Practical Solution for Skewed Geometry on Decked-Girder Bridges

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Decked-girder bridges with precast, prestressed concrete girders are used extensively throughout Washington state, particularly for local agencies with low-volume roadways. Decked girders are plant-fabricated and transported by truck to a bridge site for side-by-side placement. The deck, or driving surface of the bridge, is the top flange of the girder and is typically at least 6 in. thick. Decked girders can be fabricated in various cross sections, but the most common type in the Northwest is the decked bulb-tee girder. These sections are versatile, with overall depths ranging from 35 to 65 in. and top flange widths ranging from 4 to 8 ft. These bulb tees have the capability to span up to 160 ft.

One challenge of decked-girder construction involves a geometric issue with skewed bridge alignments. This issue can be overcome with some forethought and planning during the design phase.

Advantages to Decked Girder Construction

There are many advantages to decked-girder construction. First, decked systems are cost-effective. Both design and construction costs are lower when compared to the costs of cast-in-place deck construction. Second, construction time is reduced when erecting decked girders because the deck is fully precast. Typically, a single-span prestressed concrete superstructure can be shipped, erected, and grouted within one week. Finally, a decked-girder bridge, when properly designed and constructed, provides for easy construction and durability, good structural performance, and low maintenance for the life of the bridge.

Each bridge site should be evaluated for feasibility of this system. Not all sites are suitable for decked girders. For example, bridges with high traffic volumes or superelevation transitions are better accommodated by cast-in-place decks. Additionally, the engineer must consider access to the site and a source for the precast, prestressed concrete girders.

Consideration of Girder Camber

For precast, prestressed concrete girders, it is imperative to predict the estimated girder camber during the design phase. Camber is the upward deflection of the girder due to effective prestressing force and dead load. Although determining camber is not an exact science, camber prediction methods have a history of reasonable accuracy. Camber can be predicted using published formulas or, girder design software, or a girder manufacturer can be consulted. Camber does change over time, so camber at the time of girder setting is of particular importance.

It is advantageous to design the vertical profile of the roadway to fit the camber of the girder. If this method is not possible at a particular bridge site, the girder flanges can be thickened at the ends to result in a flat grade even when the girder is cambered.

To design the vertical profile of the roadway to fit the camber of the girder, the girder end slopes can be determined by using the following equation for a parabolic curve:

$$G = \frac{4C}{12L}$$

where

G = tangent slope at girder ends
C = net girder camber (in.) at the time of girder setting
L = span length (ft)
$2G$ = change in slope over span length of girder

For example, a 100-ft span girder with a camber of 4.5 in. has 1.5% slope at each girder end, resulting in a 3% change in grade over the girder span. To align the roadway profile grade with girder camber, the engineer would need to ensure that the vertical curve length extends the entire length of the skewed bridge, from beginning to end, including the skewed corners. The overall grade change of the vertical curve would need to be greater than 3%.


Skewed decked bulb-tee girders erected for the Hatley Bridge, Whitman County, Wash. Photo: Whitman County Public Works Department.

Skewed Decked Girders

Due to roadway or stream alignment, a bridge may need to be skewed at the ends. A geometric anomaly in the deck, known as the "sawtooth" effect, can result if the skew angle is not properly accounted for in the beam seat elevations. Let's look more deeply at this issue and visualize what can occur.

Each prestressed concrete girder in the bridge will have camber, or upward deflection. Should the girder have skewed ends, the acute corner of the girder end will be lower on the camber curve than the obtuse corner. Now, imagine setting an adjacent girder if the abutment elevations were level. Due to camber, the adjacent girder corner would not have the same elevation as the previous girder. Because each adjacent girder in the deck would not align vertically with the previous one, a "sawtooth" effect would be created across the full bridge deck.

A practical solution[1] to this issue caused by skew involves correcting the abutment seat elevations to account for camber, along with considering the longitudinal slope and cross slope. Should the girder ends be perpendicular with no skew, the effect of camber would simply be zero. The following example will show the corrections to make along the abutments. Ideally, a correction for each girder seat should be made and used to construct the abutments to the proper elevations. The equations can be used for various skews, profile grades, and cross slopes. The engineer will need to carefully consider the units of the input and the algebraic sign associated with each quantity.

