261	0.26087	300.0
11.5568	0.26087	300.0
12.7875	0.26087	300.0
13.8636	0.26087	300.0
14.0182	0.26087	300.0
14.6256	0.26087	300.0
15.2489	0.26087	300.0
15.4091	0.26087	300.0
15.4091	0.26087	300.0
16.4796	0.26087	300.0
17.7102	0.29572	300.0
18.9409	0.45711	300.0
18.9409	0.45717	300.0
20.1716	0.56171	300.0
21.4023	0.70957	282.669
22.3516	1.81122	110.74
22.633	2.3067	86.9532
22.8349	2.69441	74.4411
22.9136	2.32271	86.3539

[1] Based on 2 legs (double this value if using 4 legs)

Transverse Live Load Distribution Factor Calculations

Approximate Methods of Analysis - Article 4.6.2
Distribution Of Live Loads Per Lane
Article 4.6.2.2

Check general conditions - 4.6.2.2.1

- width of deck is constant	O.K.
- no of beams is 11	O.K.
- all beams are parallel and of approximately the same stiffness	O.K.
- roadway part of overhang, d_e, is 1.13477m	O.K.
- curvature in plan is less than the limit specified in Article 4.6.1.2	O.K.
- Cross-section is consistent with one of the cross-sections shown in Table 1	O.K.

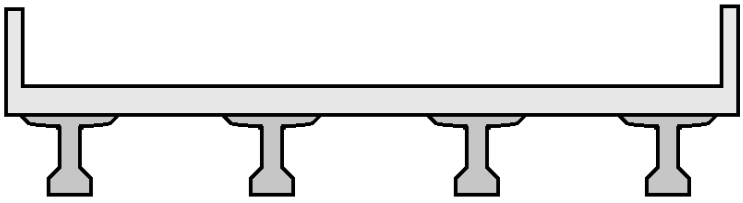
Maximum Number of Design Lanes - 3.6.1.1.1

Clear roadway width between curbs / barriers w = 20.3206m

$w/3.6576$ = 20.3206/3.6576
= 5.55571

number of design lanes = 5

Cross-section is type (k) from Table 4.6.2.2.1-1



Distribution factors for Moment

Beam is an exterior beam

For two or more design lanes loaded, first calculate the distribution factors for an interior beam

Spacing of beams,	S = 1.8051 m
Span of beam,	L = 24.6136 m
Thickness of slab,	t_s = 300.0 mm

Longitudinal stiffness parameter, K_g:

modulus of elasticity of beam material, E_b = 37.3865 kN/mm²
modulus of elasticity of deck material, E_d = 29.5566 kN/mm²

$n = E_b/E_d$ (4.6.2.2.1-2)
= 37.3865/29.5566
= 1.26491

area of non-composite beam, A = 3.61E5 mm²
moment of inertia of non-composite beam, I = 5.22E10 mm⁴
height to center of gravity of basic beam = 514.946 mm
height to center of gravity of deck = 1293.0 mm
distance between centers of gravity, e_g = 778.054 mm

hence, longitudinal stiffness parameter, K_g
$= n*(I+A*e_g^2)$ (4.6.2.2.1-1)
= 1.26491*(5.22E10+3.61E5*778.054²)
= 3.42E11 mm⁴

With one design lane loaded:
DFM_1 from lever rule for external beam
= 0.94124

With two or more design lanes loaded:

$$DFM_2 = 0.075 + \left(\frac{S}{2.9}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{K_g}{1.E3*L.t_s^3}\right)^{0.1}$$

$$= 0.075 + (1.8051/2.8956)^{0.6} * (1.8051/24.6136)^{0.2} * (3.42E11/(1000.0*24.6136*300.0^3))^{0.1}$$

= 0.49295

Since this is an exterior beam, the correction factor, e, must be applied, where e is given in Table 4.6.2.2.2d-1 as:
$e = 0.77 + d_e/2743.2$
= 0.77 + 1134.77/2743.2
= 1.17912
hence,
DFM_2 = 1.17912*0.49295
= 0.58124

The distribution factor with 1 lane loaded is critical
DFM = 0.94124

Distribution factors for Shear

Beam is an exterior beam
First calculate the distribution factors for an interior beam

Spacing of beams, S = 1.8051 m

With one design lane loaded:

DFV_1 from lever rule for external beam

$= 0.94124$

With two or more design lanes loaded:

$$DFV_2 = 0.2 + \frac{S}{3.6576} - \left[\frac{S}{10.67}\right]^{2.0}$$

$= 0.2 + 1.8051/3.6576 - (1.8051/10.668)^2$

$= 0.66489$

Since this is an exterior beam, the correction factor, e, must be applied, where e is given in Table 4.6.2.2.3b-1 as:

$e = 0.6 + d_e/\ 3048.0$

$= 0.6 + 1134.77/3048.0$

$= 0.9723$

hence,

$DFV_2 = 0.9723*0.66489$

$= 0.64647$

The distribution factor with 1 lane loaded is critical

$DFV = 0.94124$

RIGID STRUCTURE REACTIONS FOR EXTERIOR BEAMS
Article 4.6.2.2.2d

Since this is an exterior beam, and diaphragms or cross frames are present, the reaction arising from rigid cross section deflection and rotation must be considered.

From formula C4.6.2.2.2d-1:

$$R = \frac{N_l}{N_b} + \frac{X_{ext}.\Sigma e}{\Sigma x^2}$$

where,

R = reaction on exterior beam in terms of lanes
N_l = number of loaded lanes under consideration
e = eccentricity of lane center from C of G of girders
x = horizontal distance from C of G of girders to each girder
X_{ext} = value of x for exterior girder
N_b = number of beams or girders

N_b = 11

X_{ext} = 0.5*(S*(N_b-1))
= 0.5*(1805.1*(11-1))
= 9025.52 mm

Girder	x	x^2
1	9025.52	8.146E7
2	7220.41	5.213E7
3	5415.31	2.933E7
4	3610.21	1.303E7
5	1805.1	3.258E6
6	0.0	0.0
7	-1805.1	3.258E6
8	-3610.2	1.303E7
9	-5415.3	2.933E7
10	-7220.4	5.213E7
11	-9025.5	8.146E7
	TOTAL	3.584E8 = Σx^2 mm^2

```
For 1 lane loaded,
     e = 8636.29      Σe = 8636.29
     R = 1/11 + 9025.52*8636.29/3.584E8
       = 0.30838
     m = 1.2
   m.R = 1.2*0.30838
       = 0.37005
For 2 lanes loaded,
     e = 4978.69      Σe = 13615.0
     R = 2/11 + 9025.52*13615.0/3.584E8
       = 0.52465
     m = 1.0
   m.R = 1.0*0.52465
       = 0.52465
For 3 lanes loaded,
     e = 1321.09      Σe = 14936.1
     R = 3/11 + 9025.52*14936.1/3.584E8
       = 0.64883
     m = 0.85
   m.R = 0.85*0.64883
       = 0.55150
For 4 lanes loaded,
     e = -2336.5      Σe = 12599.6
     R = 4/11 + 9025.52*12599.6/3.584E8
       = 0.68090
     m = 0.65
   m.R = 0.65*0.68090
       = 0.44259
For 5 lanes loaded,
     e = -5994.1      Σe = 6605.44
     R = 5/11 + 9025.52*6605.44/3.584E8
       = 0.62087
     m = 0.65
   m.R = 0.65*0.62087
       = 0.40357
```

CALCULATION OF DISTRIBUTION FACTOR USING THE LEVER RULE

```
Spacing of beams,                        S =  1.8051 m
Roadway overhang,                       de =  1.13477 m
curb/barrier to outermost wheel (min)    =  0.6096 m
hence,

                                  1.8051+1.13477-0.6096
   max possible wheel lines,  nP = ---------------------- + 1
                                          1.8288
                                = 2
```

Exterior beam with one lane loaded:

The furthest wheel is 0.6096 m from the curb or barrier
girder line to furthest wheel = 1.8051+1.13477-0.6096
= 2.33027 m

moments about inner girder:
P*2.33027 + P*0.50147 = R_a * 1.8051
where P is the wheel load, and R_a is the reaction at the exterior girder.

hence,
R_a = 2831.75/1805.1 wheels
= 1.56875 wheels
= 0.78437 lanes/beam

From Article 3.6.1.1.2 of AASHTO LRFD the multiple lane factor for one lane loaded is 1.2.

hence distribution factor = 0.78437*1.2
= 0.94124

Distribution factor for Fatigue

Article 3.6.1.4.3b - For fatigue loads, the load distribution is as specified in Article 4.6.2 with the distribution factor for one one traffic lane being used.
Article 3.6.1.1.2 - the multiple presence factor is not applied to the fatigue limit state, and therefore must be removed from the single lane distribution factor value evaluated above

DFV_f = 0.94124/1.2
= 0.78437

SUMMARY of distribution factors

	One Design Lane Loaded	Two or More Design Lanes Loaded
Moments	0.94124	0.58124
Shears	0.94124	0.64647
Fatigue	0.78437	

