<u>Crane Girder Camber</u>

Prepared By

Gary J. Davis, P.E.
Director of Consulting Services
Integrated Machinery Solutions (IMS)
Fort Worth, Texas
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Texas Registered Engineering Firm #11499

INTEGRATED MACHINERY SOLUTIONS

www.team-ims.com · *garydavis@team-ims.com* · *817-659-2399*

Plant maintenance and inspection personnel are occasionally faced with reports of "lost camber" or "excessive deflection" of crane girders. This article provides a practical overview of crane girder camber, deflection, and bending strength to aid plant personnel in evaluating these conditions.

Girder Camber: Why is it Required?

Cambering effectively removes the dead load deflection and averages the live load deflection relative to the level profile. Cambering effectively cuts the live load deflection in half. This minimizes the trolley rail slope during live load deflection. The reduced slope means less power is required to drive the trolley uphill toward the end of the girder and less tendency to coast downhill toward the center of the span.

Fig. 1 shows the camber required by *CMAA Specification #70,* and *AIST Technical Report #6.* These codes require a camber equal to 100% of the dead load deflection plus ½ of the live load deflection. "Free" camber means the girder is free to assume its unloaded shape, i.e., no dead load or live load is present. *CMAA Specification #74* (single girder cranes) does not require that girders be cambered, but this option uses a different deflection limit.

The majority of crane manufacturers build camber into the top profile of the girder. If there is limited clearance over obstructions near the bottom of the girder, the bottom profile may also require cambering. Fig. 1 shows a crane girder cambered on the top and bottom, unloaded, and laying on its side. Girders are cambered by building them with a convex ("crowned") profile, opposite to the concave sag produced by deflection. The camber in Fig. 1 is equal to the deflection that would be produced by the girder's own weight (DL) plus ½ of the combined weight of the trolley and the rated capacity (LL).

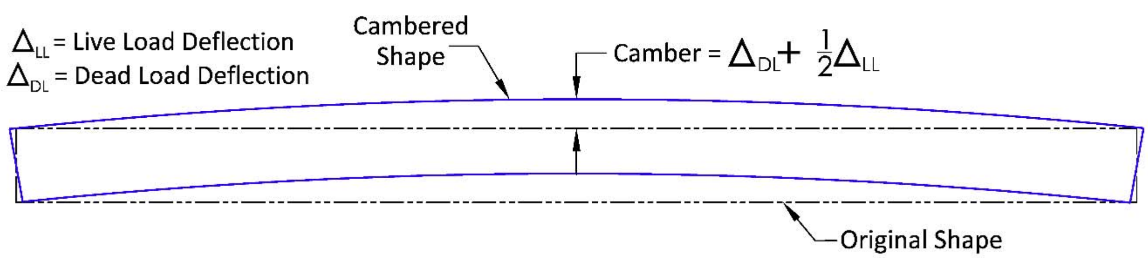

Fig. 1: "Free" Camber

Camber Field Measurements

The camber profile can be obtained by measuring trolley rail elevations at 5-foot intervals as shown in Fig. 2. Use a small laser level and a ruler to measure the elevations. The trolley should be unloaded and moved to the end of the bridge before measuring. A string or a wire cannot be used as a reference line; regardless of the amount of tension in the line, it will sag too much to produce meaningful results.

Field Data Adjustment

If the laser and/or girder are not level, adjust the field data as shown in Fig. 2. Make a scale layout of the data, as shown in Fig. 2a, and connect the ends with a straight line. The adjusted elevations are obtained relative to the line connecting the ends of the curve. Using the adjusted data, the camber is the difference between the maximum elevation and the end point (Fig. 2b). Typically, the middle 1/3 of the span may appear to be practically flat.