Example Calculation

The following equation calculates abutment elevations that account for equal skew angles at each abutment, a constant longitudinal grade, camber, and a constant cross slope, to provide for proper vertical alignment between flanges of adjacent girders at ends after setting:

> Abutment elevation = Roadway elevation at the centerline of the bridge at the centerline of bearing ± Correction for longitudinal slope ± Correction for camber ± Correction for cross slope – depth of girder – thickness of bearing pad

Given:

L = 100 ft span length
L_{abut} = 38 ft abutment length as measured along skew
θ = 30° skew angle (clockwise positive)
$Elev_1$ = 502 ft elevation at centerline of bearings at abutment 1 at centerline of roadway (point B)
$Elev_2$ = 503 ft elevation at centerline of bearings at abutment 2 at centerline of roadway (point E)
Cross slope = 1.00% cross slope of roadway (left to right)
H = 41 in. depth of girder
= 3.417 ft
t = 0.75 in. thickness of bearing pad
= 0.0625 ft
C = 4.5 in. girder camber at time of girder setting

Calculation:

Elevation correction for constant longitudinal roadway slope

$$\text{Longitudinal slope} = \frac{\left(Elev_2 - Elev_1\right)}{L} = \frac{\left(503-502\right)}{100} = +1.00\%$$

Constant longitudinal roadway slope

$$\text{Correction for longitudinal slope} = \text{Longitudinal slope}\frac{\left(L_{abut}\right)}{2}\sin\theta$$

$$= 0.010\frac{\left(38\right)}{2}\sin\left(30^{\circ}\right) = 0.095\text{ ft}$$

Elevation correction for camber

$$G = \frac{4C}{12L}$$

where

G = tangent slope at girder ends (L must be in ft and C in in.)

$$G = \frac{4C}{12L} = \frac{4\left(4.5\right)}{12\left(100\right)} = 0.0150 = 1.50\%$$

Effect on slope at girder ends due to camber:

$$\text{Correction for camber} = G\frac{\left(L_{abut}\right)}{2}\sin\theta$$

$$= 0.0150\frac{\left(38\right)}{2}\sin\left(30\right) = 0.143\text{ ft}$$

Elevation correction for constant cross slope

$$\text{Correction for cross slope} = \text{Cross slope}\frac{\left(L_{abut}\right)}{2}\cos\theta$$

$$= 0.010\frac{\left(38\right)}{2}\cos\left(30\right) = 0.165\text{ ft}$$

The same approach can be applied to determine individual seat elevations for each decked bulb tee, and to account for a crowned roadway or for different skew angles and grades at each end of a span. A correction for camber would not be needed if the girder flanges had variable thickness due to a straight grade. However, ensuring that the H value was correct to account for thickened girder depth at centerline of bearing would be needed. A variable top flange thickness is often used on straight or flat grades to avoid a "bump" due to girder camber.