Check Range of Applicability for Moments

		Applicable Range:		
S	= 1.8051	1.0668<=	S	<=4.8768
t_s	= 300.0	114.3<=	t_s	<=304.8
L	= 24.6136	6.096<=	L	<=73.152
d_e	= 1.13477	-0.3048<=	d_e	<=1.6764
N_b	= 11		N_b	>=4
		or	N_b	= 3 with lever rule check

Check Range of Applicability for Negative Moments near Supports

	Applicable Range:
L = 23.514	6.096<= L <=73.152

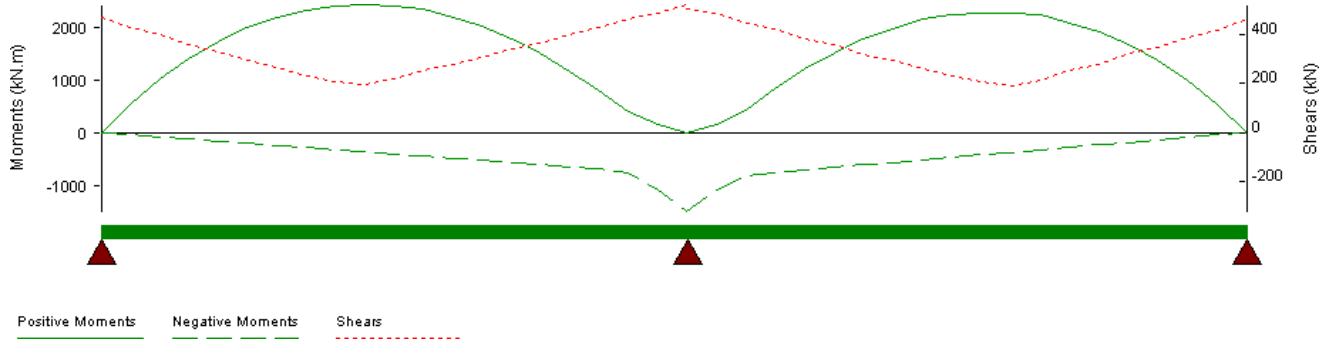
Check Range of Applicability for Shear

Applicable ranges are as for Moments, and in addition

	Applicable Range:
K_g = 1.425E5	4.162E9<= K_g <=2.91E12

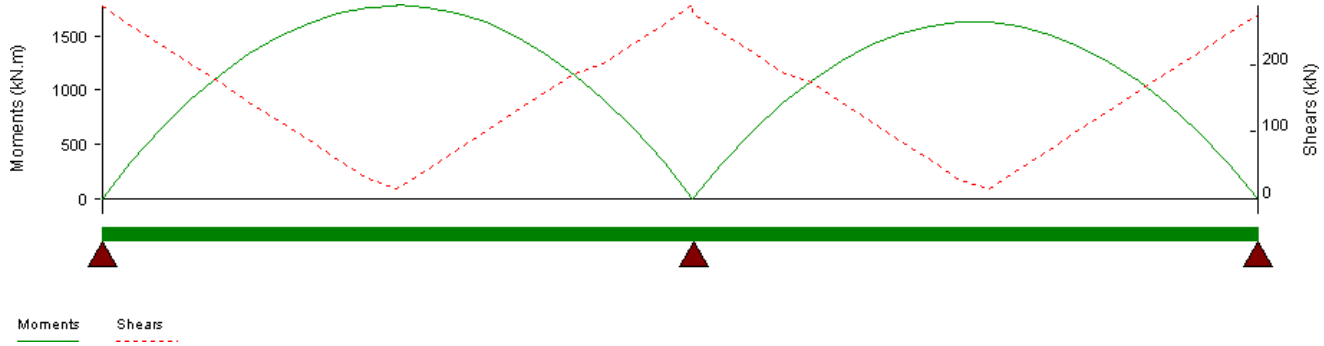
Analysis Load Envelopes

Live Load Envelope for Strength I and Service



The above envelope excludes the effects of transverse distribution.

Moments and Shears due to Dead Load



Analytical Model Data

MATERIALS

MP1: C35 Es 29.6
Type: Concrete - Parabola-Rectangle

Compressive strength f'_c: 34.473785 MPa

Strength LS stress/strain curve parameters:
slope at start of parabola: 36.373012 kN/mm²
strain at end of parabola: 0.0016136
stress at end of parabola: 29.30266 MPa
maximum strain: 0.003

Elastic modulus - E_c: 29.55662 kN/mm²
Elastic modulus - long term: 14.77831 kN/mm²
Shear modulus: 12.315258 kN/mm²
Poisson's ratio: 0.2
Compressive Stress limit factor: 0.6000000 x f'_c
Modulus of Rupture: -3.700114 MPa
Coefficient of thermal expansion: 0.0000108 /°C
Density: 23.563114 kN/m³

MP2: C56 Es 37.4
Type: Concrete - Parabola-Rectangle

Compressive strength f'_c: 55.158059 MPa

Strength LS stress/strain curve parameters:
slope at start of parabola: 46.008624 kN/mm²
strain at end of parabola: 0.0020411
stress at end of parabola: 46.884254 MPa
maximum strain: 0.003

Elastic modulus - E_c: 37.386496 kN/mm²
Elastic modulus - long term: 18.693248 kN/mm²
Shear modulus: 15.577706 kN/mm²
Poisson's ratio: 0.2
Compressive Stress limit factor: 0.6000000 x f'_c
Modulus of Rupture: -4.680315 MPa
Coefficient of thermal expansion: 0.0000108 /°C
Density: 23.563114 kN/m³

MP3: C42 Es 32.4
Type: Concrete - Parabola-Rectangle

Compressive strength f'_c: 41.368543 MPa

Strength LS stress/strain curve parameters:
slope at start of parabola: 39.844636 kN/mm²
strain at end of parabola: 0.0017677
stress at end of parabola: 35.163191 MPa
maximum strain: 0.003

Elastic modulus - E_c: 32.377654 kN/mm²
Elastic modulus - long term: 16.188827 kN/mm²
Shear modulus: 13.490689 kN/mm²
Poisson's ratio: 0.2
Compressive Stress limit factor: 0.6000000 x f'_c
Modulus of Rupture: -4.053272 MPa
Coefficient of thermal expansion: 0.0000108 /°C
Density: 23.563114 kN/m³

MP4: Grade 1862 E 197.0
Type: Prestressing Steel

Tensile strength f_{pu}: 1861.5845 MPa

Strength LS stress/strain curve parameters:

Tension	strain	stress MPa
full yield:	-0.014442	-1860.0
start yield:	-0.007553	-1488.0

Elastic modulus E_p: 197.0 kN/mm²
Shear modulus: 75.769232 kN/mm²
Yield strength f_{py}: 90.0% of f_{pu}
Initial Prestress force: 75.0% of f_{pu}
Relaxation type: Low Relaxation
Time from stressing to transfer: 0.0 days

MP5: Grade 420 E 200.0
Type: Reinforcing Steel

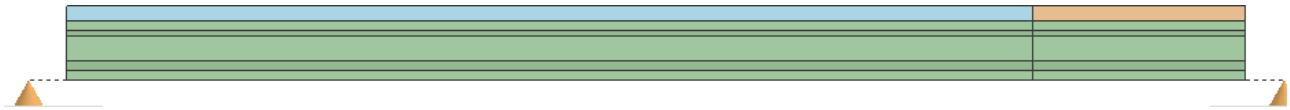
Yield strength f_y: 420.0 MPa

Strength LS stress/strain curve parameters:

	strain	stress MPa
Tension		
full yield:	-0.0041	-420.0
start yield:	-0.00168	-336.0
Compression		
start yield:	0.00168	336.0
full yield:	0.002	347.10744

Elastic modulus E_s: 200.0 kN/mm²
Shear modulus: 76.92308 kN/mm²
Max. stress limitation factor: 0.6000000 x f_y

DESIGN BEAM - SB1: PRE-TENSIONED PRESTRESSED



BEAM DEFINITION

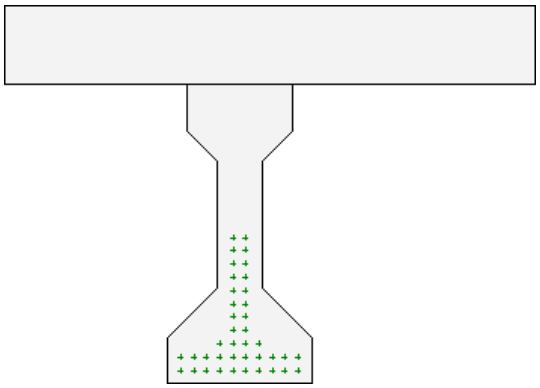
AASHTO LRFD Pre-tensioned Prestressed Beam

```
Total length of pre-tensioned beam:           23.1136 m
Distance from left support to beam end face:  -0.75 m
Distance from right support to beam end face: -0.75 m
Total distance between supports:              24.6136 m

Beam section varies along length of beam.

Number of different sections             : 2
No. of longitudinal construction stages  : 2
No. of superimposed construction stages  : 1
```

