6.7.2 DEAD LOAD CAMBER

Steel girders require cambering in order to compensate for the effects of roadway vertical curvature, dead load deflections and concrete deck shrinkage deflections. In order to maintain a constant dimension from the top of the bridge deck to the top of the girder web throughout the length of the girder, the web must be fabricated to a profile that matches the finished grade profile of the bridge, along the girder line, after all permanent design loads are applied to the girder. The camber information shall be shown on the plans at the tenth points of each span and at field splice points in both graphic (a camber diagram) and tabular form.

The first aspect of developing the camber diagram is to establish a baseline from which all camber dimensions can be measured. While any straight line, whether horizontal or sloped, is adequate for this purpose the preferred baseline is a line that connects a point at the top of the web at one end of a continuous girder to a point at the top of the web at the other end of the same girder. This line is represented on the camber diagram as a horizontal line. This baseline definition is preferred over other definitions because if the conditions stated below are met the resulting camber diagram will have zero offset from the baseline at both the beginning and end of the girder and the same camber values will be good for all girders in the cross-section, regardless of bridge skew angle.

- All girders in the cross-section are straight and the same length.
- The beginning or end of a vertical curve does not fall within the limits of the bridge (this is only critical if the bridge is skewed).
- No abrupt changes occur in the deck cross-slope on the bridge (such as the start or end of a super transition).

In those cases where the bridge geometry does not meet the above conditions the baseline may be defined, at the discretion of the engineer, as something other than what is described above. In such cases a separate camber table may be required for each girder. Curved girders will always require a separate camber table for each girder. In all cases the definition of the baseline shall be clearly indicated on the bridge plans.

It should be noted here that interior and exterior girders on straight bridges should be cambered the same even if the design dead loads are different. For camber purposes all dead loads should be distributed equally to all girders in a cross-section. If the exterior girders are cambered different from the interior it will not only be difficult to attach the cross-frames but it will be impossible to control the finished grade across the width of the deck with a screed machine supported on the exterior girders. If the screed rails are set for finishing to the exterior girders they will not be correct for finishing over the interior girders. The exterior and interior girders essentially deflect the same during deck placement due to the load distribution effects of the diaphragms.

The second part of developing the camber diagram is determining the amount of offset from the baseline to the finished position of the girder after all permanent loads have been applied. For bridges with no vertical curvature or abrupt changes in cross-section this offset will be zero the full length of the girder. Bridges fully or partially on vertical curves will have camber values varying from zero at the ends to a maximum value near the center of the girder (with positive values for crest and negative values for sag vertical curves). These values should be labeled in the camber table as vertical curve.

The third part of developing the camber diagram is determining the amount of deflection dead loads and deck shrinkage cause in the girder. There are four types of deflections to consider: the self-weight of the steel (non-composite load), the weight of the deck concrete (partial-composite load), the weight of all other dead loads such as parapet & future wearing surface (fully-composite load) and the effect of deck shrinkage over time (fully-composite load). Each one of these deflection types are calculated separately and shown in the camber table, a downward deflection is shown as positive camber and vice versa. The camber diagram shall only show the total of all camber values added together for a given point.

The calculation of the deflections for girder self-weight and the parapet & FWS are relatively straight forward, however the calculation of the deflections due to the deck concrete and shrinkage are more complex. It is ITD policy to determine deflections due to the deck concrete based on the pour sequence. The deflections of the first pour are based on the whole girder acting non-composite, then the deflections of the second pour are based on the area of the first pour acting compositely with the rest of the girder non-composite and so on until the last pour. The deflections due to each pour sequence are added together and only the total is shown in the camber table. For deck shrinkage deflections a method based on classical structure analysis is presented below. Other methods that utilize structural analysis software (such as LARSA) may also be used provided they are based on the same concrete shrinkage strain.

STEEL GIRDER CAMBER DUE TO DECK SHRINKAGE

In addition to dead load and vertical curvature, steel structures should also be cambered for the effect of concrete deck shrinkage. The deflection due to shrinkage should be calculated based on the shrinkage strain of the deck acting on the composite girder sections of the structure.

