Design Step 5.3

UNFACTORED AND FACTORED LOAD EFFECTS

Design Step 5.3.1

Summary of loads

The dead load moments and shears were calculated based on the loads shown in Design Step 5.2. The live load moments and shears were calculated using a generic live load analysis computer program. The live load distribution factors from Design Step 5.1 are applied to these values.

Table 5.3-1 - Summary of Unfactored Moments

Interior girder, Span 1 shown, Span 2 mirror image

Location*	Noncomposite					Composite		Live Load + IM	
	Girder		Slab and Haunch	Exterior Diaphragm	Total Noncomp.	Parapet	FWS	Positive HL-93	Negative HL-93
	**	***							
(ft.)	(k-ft)	(k-ft)	(k-ft)	(k-ft)	(k-ft)	(k-ft)	(k-ft)	(k-ft)	(k-ft)
0	47	0	0	0	0	0	0	0	0
1.0	108	61	62	3	125	9	12	92	-11
5.5	368	322	325	14	661	46	62	476	-58
11.0	656	609	615	28	1,252	85	114	886	-116
16.5	909	863	871	42	1,776	118	158	1,230	-174
22.0	1,128	1,082	1,093	56	2,230	144	193	1,509	-233
27.5	1,313	1,267	1,279	70	2,616	164	220	1,724	-291
33.0	1,464	1,417	1,432	84	2,933	177	237	1,882	-349
38.5	1,580	1,534	1,549	98	3,181	183	246	1,994	-407
44.0	1,663	1,616	1,633	111	3,360	183	246	2,047	-465
49.5	1,711	1,664	1,681	125	3,471	177	237	2,045	-523
54.5	1,725	1,679	1,696	138	3,512	165	222	2,015	-576
55.0	1,725	1,678	1,695	137	3,511	164	220	2,010	-581
60.5	1,705	1,658	1,675	123	3,456	144	194	1,927	-640
66.0	1,650	1,604	1,620	109	3,333	118	159	1,794	-698
71.5	1,562	1,515	1,531	95	3,141	86	115	1,613	-756
77.0	1,439	1,392	1,407	81	2,880	46	62	1,388	-814
82.5	1,282	1,236	1,248	67	2,551	1	1	1,124	-872
88.0	1,091	1,044	1,055	53	2,152	-52	-69	825	-1,124
93.5	865	819	827	39	1,686	-110	-148	524	-1,223
99.0	606	560	565	25	1,150	-176	-236	297	-1,371
104.5	312	266	268	11	546	-248	-332	113	-1,663
108.0	110	61	62	3	125	-297	-398	33	-1,921
109.0	47	0	0	0	0	-311	-418	15	-2,006
Span 2 - 0	-	0	0	0	0	-326	-438	0	-2,095

* Distance from the centerline of the end bearing

** Based on the simple span length of 110.5 ft. and supported at the ends of the girders. These values are used to calculate stresses at transfer.

*** Based on the simple span length of 109 ft. and supported at the centerline of bearings. These values are used to calculate the final stresses.

Table 5.3-2 – Summary of Factored Moments

Interior girder, Span 1 shown, Span 2 mirror image

		Service I **		Service III **	
Location*	Strength I	NC	Comp.	NC	Comp.
(ft.)	(k-ft)	(k-ft)	(k-ft)	(k-ft)	(k-ft)
0	0	0	0	0	0
1.0	346	125	112	125	94
5.5	1,809	661	584	661	488
11.0	3,394	1,252	1,085	1,252	908
16.5	4,756	1,776	1,506	1,776	1,260
22.0	5,897	2,230	1,846	2,230	1,544
27.5	6,821	2,616	2,108	2,616	1,763
33.0	7,536	2,933	2,296	2,933	1,920
38.5	8,063	3,181	2,423	3,181	2,024
44.0	8,381	3,360	2,477	3,360	2,067
49.5	8,494	3,471	2,459	3,471	2,050
54.5	8,456	3,512	2,402	3,512	1,999
55.0	8,440	3,511	2,394	3,511	1,992
60.5	8,163	3,456	2,265	3,456	1,880
66.0	7,690	3,333	2,070	3,333	1,712
71.5	7,027	3,141	1,813	3,141	1,490
77.0	6,181	2,880	1,497	2,880	1,219
82.5	5,158	2,551	1,126	2,551	901
88.0	3,967	2,152	-1,245	2,152	-1,020
93.5	2,664	1,686	-1,481	1,686	-1,237
99.0	-1,535	1,150	-1,783	1,150	-1,509
104.5	-3,035	546	-2,242	546	-1,910
108.0	-4,174	125	-2,616	125	-2,232
109.0	-4,525	0	-2,734	0	-2,333
Span 2 - 0	-4,729	0	-2,858	0	-2,439