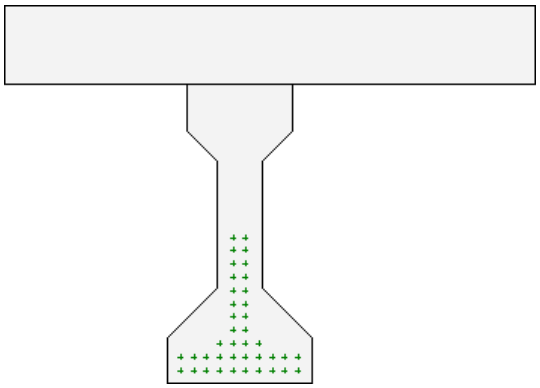
Section 1



```
Precast beam is standard section: GIRDER III
Property set for precast concrete -
                 at transfer:  MP3: C42 Es 32.4
           in final structure:  MP2: C56 Es 37.4

Cast In Place concrete - stage 1A:
    C.I.P. is from standard section:
         - width: 2.03732 m
         - depth: 0.3 m
    Property set:  MP1: C35 Es 29.6
```

Section 2



```
Precast beam is standard section: GIRDER III
Property set for precast concrete -
                 at transfer:  MP3: C42 Es 32.4
           in final structure:  MP2: C56 Es 37.4


Cast In PLace concrete - stage 1B:
    C.I.P. is from standard section:
         - width: 2.03732 m
         - depth: 0.3 m
    Property set:  MP1: C35 Es 29.6
```

Tendons

x-y coordinates mm		area mm²	Property ref	K	d_b mm	type
-228.6	50.8	98.71	MP4	60	12.7	Full stress
-177.8	50.8	98.71	MP4	60	12.7	Full stress
-127.0	50.8	98.71	MP4	60	12.7	Full stress
-76.2	50.8	98.71	MP4	60	12.7	Full stress
-25.4	50.8	98.71	MP4	60	12.7	Harped
25.4	50.8	98.71	MP4	60	12.7	Harped
76.2	50.8	98.71	MP4	60	12.7	Full stress
127.0	50.8	98.71	MP4	60	12.7	Full stress
177.8	50.8	98.71	MP4	60	12.7	Full stress
228.6	50.8	98.71	MP4	60	12.7	Full stress
-228.6	101.6	98.71	MP4	60	12.7	Full stress
-177.8	101.6	98.71	MP4	60	12.7	Full stress
-127.0	101.6	98.71	MP4	60	12.7	Full stress
-76.2	101.6	98.71	MP4	60	12.7	Full stress
-25.4	101.6	98.71	MP4	60	12.7	Harped
25.4	101.6	98.71	MP4	60	12.7	Harped
76.2	101.6	98.71	MP4	60	12.7	Full stress
127.0	101.6	98.71	MP4	60	12.7	Full stress

177.8	101.6	98.71	MP4	60	12.7 Full stress
228.6	101.6	98.71	MP4	60	12.7 Full stress
-76.2	152.4	98.71	MP4	60	12.7 Full stress
-25.4	152.4	98.71	MP4	60	12.7 Harped
25.4	152.4	98.71	MP4	60	12.7 Harped
76.2	152.4	98.71	MP4	60	12.7 Full stress
-25.4	203.2	98.71	MP4	60	12.7 Harped
25.4	203.2	98.71	MP4	60	12.7 Harped
-25.4	254.0	98.71	MP4	60	12.7 Harped
25.4	254.0	98.71	MP4	60	12.7 Harped
-25.4	304.8	98.71	MP4	60	12.7 Harped
25.4	304.8	98.71	MP4	60	12.7 Harped
-25.4	355.6	98.71	MP4	60	12.7 Harped
25.4	355.6	98.71	MP4	60	12.7 Harped
-25.4	406.4	98.71	MP4	60	12.7 Harped
25.4	406.4	98.71	MP4	60	12.7 Harped
-25.4	457.2	98.71	MP4	60	12.7 Harped
25.4	457.2	98.71	MP4	60	12.7 Harped
-25.4	508.0	98.71	MP4	60	12.7 Harped
25.4	508.0	98.71	MP4	60	12.7 Harped
-25.4	558.8	98.71	MP4	60	12.7 Harped
25.4	558.8	98.71	MP4	60	12.7 Harped

Deflected Tendons

x-y coordinates mm		deflection angle (°)	location (m) left	location (m) right	exit height (mm) left	exit height (mm) right
-25.4	50.8	3.30762	9.25	13.8636	585.386	585.386
25.4	50.8	3.30762	9.25	13.8636	585.386	585.386
-25.4	101.6	3.30762	9.25	13.8636	636.186	636.186
25.4	101.6	3.30762	9.25	13.8636	636.186	636.186
-25.4	152.4	3.30762	9.25	13.8636	686.986	686.986
25.4	152.4	3.30762	9.25	13.8636	686.986	686.986
-25.4	203.2	3.30762	9.25	13.8636	737.786	737.786
25.4	203.2	3.30762	9.25	13.8636	737.786	737.786
-25.4	254.0	3.30762	9.25	13.8636	788.586	788.586
25.4	254.0	3.30762	9.25	13.8636	788.586	788.586
-25.4	304.8	3.30762	9.25	13.8636	839.386	839.386
25.4	304.8	3.30762	9.25	13.8636	839.386	839.386
-25.4	355.6	3.30762	9.25	13.8636	890.186	890.186
25.4	355.6	3.30762	9.25	13.8636	890.186	890.186
-25.4	406.4	3.30762	9.25	13.8636	940.986	940.986
25.4	406.4	3.30762	9.25	13.8636	940.986	940.986
-25.4	457.2	3.30762	9.25	13.8636	991.786	991.786
25.4	457.2	3.30762	9.25	13.8636	991.786	991.786
-25.4	508.0	3.30762	9.25	13.8636	1042.59	1042.59
25.4	508.0	3.30762	9.25	13.8636	1042.59	1042.59
-25.4	558.8	3.30762	9.25	13.8636	1093.39	1093.39
25.4	558.8	3.30762	9.25	13.8636	1093.39	1093.39

Reinforcement

x-y coordinates mm		diameter mm	Property ref	Start m	End m	Length m
1062.01	1380.4	25.2	MP5	15.4091	23.1136	7.70455
916.486	1380.4	25.2	MP5	15.4091	23.1136	7.70455
770.963	1380.4	25.2	MP5	15.4091	23.1136	7.70455
625.44	1380.4	25.2	MP5	15.4091	23.1136	7.70455
479.917	1380.4	25.2	MP5	15.4091	23.1136	7.70455
334.394	1380.4	25.2	MP5	15.4091	23.1136	7.70455
188.871	1380.4	25.2	MP5	15.4091	23.1136	7.70455
43.3481	1380.4	25.2	MP5	15.4091	23.1136	7.70455
-102.17	1380.4	25.2	MP5	15.4091	23.1136	7.70455
-247.7	1380.4	25.2	MP5	15.4091	23.1136	7.70455
-393.22	1380.4	25.2	MP5	15.4091	23.1136	7.70455
-538.74	1380.4	25.2	MP5	15.4091	23.1136	7.70455
-684.27	1380.4	25.2	MP5	15.4091	23.1136	7.70455
-829.79	1380.4	25.2	MP5	15.4091	23.1136	7.70455

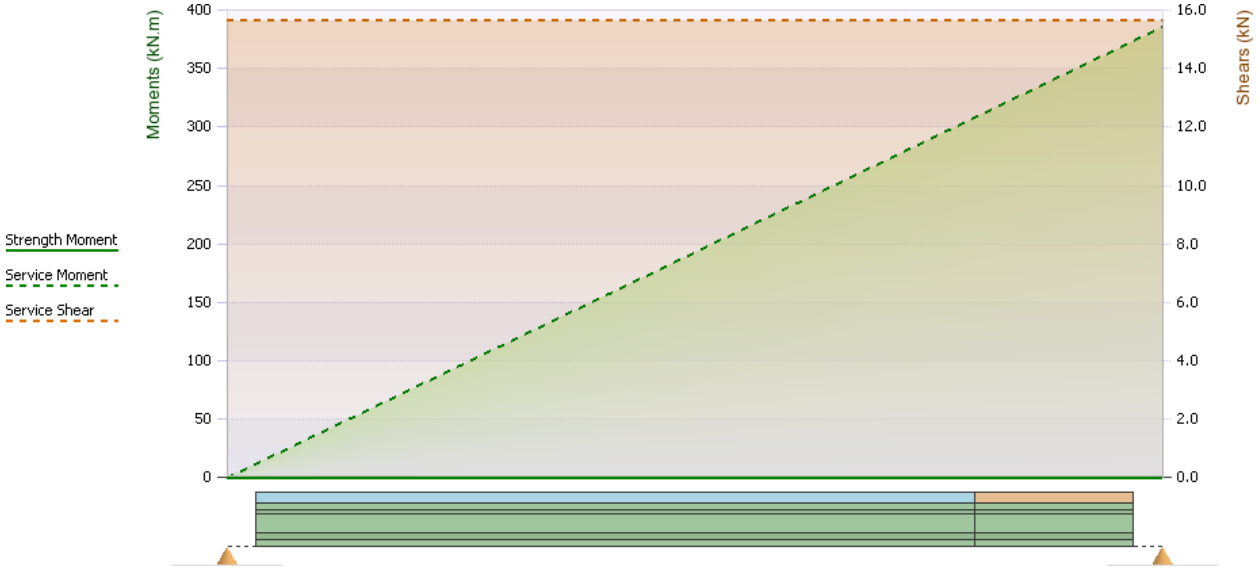
Location of sections

Position along span from left support: dimension (m)	proportion	Section	
0.0	0.0	1	Section 1
18.940918	0.819	1	Section 1
18.940918	0.819	2	Section 2
23.113647	1.0	2	Section 2