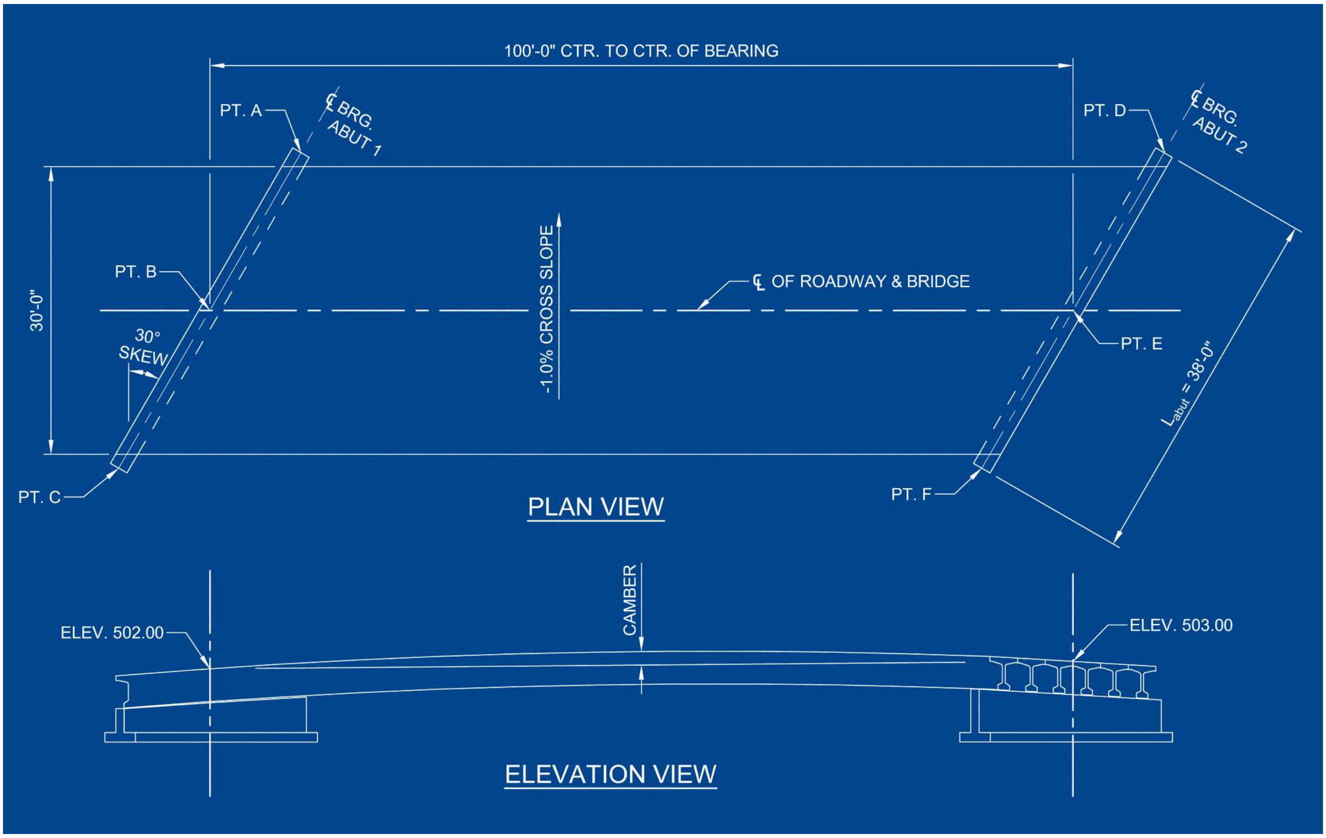
Summary of Results (ft)

	Abutment 1 (at CL Bearings)			Abutment 2 (at CL Bearings)		
	Point A	Point B	Point C	Point D	Point E	Point F
Roadway elevation at centerline of bearings at abutment at centerline of roadway	502	502	502	503	503	503
Correction for longitudinal slope	+0.095	0	–0.095	+0.095	0	–0.095
Correction for camber	+0.143	0	–0.143	–0.143	0	+0.143
Correction for cross slope	–0.165	0	+0.165	–0.165	0	+0.165
Depth of girder[a]	–3.417	–3.417	–3.417	–3.417	–3.417	–3.417
Thickness of bearing pad[a]	–0.062	–0.062	–0.062	–0.062	–0.062	–0.062
Top of abutment elevation[b]	**498.59**	**498.52**	**498.45**	**499.31**	**499.52**	**499.73**

[a] Signs have been changed to reflect subtraction in formula.

[b] Rounded to the nearest 0.01 ft as typical for most bridge construction.

Note: Points are identified in plan view of figure that follows. CL = centerline.



Plan and elevation views of typical decked bulb-tee girder bridge. Note: Points for design example are labeled in plan view. Figure: Nicholls Kovich Engineering, PLLC.

Finished deck of skewed decked bulb-tee girders for the Old Blewett No. 1 Bridge, Chelan County, Wash. Photo: Chelan County Public Works Department.

Conclusion

This practical procedure will provide for a span in which the top flange edges of adjacent decked girders align within reasonable tolerances. Many decked-girder projects have used this practical procedure with great success, including the Old Blewett No. 1 Bridge over Peshastin Creek in Chelan County, Wash.

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Reference

1. Oesterle, R.G., A.F. Elremaily, R. Eriksson, C. Prussack, and Z. Ma. 2009. *Guidelines for Design and Construction of Decked Precast, Prestressed Concrete Girder Bridges.* Final report prepared for National Cooperative Highway Research Program, Transportation Research Board, National Research Council. NCHRP Project 12-69. http://onlinepubs.trb.org/onlinepubs/nchrp/docs/nchrp12-69_fr_guidelines.pdf.