Load Factor Combinations

Strength I = 1.25(DC) + 1.5(DW) + 1.75(LL + IM)

Service I = 1.0[DC + DW + (LL + IM)]

Service III = 1.0(DC + DW) + 0.8(LL + IM)

* Distance from the centerline of the end bearing

** For service limit states, moments are applied to the section of the girder, i.e. noncomposite or composite, that resists these moments. Hence, noncomposite and composite moments have to be separated for service load calculations.

Table 5.3-3 - Summary of Unfactored Shear

Interior girder, Span 1 shown, Span 2 mirror image

Location*	Noncomposite				Composite		Live Load + IM	
	Girder	Slab and Haunch	Exterior Diaphragm	Total Noncomp.	Parapet	FWS	Positive HL-93	Negative HL-93
(ft.)	(k)	(k)	(k)	(k)	(k)	(k)	(k)	(k)
0	61.6	62.2	2.5	126.4	8.9	12.0	113.3	-12.9
1.0	60.5	61.1	2.5	124.1	8.7	11.7	111.7	-12.9
5.5	55.4	55.9	2.5	113.9	7.7	10.4	104.3	-13.0
11.0	49.2	49.7	2.5	101.4	6.5	8.8	95.5	-13.4
16.5	43.0	43.4	2.5	88.9	5.4	7.2	86.9	-15.9
22.0	36.7	37.1	2.5	76.4	4.2	5.6	78.7	-20.6
27.5	30.5	30.8	2.5	63.9	3.0	4.0	70.8	-26.0
33.0	24.3	24.6	2.5	51.4	1.8	2.4	63.1	-32.8
38.5	18.1	18.3	2.5	38.9	0.6	0.8	55.9	-39.8
44.0	11.9	12.0	2.5	26.4	-0.6	-0.8	48.9	-46.8
49.5	5.7	5.7	2.5	13.9	-1.8	-2.4	42.4	-54.0
54.5	0	0	-2.5	-2.5	-2.9	-3.8	36.8	-60.5
55.0	-0.6	-0.6	-2.5	-3.7	-3.0	-4.0	36.2	-61.2
60.5	-6.8	-6.9	-2.5	-16.2	-4.2	-5.6	30.4	-68.4
66.0	-13.0	-13.1	-2.5	-28.7	-5.3	-7.2	25.0	-75.7
71.5	-19.2	-19.4	-2.5	-41.2	-6.5	-8.8	20.0	-82.9
77.0	-25.4	-25.7	-2.5	-53.7	-7.7	-10.4	15.4	-90.1
82.5	-31.7	-32.0	-2.5	-66.1	-8.9	-12.0	11.3	-97.3
88.0	-37.9	-38.3	-2.5	-78.6	-10.1	-13.6	8.2	-104.3
93.5	-44.1	-44.5	-2.5	-91.1	-11.3	-15.1	5.5	-111.3
99.0	-50.3	-50.8	-2.5	-103.6	-12.5	-16.7	3.2	-118.0
104.5	-56.5	-57.1	-2.5	-116.1	-13.7	-18.3	1.2	-124.7
108.0	-60.5	-61.1	-2.5	-124.1	-14.4	-19.4	0.4	-128.7
109.0	-61.6	-62.2	-2.5	-126.4	-14.6	-19.6	0.2	-129.9
Span 2 - 0	0	0	0	0	-14.8	-19.9	0	-131.1