From Article 5.4.2.3.3 the shrinkage strain can be calculated as follows: $\varepsilon_{sh} = -k_{vs}\, k_{hs}\, k_f\, k_{td}\,(0.00048)$

where: ε_{sh} = shrinkage strain of plain concrete
k_{vs} = factor for volume to surface ratio (assume 1.0 for decks)
k_{hs} = humidity factor (1.16 for Idaho based on an average humidity of 60%)
k_f = factor for concrete strength (1.0 for 4000 psi concrete)
k_{td} = time development factor (0.99 after ten years)

Using these assumptions; $\varepsilon_{sh} = -0.00055$

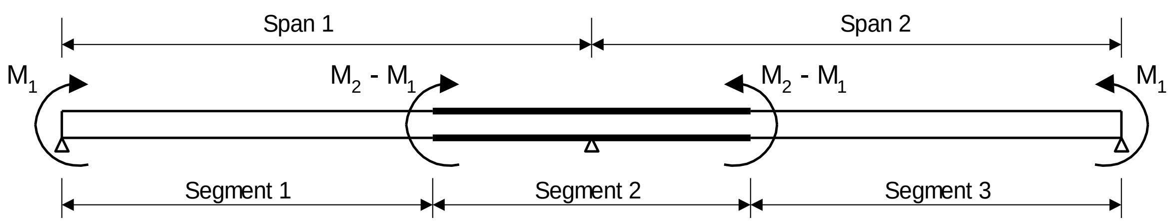
The shrinkage deflection of composite beams can be determined by substituting an equivalent compression force for the shrinkage strain, this force is applied to the ends of each girder segment at mid depth of the deck. For deflection purposes this eccentric compression load has the same effect as applying a positive moment to the ends of each girder segment (a segment being a length of girder with the same section properties). The magnitude of the applied moments is equal to the compression force times the distance from the mid depth of the deck to the c.g. of the composite section for that segment. Where two segments join the applied moment is the difference between the calculated moments for each segment. The equivalent force and moments are determined as follows:

$F_{sh} = (1-\rho)\varepsilon_{sh}\, AE/3$ (this expression is divided by 3 to account for creep)

$M_i = |F_{sh}(cg_i - T/2)|$ (Moment is always positive)

where: F_{sh} = compression force required to produce a strain equal to ε_{sh}
M_i = moment applied to each end of a particular segment to model the shrinkage effect
A = tributary area of the deck per girder (use total area of deck divided by number of girders)
E = modulus of elasticity of the concrete
cg_i = center of gravity as measured from the top of a particular composite section
T = thickness of the deck
ρ = average ratio of longitudinal deck steel to deck area for a given girder segment

Example of a two span bridge with two different girder sections:

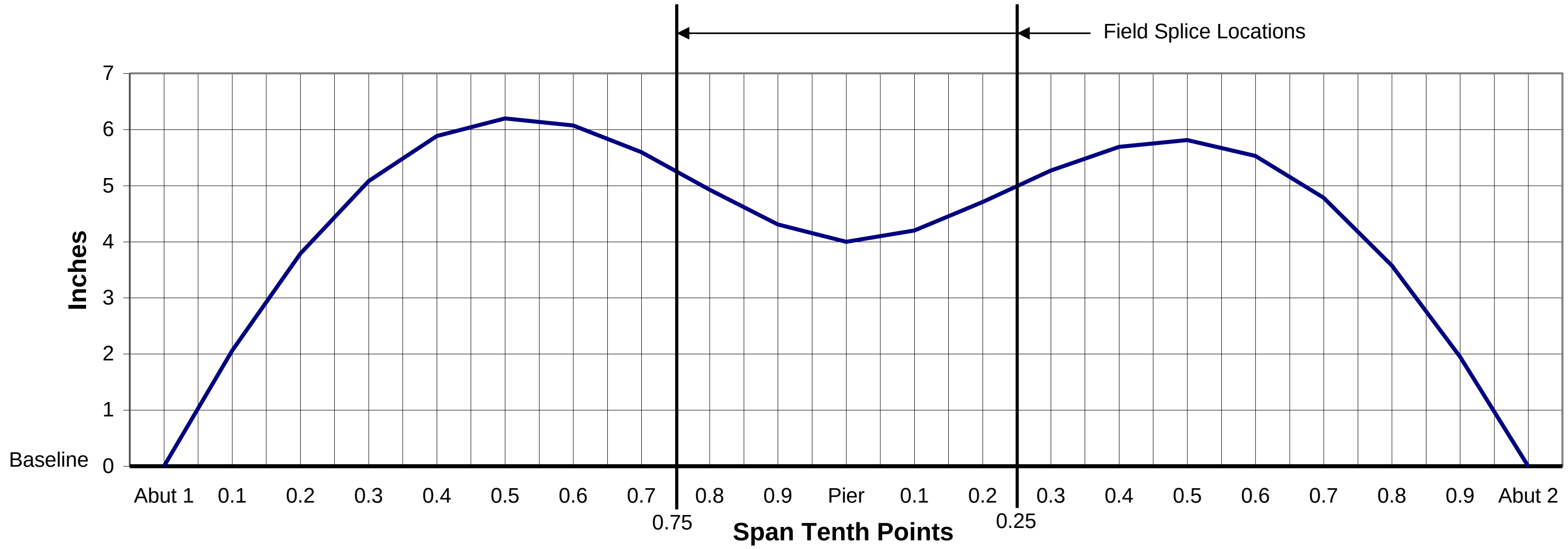


The composite "I" for the girder sections in this analysis should be based on "3n" to account for the long-term creep effect and, at the engineer's option, the transformed deck section to take advantage of the deck reinforcement. It should be noted that while M_1,M_2 etc. are always positive, the difference can be negative. The resulting deflections for this load case are equivalent to the shrinkage deflections. These deflections can then be added to the dead load deflections and combined with the vertical curvature corrections to determine the total camber. This method is appropriate for both single and multiple spans.

Revisions:

June 2006 Revised the shrinkage strain calculations to comply with the 2005 Interims.
Oct 2009 Revised M_i equation to ensure that it is always positive.

Example of a Steel Girder Camber Diagram



		Span 1											**Span 2**										
Span Point	Abut 1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	Field Splice 0.75	0.8	0.9	Pier	0.1	0.2	Field Splice 0.25	0.3	0.4	0.5	0.6	0.7	0.8	0.9	Abut 2
Girder D.L.	0	0.18	0.34	0.44	0.49	0.47	0.40	0.29	0.22	0.16	0.05	0	0.05	0.16	0.22	0.29	0.40	0.47	0.49	0.44	0.34	0.18	0
* Deck D.L.	0	0.75	1.39	1.83	2.04	1.99	1.71	1.26	0.99	0.71	0.24	0	0.13	0.49	0.71	0.93	1.33	1.60	1.68	1.53	1.17	0.64	0
Shrinkage	0	0.20	0.32	0.37	0.36	0.31	0.24	0.16	0.12	0.08	0.02	0	0.02	0.08	0.12	0.16	0.24	0.31	0.36	0.37	0.32	0.20	0
All Other D.L.	0	0.16	0.30	0.40	0.44	0.42	0.36	0.26	0.20	0.14	0.04	0	0.04	0.14	0.20	0.26	0.36	0.42	0.44	0.40	0.30	0.16	0
Total Deflection Camber	0	1.30	2.35	3.04	3.32	3.20	2.71	1.96	1.52	1.09	0.35	0	0.24	0.87	1.24	1.63	2.33	2.81	2.97	2.74	2.14	1.19	0
Vertical Curve	0	0.76	1.44	2.04	2.56	3.00	3.36	3.64	3.75	3.84	3.96	4.00	3.96	3.84	3.75	3.64	3.36	3.00	2.56	2.04	1.44	0.76	0
Total Camber	0	2.06	3.79	5.08	5.88	6.20	6.07	5.60	5.27	4.93	4.31	4.00	4.20	4.71	4.99	5.27	5.69	5.81	5.53	4.78	3.58	1.95	0

* The deck dead load deflections are not symmetrical because they are based on a three part deck placement sequence.