PRE-TENSIONED BEAM LOADING DATA

Approximate Methods of Analysis are used - Article 4.6.2
Live Load Distribution Factor for +ve Moment = 0.94124 lanes/beam
Live Load Distribution Factor for -ve Moment = 0.94124 lanes/beam
Live Load Distribution Factor for Shear = 0.94124 lanes/beam
Live Load Distribution Factor for Fatigue = 0.78437 lanes/beam

Temperature gradient secondary loads - positive temp grad



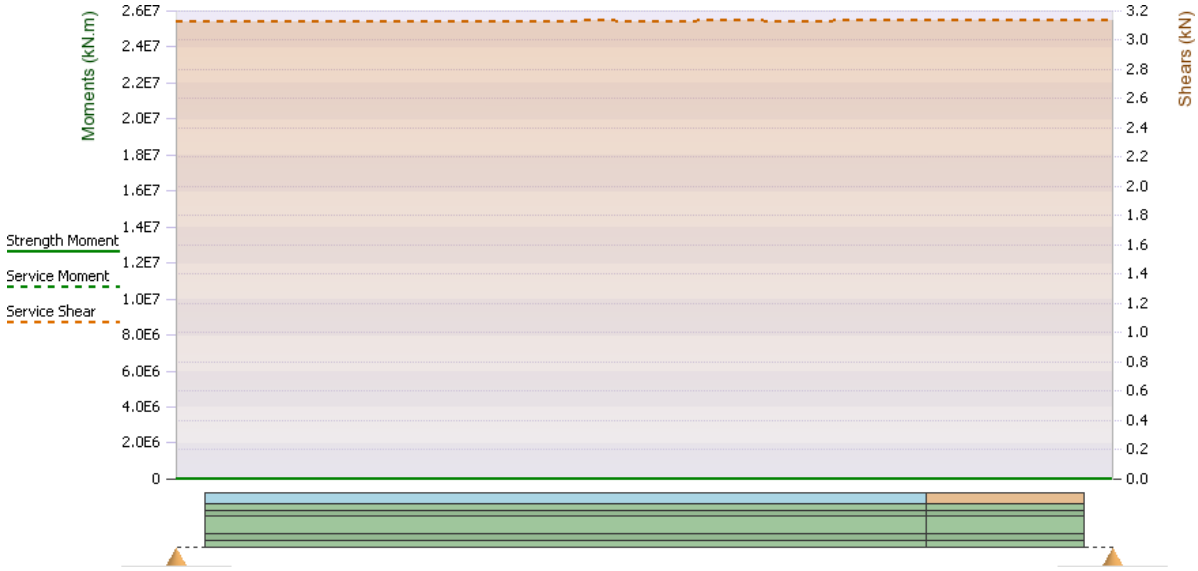
Loading is defined for the distance between supports

Span Location (from left support)		Moment kN.m		Shear kN		Axial kN	
dim (m)	pro	Strength	Service	Strength	Service	Strength	Service
0.0	0.0	0.0	0.0	0.0	15.6548	0.0	0.0
1.2306823	0.05	0.0	19.265	0.0	15.6548	0.0	0.0
2.4613647	0.1	0.0	38.5311	0.0	15.6562	0.0	0.0
3.692047	0.15	0.0	57.8006	0.0	15.6616	0.0	0.0
4.9227294	0.2	0.0	77.0799	0.0	15.6544	0.0	0.0
6.1534117	0.25	0.0	96.3319	0.0	15.6552	0.0	0.0
7.384094	0.3	0.0	115.613	0.0	15.6632	0.0	0.0
8.6147764	0.35	0.0	134.885	0.0	15.6536	0.0	0.0
9.8454587	0.4	0.0	154.142	0.0	15.652	0.0	0.0
11.076141	0.45	0.0	173.41	0.0	15.6679	0.0	0.0
12.306823	0.5	0.0	192.707	0.0	15.6711	0.0	0.0
13.537506	0.55	0.0	211.982	0.0	15.6616	0.0	0.0
14.768188	0.6	0.0	231.256	0.0	15.6624	0.0	0.0
15.99887	0.65	0.0	250.533	0.0	15.6663	0.0	0.0
17.229553	0.7	0.0	269.816	0.0	15.6639	0.0	0.0
18.460235	0.75	0.0	289.088	0.0	15.6711	0.0	0.0
19.690917	0.8	0.0	308.389	0.0	15.6778	0.0	0.0
20.9216	0.85	0.0	327.677	0.0	15.6749	0.0	0.0
22.152282	0.9	0.0	346.97	0.0	15.6775	0.0	0.0
23.382964	0.95	0.0	366.265	0.0	15.6776	0.0	0.0
24.613647	1.0	0.0	385.558	0.0	15.6776	0.0	0.0

These loads are transferred from the following analysis run:

Location: Span 1
Analysis time: 10/27/2016 15:48:35
Analysis Loadcase - Linebeam with Temperature or Shrinkage
- Factor for Strength: 0.0 Service: 0.5

Temperature gradient secondary loads - reverse temp grad



Loading is defined for the distance between supports

Span Location (from left support)		Moment kN.m		Shear kN		Axial kN	
dim (m)	pro	Strength	Service	Strength	Service	Strength	Service
0.0	0.0	0.0	1.55E-4	0.0	3.13105	0.0	0.0
1.2306823	0.05	0.0	-3.8524	0.0	3.13105	0.0	0.0
2.4613647	0.1	0.0	-7.7065	0.0	3.13165	0.0	0.0
3.692047	0.15	0.0	-11.561	0.0	3.1318	0.0	0.0
4.9227294	0.2	0.0	-15.415	0.0	3.1312	0.0	0.0
6.1534117	0.25	0.0	-19.268	0.0	3.1318	0.0	0.0
7.384094	0.3	0.0	-23.124	0.0	3.13081	0.0	0.0
8.6147764	0.35	0.0	-26.974	0.0	3.13041	0.0	0.0
9.8454587	0.4	0.0	-30.829	0.0	3.13279	0.0	0.0
11.076141	0.45	0.0	-34.685	0.0	3.13319	0.0	0.0
12.306823	0.5	0.0	-38.54	0.0	3.13279	0.0	0.0
13.537506	0.55	0.0	-42.395	0.0	3.13299	0.0	0.0
14.768188	0.6	0.0	-46.252	0.0	3.13358	0.0	0.0
15.99887	0.65	0.0	-50.108	0.0	3.13259	0.0	0.0
17.229553	0.7	0.0	-53.962	0.0	3.13299	0.0	0.0
18.460235	0.75	0.0	-57.82	0.0	3.13438	0.0	0.0
19.690917	0.8	0.0	-61.677	0.0	3.13453	0.0	0.0
20.9216	0.85	0.0	-65.535	0.0	3.13532	0.0	0.0
22.152282	0.9	0.0	-69.394	0.0	3.13568	0.0	0.0
23.382964	0.95	0.0	-73.253	0.0	3.13548	0.0	0.0
24.613647	1.0	0.0	-77.112	0.0	3.13548	0.0	0.0

These loads are transferred from the following analysis run:

Location: Span 1
Analysis time: 10/27/2016 15:48:35
Analysis Loadcase - Linebeam with Temperature or Shrinkage
- Factor for Strength: 0.0 Service: 0.5