* Distance from the centerline of the end bearing

Table 5.3-4 – Summary of Factored Shear

Interior girder, Span 1 shown, Span 2 mirror image

Location*	Strength I	Service I	Service III
(ft.)	(k)	(k)	(k)
0	385.4	260.6	237.9
1.0	379.0	256.2	233.8
5.5	350.0	236.2	215.4
11.0	315.1	212.1	193.0
16.5	280.7	188.3	170.9
22.0	246.8	164.8	149.1
27.5	213.4	141.6	127.5
33.0	180.6	118.7	106.1
38.5	148.3	96.2	85.0
44.0	116.7	74.0	64.2
49.5	85.7	52.1	43.6
54.5	-118.4	-69.7	-57.6
55.0	-121.3	-71.8	-59.6
60.5	-153.5	-94.3	-80.6
66.0	-185.7	-116.9	-101.7
71.5	-217.9	-139.4	-122.8
77.0	-250.0	-161.8	-143.8
82.5	-282.0	-184.3	-164.8
88.0	-313.8	-206.6	-185.7
93.5	-345.4	-228.8	-206.6
99.0	-376.8	-250.9	-227.3
104.5	-407.9	-272.8	-247.8
108.0	-427.4	-286.6	-260.8
109.0	-433.0	-290.5	-264.5
Span 2 - 0	-277.8	-165.8	-139.6

Load Factor Combinations
Strength I = 1.25(DC) + 1.5(DW) + 1.75(LL + IM)
Service I = 1.0[DC + DW + (LL + IM)]
Service III = 1.0(DC + DW) + 0.8(LL + IM)

* Distance from the centerline of the end bearing

Table 5.3-5 - Summary of Unfactored Moments

Exterior girder, Span 1 shown, Span 2 mirror image

Location*	Noncomposite					Composite		Live Load + IM	
	Girder		Slab and Haunch	Exterior Diaphragm	Total Noncomp.	Parapet	FWS	Positive HL-93	Negative HL-93
	**	***							
(ft.)	(k-ft)	(k-ft)	(k-ft)	(k-ft)	(k-ft)	(k-ft)	(k-ft)	(k-ft)	(k-ft)
0	47	0	0	0	0	0	0	0	0
1.0	108	61	55	1	117	9	8	93	-11
5.5	368	322	288	7	616	46	41	482	-59
11.0	656	609	545	14	1,168	85	77	897	-118
16.5	909	863	771	21	1,655	118	106	1,245	-177
22.0	1,128	1,082	967	28	2,076	144	130	1,528	-236
27.5	1,313	1,267	1,132	35	2,434	164	148	1,746	-294
33.0	1,464	1,417	1,267	42	2,726	177	160	1,906	-353
38.5	1,580	1,534	1,371	49	2,954	183	165	2,019	-412
44.0	1,663	1,616	1,445	56	3,117	183	166	2,073	-471
49.5	1,711	1,664	1,488	63	3,215	177	160	2,071	-530
54.5	1,725	1,679	1,501	69	3,248	165	149	2,041	-583
55.0	1,725	1,678	1,501	68	3,247	164	148	2,035	-589
60.5	1,705	1,658	1,482	61	3,202	144	130	1,951	-648
66.0	1,650	1,604	1,434	54	3,092	118	107	1,816	-706
71.5	1,562	1,515	1,355	48	2,917	86	77	1,633	-765
77.0	1,439	1,392	1,245	41	2,678	46	42	1,406	-824
82.5	1,282	1,236	1,105	34	2,374	1	1	1,139	-883
88.0	1,091	1,044	934	27	2,005	-52	-47	836	-1,138
93.5	865	819	732	20	1,571	-110	-100	531	-1,238
99.0	606	560	500	13	1,072	-176	-159	300	-1,389
104.5	312	266	238	6	509	-248	-224	114	-1,683
108.0	110	61	55	1	117	-297	-268	33	-1,945
109.0	47	0	0	0	0	-311	-281	15	-2,031
Span 2 - 0	-	0	0	0	0	-326	-294	0	-2,121

* Distance from the centerline of the end bearing

** Based on the simple span length of 110.5 ft. and supported at the ends of the girders. These values are used to calculate stresses at transfer.