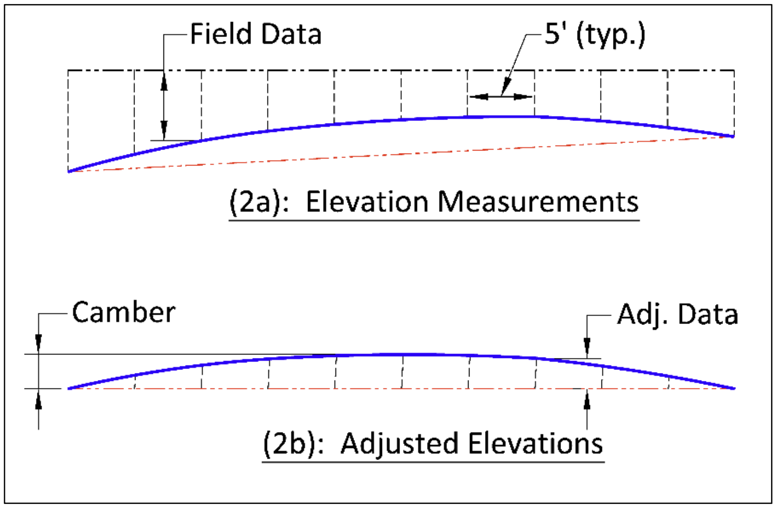

Fig. 2: Camber Measurements

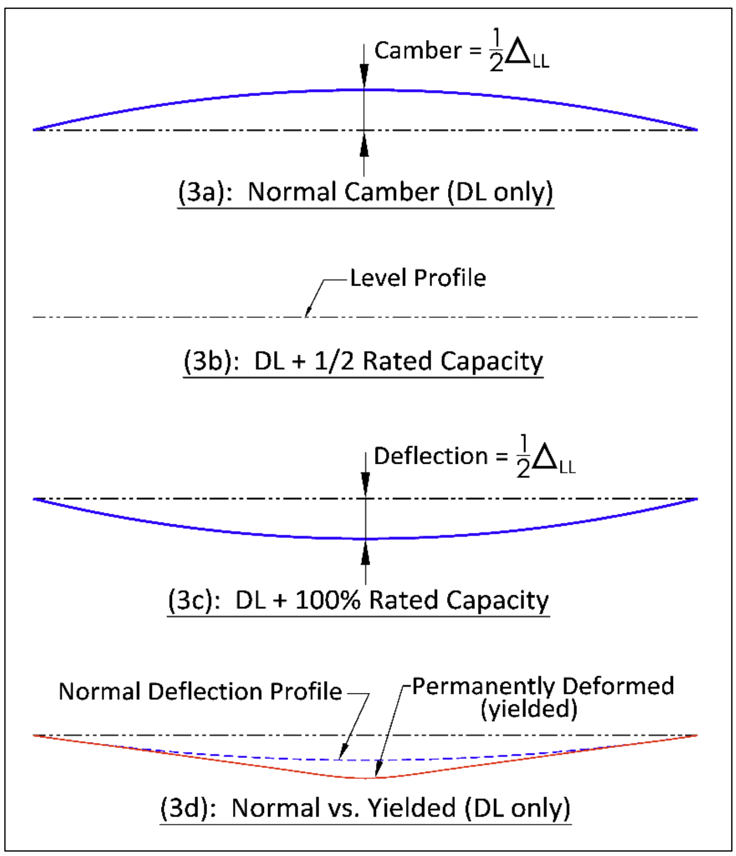

Fig. 3: Girder Profiles

Interpretation of Camber Measurements

The camber requirement should be obtained from the crane manufacturer (or a qualified person) and compared to the field measurements. Fig. 3 shows ideal camber profiles for no load, ½ rated capacity, and full rated capacity. Fig. 3d illustrates the difference between a normal dead load deflection profile and a deformed profile from a severe overload. After a severe overload, cambered and uncambered girders may have a slight "kink" near the center of the span. When the measured camber is less than the required amount, check the following:

1. Determine if the original fabrication included the required camber.
2. Check for buckled flanges and webs.
3. Check the trolley rail for local deformation between the diaphragm support points.
4. Check for local buckling at the top edge of the diaphragms that support the trolley rail.
5. Check the welds for the diaphragms supporting the trolley rail.
6. A borescope is required for inspecting internal components.
7. Determine if the diaphragm spacing for the trolley rail support is adequate. (Engineering required).
8. Check the condition of the bottom flange for fractures.
9. If the elevation profile shows a negative camber greater than what would be produced by the dead load deflection, and/or the profile shows a "kink" (see Fig. 3d), it may indicate a severe overload.

In addition to this list, the entire structural and mechanical load path should be thoroughly inspected. Refer to Reference 1: *Guidelines for Inspecting Overhead Crane Structures* for more information.

Girder Deflection

Girder deflection is not directly related to strength. No conclusions can be made about girder strength based on a deflection measurement alone. A crane may have a large deflection and ample bending strength, while a different crane may be overstressed and show very little deflection. Design code deflection limits are based on the live load only and determined as a percentage of the crane span.

Measuring Deflection

Some purchasing specifications require deflection measurements during load testing for design verification. Deflection measurements are only meaningful if the magnitude of the lifted load and trolley weight are accurately known. Deflection can be measured relative to a point on the floor using a laser distance meter and a small level as follows:

1) Move the unloaded trolley to the end of the bridge.
2) Mark a small target area at the center of the crane span, on the bottom flange of the girder, visible from the floor.
3) Place the base of the laser meter on the floor and use the level to ensure that the laser beam is plumb in all directions while pointed on the target.
4) Mark the spot on the floor where the laser meter is plumb and pointing on the target.
5) After marking the laser base location, the laser should already be plumb for later measurements and the level should not be needed.
6) Measure and record the distance between the marked spot on the floor and the target spot on the girder.
7) For this example, lift 50% of the rated crane capacity and move the load to the center of the span.