Shrinkage and creep secondary load effects

Loading is defined for the distance between supports

Span Location (from left support)		Moment kN.m		Shear kN		Axial kN	
dim (m)	pro	Strength	Service	Strength	Service	Strength	Service
0.0	0.0	0.0	0.0	0.45501	0.91002	0.0	0.0
1.2306823	0.05	-0.5598	-1.1197	0.45501	0.91002	0.0	0.0
2.4613647	0.1	-1.1199	-2.2399	0.45486	0.90973	0.0	0.0
3.692047	0.15	-1.6794	-3.3589	0.45515	0.91030	0.0	0.0
4.9227294	0.2	-2.2402	-4.4805	0.45546	0.91092	0.0	0.0
6.1534117	0.25	-2.8005	-5.601	0.45535	0.91070	0.0	0.0
7.384094	0.3	-3.361	-6.7221	0.45520	0.91040	0.0	0.0
8.6147764	0.35	-3.9209	-7.8418	0.45446	0.90892	0.0	0.0
9.8454587	0.4	-4.4796	-8.9593	0.45562	0.91125	0.0	0.0
11.076141	0.45	-5.0424	-10.085	0.45661	0.91323	0.0	0.0
12.306823	0.5	-5.6035	-11.207	0.45622	0.91244	0.0	0.0
13.537506	0.55	-6.1653	-12.331	0.45691	0.91382	0.0	0.0
14.768188	0.6	-6.7282	-13.456	0.45634	0.91268	0.0	0.0
15.99887	0.65	-7.2885	-14.577	0.45565	0.9113	0.0	0.0
17.229553	0.7	-7.8497	-15.699	0.45614	0.91229	0.0	0.0
18.460235	0.75	-8.4113	-16.823	0.45685	0.91371	0.0	0.0
19.690917	0.8	-8.9742	-17.948	0.45759	0.91519	0.0	0.0
20.9216	0.85	-9.5376	-19.075	0.45793	0.91586	0.0	0.0
22.152282	0.9	-10.101	-20.203	0.45807	0.91614	0.0	0.0
23.382964	0.95	-10.665	-21.33	0.45806	0.91613	0.0	0.0
24.613647	1.0	-11.229	-22.458	0.45806	0.91613	0.0	0.0

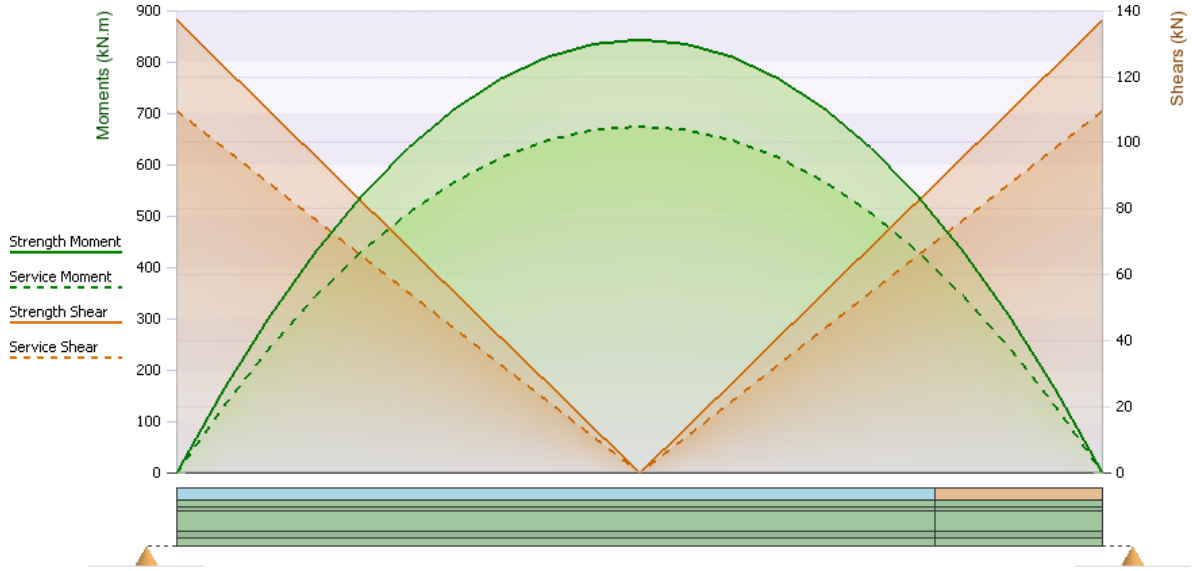
These loads are transferred from the following analysis run:

Location: Span 1
Analysis time: 10/27/2016 15:48:35
Analysis Loadcase - Linebeam with Temperature or Shrinkage
- Factor for Strength: 0.5 Service: 1.0

Settlement of supports

- none defined -

Beam Erection Stage Loading



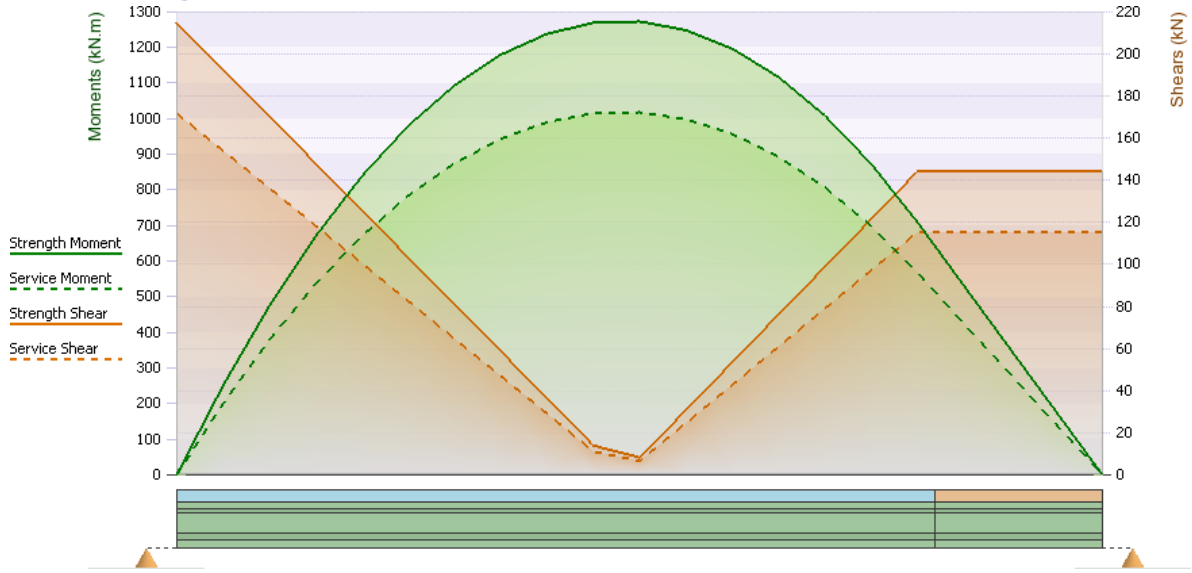
Loading is defined for the distance between beam end faces

Span Location (from left end)		Moment		Shear		Axial	
		kN.m		kN		kN	
dim (m)	pro	Strength	Service	Strength	Service	Strength	Service
0.0	0.0	0.0	0.0	137.054	109.643	0.0	0.0
1.1556823	0.05	160.224	128.179	123.343	98.6745	0.0	0.0
2.3113647	0.1	303.574	242.859	109.632	87.7057	0.0	0.0
3.467047	0.15	430.058	344.046	95.9212	76.737	0.0	0.0
4.6227293	0.2	539.658	431.726	82.1907	65.7526	0.0	0.0
5.7784117	0.25	632.363	505.89	68.4603	54.7682	0.0	0.0
6.934094	0.3	708.144	566.515	54.7298	43.7838	0.0	0.0
8.0897763	0.35	767.089	613.671	41.0775	32.862	0.0	0.0
9.2454587	0.4	809.14	647.312	27.5228	22.0182	0.0	0.0
10.401141	0.45	834.628	667.703	13.8118	11.0495	0.0	0.0
11.556823	0.5	843.203	674.562	0.13995	0.11196	0.0	0.0
12.712506	0.55	834.785	667.828	13.6101	10.888	0.0	0.0
13.868188	0.6	809.628	647.703	27.3796	21.9037	0.0	0.0
15.02387	0.65	767.48	613.984	41.1296	32.9037	0.0	0.0
16.179553	0.7	708.437	566.75	54.8601	43.8881	0.0	0.0
17.335235	0.75	632.538	506.031	68.5515	54.8412	0.0	0.0
18.490917	0.8	539.746	431.796	82.2038	65.763	0.0	0.0
19.6466	0.85	430.058	344.046	95.8952	76.7162	0.0	0.0
20.802282	0.9	303.598	242.878	109.626	87.7005	0.0	0.0
21.957964	0.95	160.252	128.202	123.355	98.6838	0.0	0.0
23.113647	1.0	0.0	0.0	137.072	109.658	0.0	0.0

These loads are transferred from the following analysis run:

Location: Span 1
Analysis time: 10/27/2016 15:48:35
Analysis Loadcase - Linebeam with Erection of beam
- Factor for Strength: 1.25 Service: 1.0