*** Based on the simple span length of 109 ft. and supported at the centerline of bearings. These values are used to calculate the final stresses.

Table 5.3-6 – Summary of Factored Moments

Exterior girder, Span 1 shown, Span 2 mirror image

		Service I **		Service III **	
Location*	Strength I	NC	Comp.	NC	Comp.
(ft.)	(k-ft)	(k-ft)	(k-ft)	(k-ft)	(k-ft)
0	0	0	0	0	0
1.0	331	117	110	117	91
5.5	1,734	616	570	616	473
11.0	3,251	1,168	1,059	1,168	879
16.5	4,554	1,655	1,469	1,655	1,220
22.0	5,644	2,076	1,801	2,076	1,496
27.5	6,524	2,434	2,057	2,434	1,708
33.0	7,203	2,726	2,242	2,726	1,861
38.5	7,702	2,954	2,368	2,954	1,964
44.0	8,001	3,117	2,422	3,117	2,007
49.5	8,103	3,215	2,407	3,215	1,993
54.5	8,061	3,248	2,355	3,248	1,947
55.0	8,047	3,247	2,347	3,247	1,940
60.5	7,793	3,202	2,226	3,202	1,836
66.0	7,351	3,092	2,041	3,092	1,678
71.5	6,727	2,917	1,796	2,917	1,469
77.0	5,928	2,678	1,494	2,678	1,213
82.5	4,961	2,374	1,140	2,374	912
88.0	3,834	2,005	-1,237	2,005	-1,009
93.5	2,605	1,571	-1,448	1,571	-1,201
99.0	-1,547	1,072	-1,723	1,072	-1,445
104.5	-2,954	509	-2,154	509	-1,818
108.0	-4,031	117	-2,510	117	-2,121
109.0	-4,364	0	-2,623	0	-2,217
Span 2 - 0	-4,560	0	-2,741	0	-2,317

Load Factor Combinations

Strength I = 1.25(DC) + 1.5(DW) + 1.75(LL + IM)
Service I = 1.0[DC + DW + (LL + IM)]
Service III = 1.0(DC + DW) + 0.8(LL + IM)

* Distance from the centerline of the end bearing

** For service limit states, moments are applied to the section of the girder, i.e. noncomposite or composite, that resists these moments. Hence, noncomposite and composite moments have to be separated for service load calculations.

Table 5.3-7 - Summary of Unfactored Shear

Exterior girder, Span 1 shown, Span 2 mirror image

	Noncomposite				Composite		Live Load + IM	
Location*	Girder	Slab and Haunch	Exterior Diaphragm	Total Noncomp.	Parapet	FWS	Positive HL-93	Negative HL-93
(ft.)	(k)	(k)	(k)	(k)	(k)	(k)	(k)	(k)
0	61.6	55.1	1.3	117.9	8.9	8.1	98.4	-11.2
1.0	60.5	54.1	1.3	115.8	8.7	7.9	97.0	-11.2
5.5	55.4	49.5	1.3	106.2	7.7	7.0	90.6	-11.3
11.0	49.2	44.0	1.3	94.4	6.5	5.9	82.9	-11.6
16.5	43.0	38.4	1.3	82.6	5.4	4.8	75.5	-13.8
22.0	36.7	32.8	1.3	70.8	4.2	3.8	68.3	-17.9
27.5	30.5	27.3	1.3	59.1	3.0	2.7	61.4	-22.6
33.0	24.3	21.7	1.3	47.3	1.8	1.6	54.8	-28.5
38.5	18.1	16.2	1.3	35.5	0.6	0.5	48.5	-34.5
44.0	11.9	10.6	1.3	23.7	-0.6	-0.5	42.5	-40.7
49.5	5.7	5.1	1.3	12.0	-1.8	-1.6	36.8	-46.9
54.5	0	0	-1.3	-1.3	-2.9	-2.6	31.9	-52.6
55.0	-0.6	-0.5	-1.3	-2.3	-3.0	-2.7	31.4	-53.1
60.5	-6.8	-6.1	-1.3	-14.1	-4.2	-3.8	26.4	-59.4
66.0	-13.0	-11.6	-1.3	-25.9	-5.3	-4.8	21.7	-65.7
71.5	-19.2	-17.2	-1.3	-37.7	-6.5	-5.9	17.4	-72.0
77.0	-25.4	-22.7	-1.3	-49.4	-7.7	-7.0	13.4	-78.3
82.5	-31.7	-28.3	-1.3	-61.2	-8.9	-8.0	9.8	-84.5
88.0	-37.9	-33.9	-1.3	-73.0	-10.1	-9.1	7.2	-90.6
93.5	-44.1	-39.4	-1.3	-84.8	-11.3	-10.2	4.8	-96.6
99.0	-50.3	-45.0	-1.3	-96.5	-12.5	-11.3	2.8	-102.5
104.5	-56.5	-50.5	-1.3	-108.3	-13.7	-12.3	1.0	-108.3
108.0	-60.5	-54.1	-1.3	-115.8	-14.4	-13.0	0.4	-111.8
109.0	-61.6	-55.1	-1.3	-117.9	-14.6	-13.2	0.2	-112.8
Span 2 - 0	0	0	0	0	-14.8	-13.4	0	-113.8