8) Measure and record the distance from the marked spot on the floor and the target spot on the girder.
9) The deflection is the difference between the two measurements.

If the required camber is unknown, it can be determined by measuring the deflection with 50% of the rated crane capacity. The deflection measured in this example should be approximately equal to the required camber as shown in Fig. 3a.

Yield Strength and Loss of Camber

If no other girder elements have failed, loss of camber does not indicate loss of bending strength. Steel is elastic below the *yield strength* and the girder will spring back to its original shape after the load is removed. Design codes require the stress to be below the yield strength at rated capacity. If the load is large enough to exceed the yield strength by more than about 10%, the girder will not return to its original shape and this will appear as lost camber.

The next time the girders are loaded (equal to or less than the rated capacity), they will deflect the normal incremental amount and the stress will be at the normal level. The only difference is that the starting point for the deflection increment will be at a lower elevation due to the lost camber. Additional camber will be lost each time the girder is loaded past the yield strength. Some ductility will be lost, but the bending strength of the girder does not decrease.

Internal Residual Stress

Weld shrinkage from girder fabrication creates zones of longitudinal *residual stress* at (or near) the yield point. This locked-in stress will cause a slight camber loss after load testing. This type of camber loss is a one-time event and is too small to measure. Initial loading with the test load provides mechanical stress-relief for the welds by removing most of the internal stress in the working stress range.

Ultimate Girder Strength

At the first onset of yielding, only the outermost surface of the girder starts to yield and the remainder of the section remains elastic. The yielded portion can only support the load that caused the first yielding, and nothing more. As the load increases, more of the section yields. When the entire cross section has yielded, the girder cannot support any increase in load. If additional load is applied, the girder will not offer any resistance and only more deformation will occur. This is the *ultimate strength* for bending of the cross section. The girder can fail by other limit states (buckling, shear, welds, etc.) before ever reaching the ultimate strength.

Overloading Scenarios

A computer model for bending of a typical box girder was used to estimate the magnitude of overload required to cause a measurable camber loss. The results are shown in Fig. 4. The threshold for a measureable camber loss was assumed as 1/8”. At the first onset of yielding, the girder still returns to its original shape when the load is removed. The ultimate bending strength is included as an upper limit reference. The chart was created with specific assumptions and only provides an “order of magnitude” for the various loadings required for camber loss.

	% Rated Capacity		
CMAA Class	**First Onset of Yielding**	**First Measurable Camber Loss**	**Ultimate Bending Strength**
C	185%	200%	310%
D	185%	200%	310%
E	235%	255%	390%
F	305%	330%	510%

Fig. 4: Estimated % Overload for Camber Loss

The analysis shows that camber loss from an overload is certainly possible, but the likelihood depends on the crane class. It also depends on the type of hoist drive. A.C. magnetic wound rotor hoist drives can deliver up to a 300% overload based on the motor "pull-out torque". D.C. series magnetic hoist drives can produce up to 600% of the rated motor torque for short periods. Present-day VFD drives cannot produce an overload large enough for camber loss. Typical VFD drives monitor the motor current and shut down at about 125% of the rated capacity. When considering overload multiples of two or three times the rated capacity, a "load snag" scenario would be a more likely operator error versus hoisting a freely suspended load. The ultimate bending strength for wide flange girders is about 40% less than box girders.

Conclusions and Recommendations

Loss of camber (for box girders) due to an overcapacity lift requires lifting 185 to 200% the rated crane capacity. Other failure modes can occur before reaching the load that causes camber loss. If overload is suspected as the root cause for camber loss, the entire structural and mechanical load path should be thoroughly inspected. Consult with an expert when making this assessment and deciding on a course of action. If in-house expertise is not available, consult with an engineering firm that is regularly engaged in structural design and inspection of overhead cranes and hoisting equipment.

References

1. Gary J. Davis, *Guidelines for Inspecting Overhead Crane Structures,* Integrated Machinery Solutions, Fort Worth, Texas, July 2011. Full text available at: http://www.scribd.com/doc/83331227/Guidelines-for-Inspecting-Overhead-Crane-Structures-Full-version

2. Charles G. Salmon, John E. Johnson, *Steel Structures, Design and Behavior,* Intext Educational Publishers, New York, NY, 1971.

3. R. L. Brockenbrough, B. G. Johnston, *Steel Design Manual,* United States Steel Corporation, Pittsburgh, PA, 1981.