Construction stage 1A



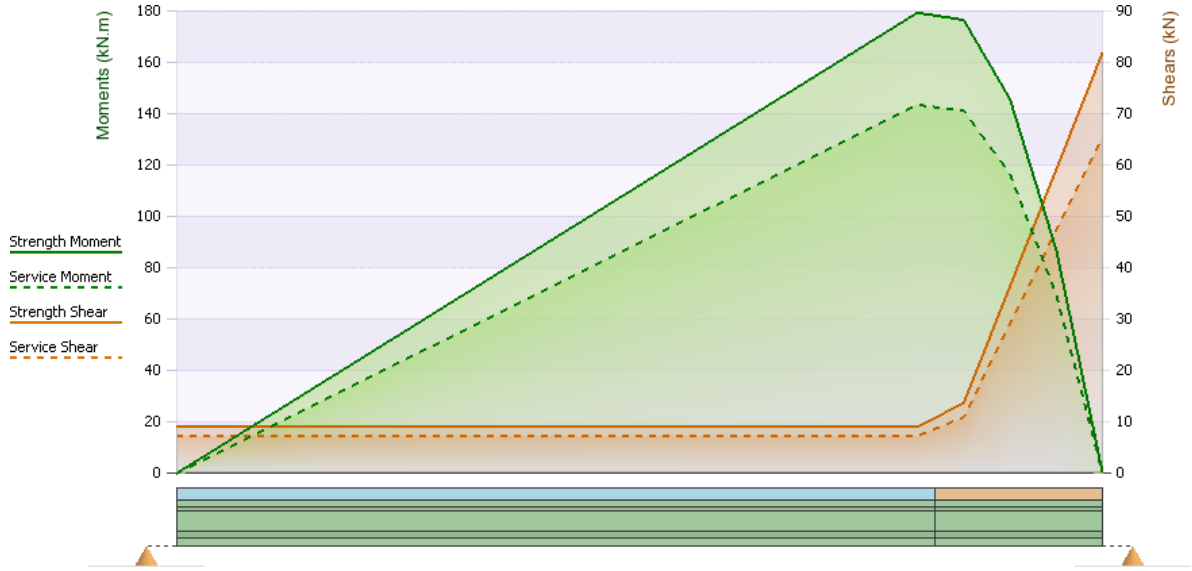
Loading is defined for the distance between beam end faces

Span Location (from left end)		Moment kN.m		Shear kN		Axial kN	
dim (m)	pro	Strength	Service	Strength	Service	Strength	Service
0.0	0.0	0.0	0.0	214.662	171.73	0.0	0.0
1.1556823	0.05	250.535	200.428	192.487	153.99	0.0	0.0
2.3113647	0.1	473.725	378.98	170.318	136.254	0.0	0.0
3.467047	0.15	669.649	535.719	147.992	118.394	0.0	0.0
4.6227293	0.2	838.122	670.497	125.725	100.58	0.0	0.0
5.7784117	0.25	979.153	783.323	103.321	82.6568	0.0	0.0
6.934094	0.3	1092.7	874.163	80.9561	64.7648	0.0	0.0
8.0897763	0.35	1178.62	942.895	58.8256	47.0605	0.0	0.0
9.2454587	0.4	1237.15	989.72	36.5388	29.2311	0.0	0.0
10.401141	0.45	1268.36	1014.69	14.0958	11.2767	0.0	0.0
11.556823	0.5	1271.95	1017.56	8.38623	6.70898	0.0	0.0
12.712506	0.55	1247.65	998.117	30.8683	24.6947	0.0	0.0
13.868188	0.6	1195.79	956.63	53.5457	42.8365	0.0	0.0
15.02387	0.65	1115.96	892.768	76.223	60.9784	0.0	0.0
16.179553	0.7	1008.3	806.64	98.8223	79.0578	0.0	0.0
17.335235	0.75	872.808	698.246	121.461	97.1685	0.0	0.0
18.490917	0.8	709.346	567.477	144.121	115.297	0.0	0.0
19.6466	0.85	531.904	425.523	144.023	115.219	0.0	0.0
20.802282	0.9	354.619	283.695	144.082	115.266	0.0	0.0
21.957964	0.95	177.33	141.864	144.091	115.273	0.0	0.0
23.113647	1.0	0.0	0.0	144.091	115.273	0.0	0.0

These loads are transferred from the following analysis run:

Location: Span 1
Analysis time: 10/27/2016 15:48:35
Analysis Loadcase - Linebeam with Construction stage 1A
- Factor for Strength: 1.25 Service: 1.0

Construction stage 1B



Loading is defined for the distance between beam end faces

Span Location (from left end)		Moment kN.m		Shear kN		Axial kN	
dim (m)	pro	Strength	Service	Strength	Service	Strength	Service
0.0	0.0	0.0	2.44E-4	9.104	7.2832	0.0	0.0
1.1556823	0.05	11.2048	8.96387	9.10278	7.28223	0.0	0.0
2.3113647	0.1	22.4097	17.9277	9.10156	7.28125	0.0	0.0
3.467047	0.15	33.6096	26.8877	9.10645	7.28516	0.0	0.0
4.6227293	0.2	44.8096	35.8477	9.104	7.2832	0.0	0.0
5.7784117	0.25	56.0132	44.8105	9.10156	7.28125	0.0	0.0
6.934094	0.3	67.2192	53.7754	9.09668	7.27734	0.0	0.0
8.0897763	0.35	78.4229	62.7383	9.09668	7.27734	0.0	0.0
9.2454587	0.4	89.6265	71.7012	9.0918	7.27344	0.0	0.0
10.401141	0.45	100.813	80.6504	9.10156	7.28125	0.0	0.0
11.556823	0.5	112.002	89.6016	9.10156	7.28125	0.0	0.0
12.712506	0.55	123.193	98.5547	9.09668	7.27734	0.0	0.0
13.868188	0.6	134.39	107.512	9.08203	7.26562	0.0	0.0
15.02387	0.65	145.581	116.465	9.08691	7.26953	0.0	0.0
16.179553	0.7	156.763	125.41	9.09668	7.27734	0.0	0.0
17.335235	0.75	167.957	134.365	9.0625	7.25	0.0	0.0
18.490917	0.8	179.117	143.294	9.07077	7.25661	0.0	0.0
19.6466	0.85	176.296	141.037	13.6588	10.927	0.0	0.0
20.802282	0.9	145.503	116.403	36.3882	29.1106	0.0	0.0
21.957964	0.95	86.7379	69.3903	59.1151	47.2921	0.0	0.0
23.113647	1.0	0.0	0.0	81.844	65.4752	0.0	0.0

These loads are transferred from the following analysis run:

Location: Span 1
Analysis time: 10/27/2016 15:48:35
Analysis Loadcase - Linebeam with Construction stage 1B
- Factor for Strength: 1.25 Service: 1.0