* Distance from the centerline of the end bearing

Table 5.3-8 – Summary of Factored Shear

Exterior girder, Span 1 shown, Span 2 mirror image

Location*	Strength I	Service I	Service III
(ft.)	(k)	(k)	(k)
0	342.9	233.3	213.7
1.0	337.2	229.4	210.0
5.5	311.3	211.4	193.3
11.0	280.1	189.7	173.2
16.5	249.3	168.3	153.2
22.0	219.0	147.1	133.4
27.5	189.1	126.2	113.9
33.0	159.7	105.5	94.6
38.5	130.9	85.2	75.5
44.0	102.5	65.1	56.6
49.5	74.8	45.4	38.0
54.5	-101.0	-59.3	-48.7
55.0	-103.6	-61.1	-50.5
60.5	-132.4	-81.4	-69.5
66.0	-161.3	-101.8	-88.6
71.5	-190.1	-122.1	-107.7
77.0	-218.8	-142.4	-126.7
82.5	-247.5	-162.6	-145.7
88.0	-276.0	-182.8	-164.7
93.5	-304.4	-202.8	-183.5
99.0	-332.5	-222.8	-202.2
104.5	-360.4	-242.5	-220.9
108.0	-377.9	-255.0	-232.7
109.0	-382.9	-258.6	-236.0
Span 2 - 0	-237.8	-142.1	-119.3

Load Factor Combinations
Strength I = 1.25(DC) + 1.5(DW) + 1.75(LL + IM)
Service I = 1.0[DC + DW + (LL + IM)]
Service III = 1.0(DC + DW) + 0.8(LL + IM)

* Distance from the centerline of the end bearing

Based on the analysis results, the interior girder controls the design. The remaining sections covering the superstructure design are based on the interior girder analysis. The exterior girder calculations would be identical.

Design Step 5.3.2

ANALYSIS OF CREEP AND SHRINKAGE EFFECTS

Design Step 5.3.2.1

Creep effects

The compressive stress in the beams due to prestressing causes the prestressed beams to creep. For simple span pretensioned beams under dead loads, the highest compression in the beams is typically at the bottom, therefore, creep causes the camber to increase, i.e., causes the upward deflection of the beam to increase. This increased upward deflection of the simple span beam is not accompanied by stresses in the beam since there is no rotational restraint of the beam ends. When simple span beams are made continuous through a connection at the intermediate support, the rotation at the ends of the beam due to creep taking place after the connection is established are restrained by the continuity connection. This results in the development of fixed end moments (FEM) that maintain the ends of the beams as flat. As shown schematically in Figure 5.3-1 for a two-span bridge, the initial deformation is due to creep that takes place before the continuity connection is established. If the beams were left as simple spans, the creep deformations would increase; the deflected shape would appear as shown in part "b" of the figure. However, due to the continuity connection, fixed end moments at the ends of the beam will be required to restrain the end rotations after the continuity connection is established as shown in part "c" of the figure. The beam is analyzed under the effects of the fixed end moments to determine the final creep effects.

Similar effects, albeit in the opposite direction, take place under permanent loads. For ease of application, the effect of the dead load creep and the prestressing creep are analyzed separately. Figures 5.3-2 and 5.3-3 show the creep moment for a two-span bridge with straight strands. Notice that the creep due to prestressing and the creep due to dead load result in restrained moments of opposite sign. The creep from prestressing typically has a larger magnitude than the creep from dead loads.

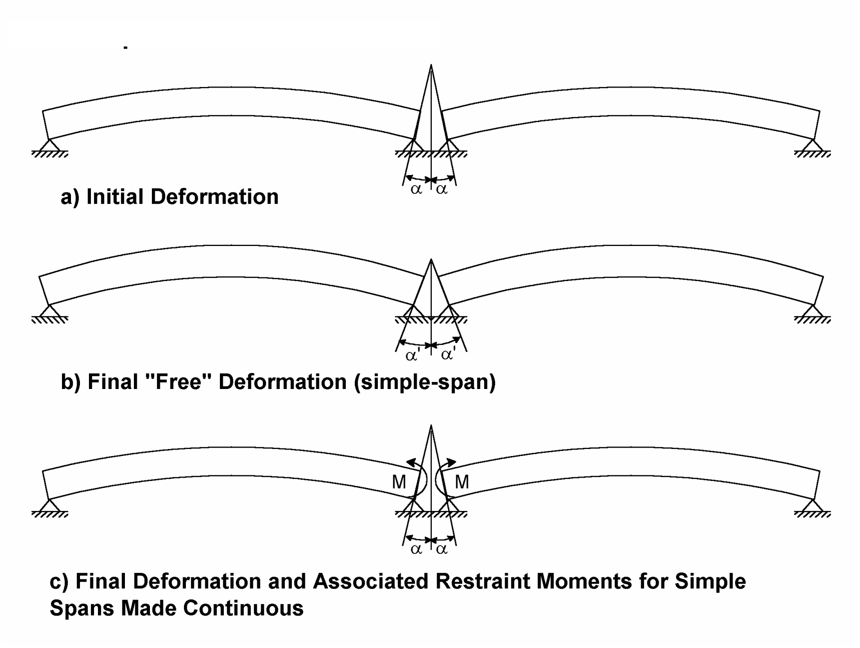


Figure 5.3-1 - Prestressed Creep Deformations and Restraint Moments

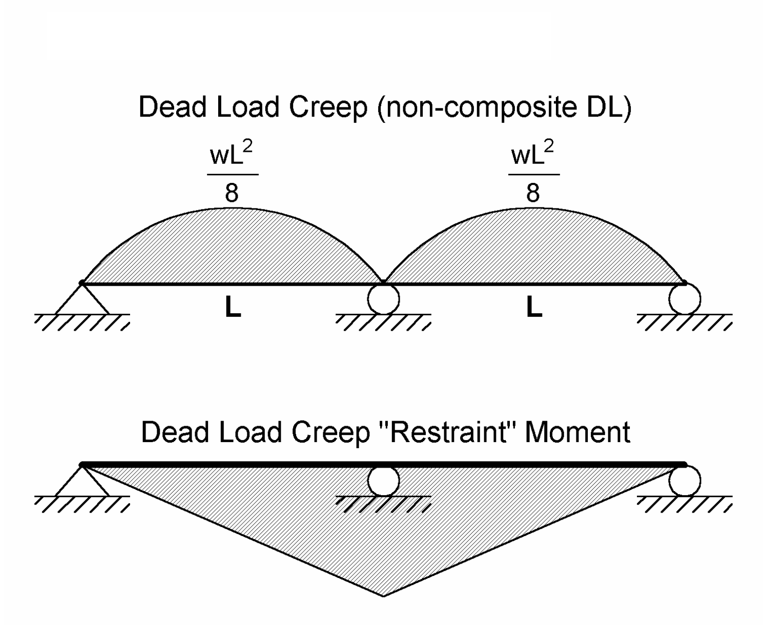


Figure 5.3-2 - Dead Load Creep Moment