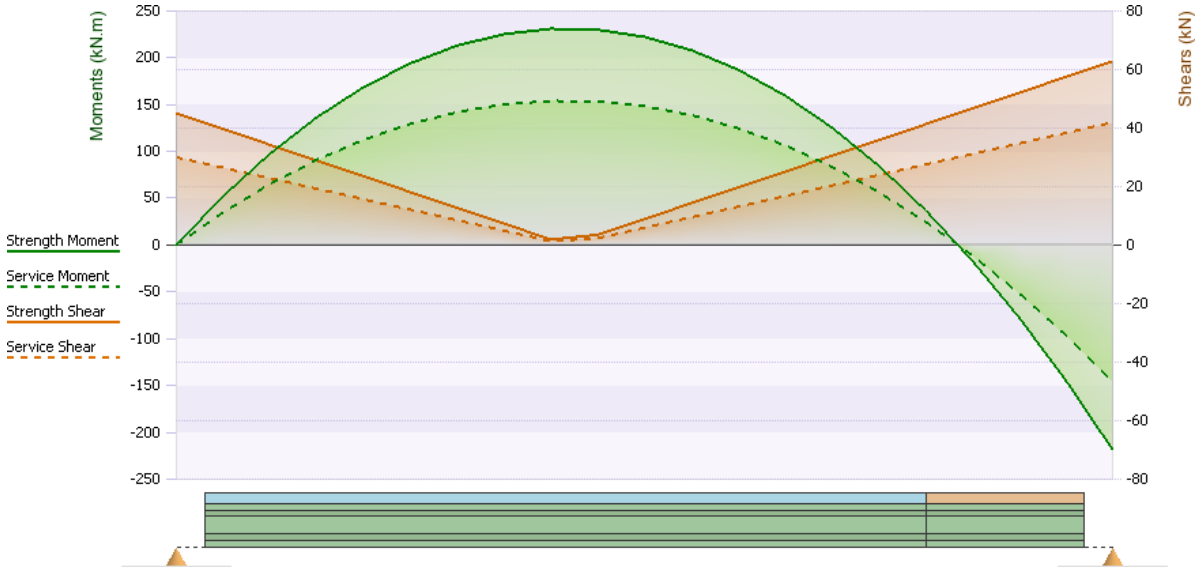
Construction stage 2

- none defined -

Construction stage 3

- none defined -

Superimposed dead load 1



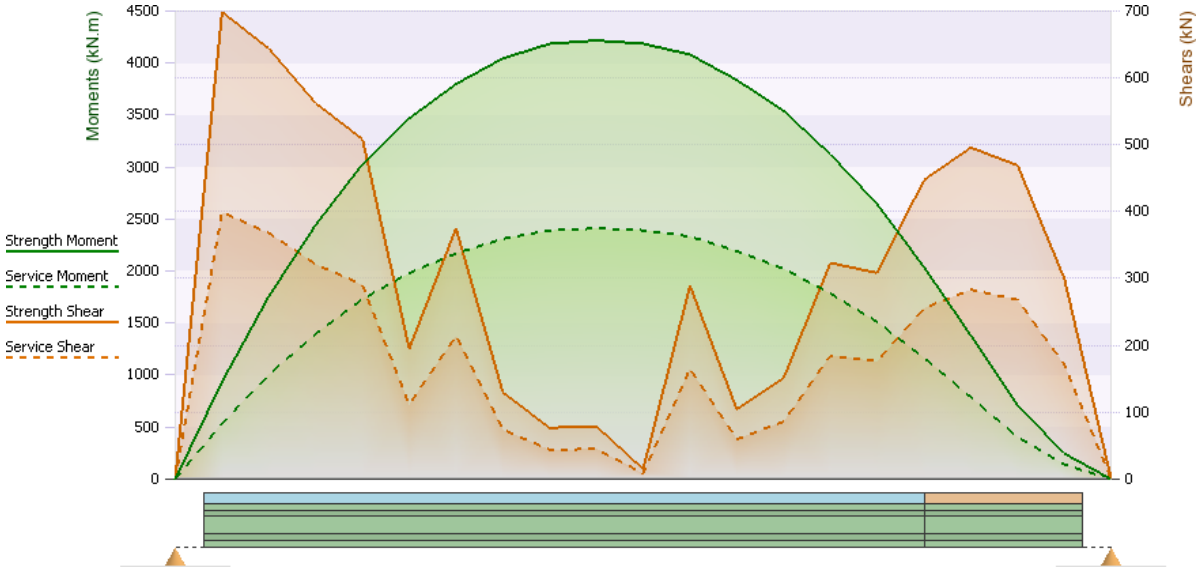
Loading is defined for the distance between supports

Span Location (from left support)		Moment kN.m		Shear kN		Axial kN	
dim (m)	pro	Strength	Service	Strength	Service	Strength	Service
0.0	0.0	0.0	0.0	45.0037	30.0025	0.0	0.0
1.2306823	0.05	52.0712	34.7141	39.6125	26.4083	0.0	0.0
2.4613647	0.1	97.5081	65.0054	34.2204	22.8136	0.0	0.0
3.692047	0.15	136.306	90.8704	28.8357	19.2238	0.0	0.0
4.9227294	0.2	168.476	112.317	23.4494	15.633	0.0	0.0
6.1534117	0.25	194.012	129.342	18.0617	12.0412	0.0	0.0
7.384094	0.3	212.91	141.94	12.6814	8.45424	0.0	0.0
8.6147764	0.35	225.202	150.135	7.28342	4.85561	0.0	0.0
9.8454587	0.4	230.871	153.914	1.86496	1.2433	0.0	0.0
11.076141	0.45	229.85	153.233	3.4993	2.33287	0.0	0.0
12.306823	0.5	222.212	148.141	8.8782	5.9188	0.0	0.0
13.537506	0.55	207.968	138.645	14.2923	9.52818	0.0	0.0
14.768188	0.6	187.048	124.699	19.6712	13.1141	0.0	0.0
15.99887	0.65	159.523	106.348	25.0442	16.6961	0.0	0.0
17.229553	0.7	125.39	83.5935	30.4612	20.3075	0.0	0.0
18.460235	0.75	84.5856	56.3904	35.8548	23.9032	0.0	0.0
19.690917	0.8	37.151	24.7673	41.2425	27.495	0.0	0.0
20.9216	0.85	-16.927	-11.284	46.6382	31.0921	0.0	0.0
22.152282	0.9	-77.639	-51.759	52.0277	34.6852	0.0	0.0
23.382964	0.95	-144.98	-96.655	57.4147	38.2765	0.0	0.0
24.613647	1.0	-218.96	-145.97	62.8028	41.8686	0.0	0.0

These loads are transferred from the following analysis run:

Location: Span 1
Analysis time: 10/27/2016 15:48:35
Analysis Loadcase - Linebeam with Superimposed dead load
- Factor for Strength: 1.5 Service: 1.0

Transient Load BM 1 : [Max +ve] - Strength I & Service



Loading is defined for the distance between supports

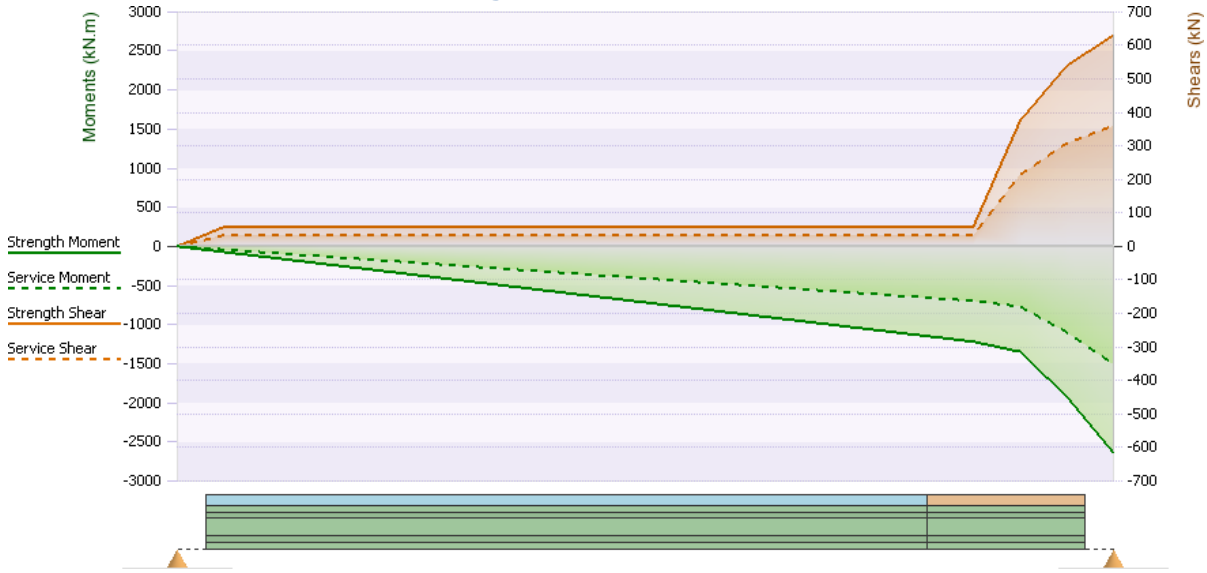
Span Location (from left support)		Moment kN.m		Shear kN		Axial kN	
dim (m)	pro	Strength	Service	Strength	Service	Strength	Service
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.2306823	0.05	933.653	533.516	698.206	398.975	0.0	0.0
2.4613647	0.1	1757.05	1004.03	643.578	367.759	0.0	0.0
3.692047	0.15	2441.54	1395.16	562.069	321.182	0.0	0.0
4.9227294	0.2	3026.65	1729.52	508.169	290.382	0.0	0.0
6.1534117	0.25	3465.6	1980.34	194.877	111.358	0.0	0.0
7.384094	0.3	3796.91	2169.66	374.847	214.198	0.0	0.0
8.6147764	0.35	4042.67	2310.1	129.432	73.9613	0.0	0.0
9.8454587	0.4	4183.06	2390.32	76.6881	43.8218	0.0	0.0
11.076141	0.45	4215.29	2408.74	78.8976	45.0844	0.0	0.0
12.306823	0.5	4184.44	2391.11	14.9847	8.56269	0.0	0.0
13.537506	0.55	4079.65	2331.23	289.14	165.223	0.0	0.0
14.768188	0.6	3835.13	2191.5	104.081	59.4748	0.0	0.0
15.99887	0.65	3538.84	2022.2	150.813	86.179	0.0	0.0
17.229553	0.7	3121.48	1783.7	323.189	184.679	0.0	0.0
18.460235	0.75	2641.83	1509.62	308.208	176.119	0.0	0.0
19.690917	0.8	2037.27	1164.15	447.208	255.547	0.0	0.0
20.9216	0.85	1379.84	788.478	495.498	283.142	0.0	0.0
22.152282	0.9	708.738	404.993	469.11	268.063	0.0	0.0
23.382964	0.95	245.162	140.092	299.285	171.02	0.0	0.0
24.613647	1.0	0.0	0.0	0.0	0.0	0.0	0.0

The loading shown excludes the distribution factors applied during design.

These loads are transferred from the following analysis run:

Location: Span 1
Analysis time: 10/27/2016 15:48:35
Analysis Loadcase - Moving Load for Maximum +ve Moments
- Factor for Strength: 1.75 Service: 1.0

Transient Load BM 2 : [Max -ve] - Strength I & Service



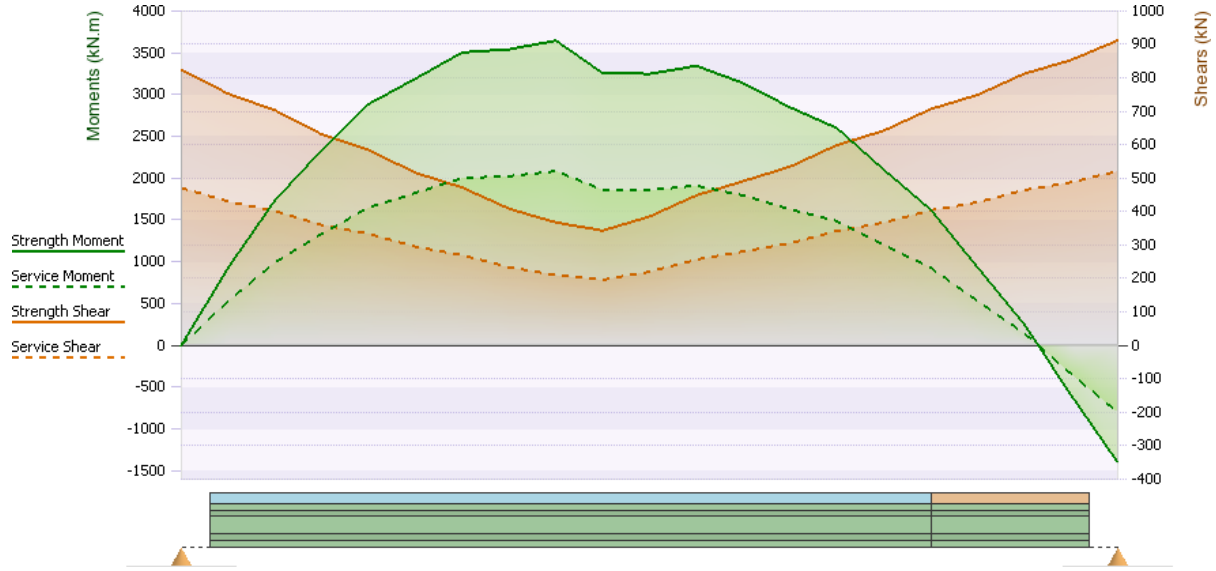
Loading is defined for the distance between supports

Span Location (from left support)		Moment kN.m		Shear kN		Axial kN	
dim (m)	pro	Strength	Service	Strength	Service	Strength	Service
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.2306823	0.05	-71.74	-40.994	58.2869	33.3068	0.0	0.0
2.4613647	0.1	-143.47	-81.986	58.2797	33.3027	0.0	0.0
3.692047	0.15	-215.21	-122.97	58.2762	33.3007	0.0	0.0
4.9227294	0.2	-286.9	-163.94	58.2949	33.3114	0.0	0.0
6.1534117	0.25	-358.64	-204.94	58.2452	33.283	0.0	0.0
7.384094	0.3	-430.35	-245.91	58.2747	33.2998	0.0	0.0
8.6147764	0.35	-502.08	-286.9	58.2963	33.3122	0.0	0.0
9.8454587	0.4	-573.84	-327.91	58.2151	33.2657	0.0	0.0
11.076141	0.45	-645.44	-368.82	58.2693	33.2968	0.0	0.0
12.306823	0.5	-717.13	-409.79	58.2228	33.2702	0.0	0.0
13.537506	0.55	-788.75	-450.71	58.2081	33.2618	0.0	0.0
14.768188	0.6	-860.34	-491.62	58.2702	33.2972	0.0	0.0
15.99887	0.65	-932.01	-532.58	58.2872	33.307	0.0	0.0
17.229553	0.7	-1003.8	-573.58	58.1495	33.2283	0.0	0.0
18.460235	0.75	-1075.4	-614.49	58.0351	33.1629	0.0	0.0
19.690917	0.8	-1146.8	-655.34	58.0488	33.1707	0.0	0.0
20.9216	0.85	-1218.3	-696.16	57.9702	33.1258	0.0	0.0
22.152282	0.9	-1347.8	-770.19	374.808	214.176	0.0	0.0
23.382964	0.95	-1923.8	-1099.3	539.306	308.175	0.0	0.0
24.613647	1.0	-2644.2	-1511.0	630.837	360.478	0.0	0.0

The loading shown excludes the distribution factors applied during design.
These loads are transferred from the following analysis run:

Location: Span 1
Analysis time: 10/27/2016 15:48:35
Analysis Loadcase - Moving Load for Maximum -ve Moments
- Factor for Strength: 1.75 Service: 1.0

Transient Load SF + assoc. BM 1 - Strength I & Service



Loading is defined for the distance between supports

Span Location (from left support)		Moment kN.m		Shear kN		Axial kN	
dim (m)	pro	Strength	Service	Strength	Service	Strength	Service
0.0	0.0	0.0	0.0	823.866	470.781	0.0	0.0
1.2306823	0.05	927.791	530.166	752.11	429.777	0.0	0.0
2.4613647	0.1	1734.18	990.961	702.709	401.548	0.0	0.0
3.692047	0.15	2336.32	1335.04	630.469	360.268	0.0	0.0
4.9227294	0.2	2885.1	1648.63	583.846	333.627	0.0	0.0
6.1534117	0.25	3189.06	1822.32	515.731	294.703	0.0	0.0
7.384094	0.3	3502.48	2001.42	471.718	269.553	0.0	0.0
8.6147764	0.35	3540.0	2022.86	408.164	233.237	0.0	0.0
9.8454587	0.4	3643.81	2082.18	367.195	209.826	0.0	0.0
11.076141	0.45	3254.11	1859.49	343.006	196.004	0.0	0.0
12.306823	0.5	3247.22	1855.56	385.062	220.036	0.0	0.0
13.537506	0.55	3341.79	1909.59	448.516	256.295	0.0	0.0
14.768188	0.6	3133.53	1790.59	490.886	280.506	0.0	0.0
15.99887	0.65	2845.29	1625.88	534.287	305.307	0.0	0.0
17.229553	0.7	2596.97	1483.98	598.752	342.144	0.0	0.0
18.460235	0.75	2099.92	1199.95	641.84	366.765	0.0	0.0
19.690917	0.8	1623.19	927.539	706.073	403.47	0.0	0.0
20.9216	0.85	933.739	533.565	748.777	427.873	0.0	0.0
22.152282	0.9	250.131	142.932	811.939	463.965	0.0	0.0
23.382964	0.95	-597.3	-341.31	852.994	487.425	0.0	0.0
24.613647	1.0	-1404.9	-802.81	911.837	521.05	0.0	0.0

The loading shown excludes the distribution factors applied during design.

These loads are transferred from the following analysis run:

Location: Span 1
Analysis time: 10/27/2016 15:48:35
Analysis Loadcase - Moving Load for Maximum Shears
- Factor for Strength: 1.75 Service: 1.0

STRUCTURE GEOMETRY

Line Beam Structure with 2 spans as follows:

Span Ref	Span Length m	Elements in span	Support at Left of span Displacement	Rotation
1	24.6136	20	fixed	free
2	23.514	19	fixed	free
	End support:		fixed	free

STRUCTURE PROPERTIES

STRUCTURE PROPERTY DATA

SP1: PS Beam

Type: Prestressed Design Beam
Reference: SB1: Pre-tensioned Prestressed
Material: MP2: C56 Es 37.4
Slab density factor: 1.0

Ref	*Dim* m	A_x mm²	A_y mm²	A_z mm²	I_y mm⁴	I_z mm⁴	*C* mm⁴	γ kN/m³
1	-0.13465	844160.5	0.0	0.0	1.809E11	1.75E11	1.623E10	27.38602
2	15.86421	875994.0	0.0	0.0	1.863E11	1.86E11	1.623E10	26.816766
3	20.78694	398320.8	0.0	0.0	7.755E10	1.84E10	1.623E10	58.975904
4	23.24831	360967.0	0.0	0.0	5.219E10	5.0849E9	1.623E10	64.04518

Notes: Axes refer to line beam local axes.
γ = (unit length weight) / (transformed section area)

Cracked Section Details:
from left: 0.0 m
from right: 3.46705 m

Assigned to the following line beam spans:
1

SP2: PS Beam

Type: Prestressed Design Beam
Reference: SB2: Pre-tensioned Prestressed
Material: MP2: C56 Es 37.4
Slab density factor: 1.0

Ref	*Dim* m	A_x mm²	A_y mm²	A_z mm²	I_y mm⁴	I_z mm⁴	*C* mm⁴	γ kN/m³
1	-0.13121	360967.0	0.0	0.0	5.219E10	5.0849E9	1.623E10	64.015418
2	1.106365	398320.8	0.0	0.0	7.755E10	1.84E10	1.623E10	58.948933
3	3.581519	875994.0	0.0	0.0	1.863E11	1.86E11	1.623E10	26.804503
4	8.531826	844160.5	0.0	0.0	1.809E11	1.75E11	1.623E10	27.373294

Notes: Axes refer to line beam local axes.

γ = (unit length weight) / (transformed section area)

Cracked Section Details:
from left: 3.30209 m
from right: 0.0 m

Assigned to the following line beam spans:
2

STRUCTURE LOADS

LIVE LOAD ENVELOPE DATA

```
The following vehicles may be included in the envelope, in
addition to the lane load of 0.009 MPa which is always included:
    Design Truck
    Design Tandem
    Double Design Truck
    Double Design Tandem
The Dynamic Load Allowance for these vehicles is 33%

Vehicles move in both directions at increments of 0.5 m
```