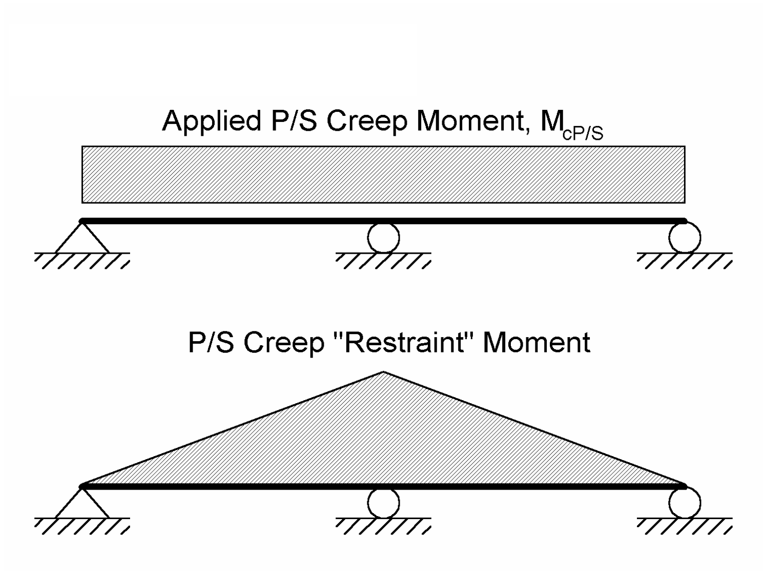


Figure 5.3-3 - Prestressed Creep Moment

Shrinkage effects

The shrinkage of the pretensioned beams is different from the shrinkage of the deck slab. This is due to the difference in the age, concrete strength, and method of curing of the two concretes. Unlike creep, differential shrinkage induces stresses in all prestressed composite beams, including simple spans. The larger shrinkage of the deck causes the composite beams to sag as shown in Figure 5.3-4. The restraint and final moments are also shown schematically in the figure.

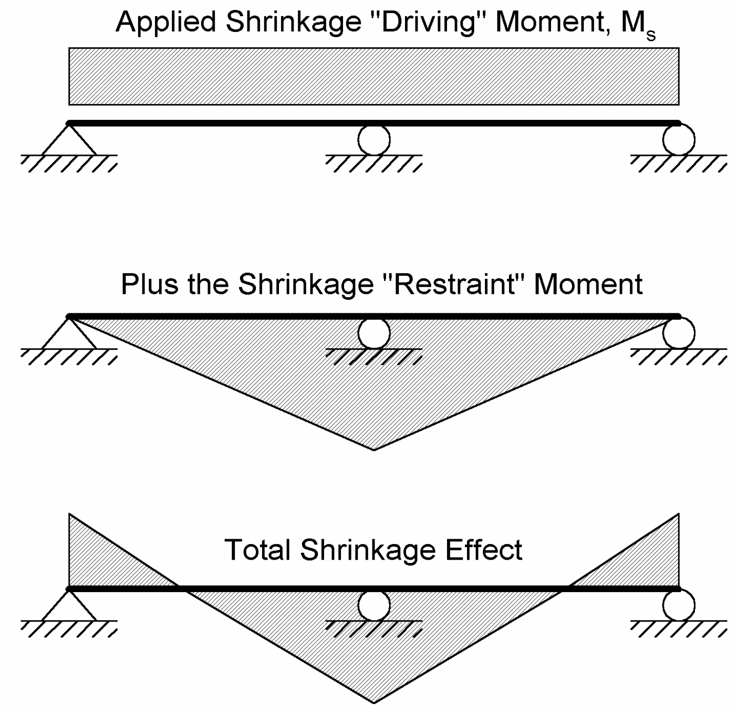
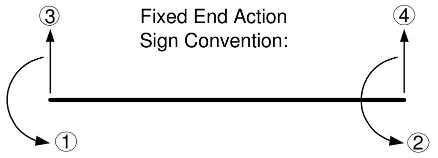


Figure 5.3-4 - Shrinkage Moment

Calculations of creep and shrinkage effects

The effect of creep and shrinkage may be determined using the method outlined in the publication entitled "Design of Continuous Highway Bridges with Precast, Prestressed Concrete Girders" published by the Portland Cement Association (PCA) in August 1969. This method is based on determining the fixed end moments required to restrain the ends of the simple span beam after the continuity connection is established. The continuous beam is then analyzed under the effect of these fixed end moments. For creep effects, the result of this analysis is the final result for creep effects. For shrinkage, the result of this analysis is added to the constant moment from shrinkage to determine the final shrinkage effects. Based on the PCA method, Table 5.3-9 gives the value of the fixed end moments for the continuous girder exterior and interior spans with straight strands as a function of the length and section properties of each span. The fixed end moments for dead load creep and shrinkage are also applicable to beams with draped strands. The PCA publication has formulas that may be used to determine the prestress creep fixed end moments for beams with draped strands.

Table 5.3-9 - Fixed End Actions for Creep and Shrinkage Effects



Note: FEA taken from 1969 PCA document, *Design of Continuous Highway Bridges with Precast, Prestressed Concrete Girders*

	DL Creep			P/S Creep			Shrinkage		
	Left End Span	Interior Span	Right End Span	Left End Span	Interior Span	Right End Span	Left End Span	Interior Span	Right End Span
Left Moment (1)	0	$2/3(M_D)$	M_D	0	$2EI\theta/L$	$3EI\theta/L$	0	M_s	$1.5M_s$
Right Moment (2)	$-M_D$	$-2/3(M_D)$	0	$-3EI\theta/L$	$-2EI\theta/L$	0	$-1.5M_s$	$-M_s$	0
Left Shear (3)	$-M_D/L$	0	M_D/L	$-3EI\theta/L^2$	0	$3EI\theta/L^2$	$-3M_s/2L$	0	$3M_s/2L$
Right Shear (4)	M_D/L	0	$-M_D/L$	$3EI\theta/L^2$	0	$-3EI\theta/L^2$	$3M_s/2L$	0	$-3M_s/2L$

Notation for Fixed End Actions:

M_D = maximum non-composite dead load moment
L = simple span length
E_c = modulus of elasticity of beam concrete (final)
I = moment of inertia of composite section
θ = end rotation due to eccentric P/S force
M_s = applied moment due to differential shrinkage between slab and beam

Design Step 5.3.2.3

Effect of beam age at the time of the continuity connection application

The age of the beam at the time of application of the continuity connection has a great effect on the final creep and shrinkage moments. As the age of the beam increases before pouring the deck and establishing the continuity connection, the amount of creep, and the resulting creep load effects, that takes place after the continuity connection is established gets smaller. The opposite happens to the shrinkage effects as a larger amount of beam shrinkage takes place before establishing the continuity connection leading to larger differential shrinkage between the beam and the deck.

Due to practical considerations, the age of the beam at the time the continuity connection is established can not be determined with high certainty at the time of design. In the past, two approaches were followed by bridge owners to overcome this uncertainty:

1) *Ignore the effects of creep and shrinkage in the design of typical bridges. (The jurisdictions following this approach typically have lower stress limits at service limit states to account for the additional loads from creep and shrinkage.)*

2) *Account for creep and shrinkage using the extreme cases for beam age at the time of establishing the continuity connection. This approach requires determining the effect of creep and shrinkage for two different cases: a deck poured over a relatively "old" beam and a deck poured over a relatively "young" beam. One state that follows this approach is Pennsylvania. The two ages of the girders assumed in the design are 30 and 450 days. In case the beam age is outside these limits, the effect of creep and shrinkage is reanalyzed prior to construction to ensure that there are no detrimental effects on the structure.*

For this example, creep and shrinkage effects were ignored. However, for reference purposes, calculations for creep and shrinkage are shown in Appendix C.