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"Trunnion Alignment
On Bascule Bridges"

INTRODUCTION

The alignment of trunnions on bascule bridges is vital to long term, reliable operation. Their misalignment leads to increased wear of the bearings, and increased stress levels in the trunnions and bridge superstructure. The inspection of trunnion alignment has long been an arduous task. Accesibility is often limited, and past methods have been cumbersome at best. For these reasons, alignment inspection is regularly overlooked and disregarded during the normal biannual inspection of a bridge.

Unfortunately, even for those times when we do decide to commence forward with an alignment inspection, we are left with little more than our own judgement as to the inspection method and the criteria for our data evaluation. This is due to the fact that inspection manuals offer little guidance regarding the procedures for alignment inspection, and current AASHTO and AREA codes specify only the briefest of standards.

PURPOSE

The purpose of this paper is two-fold. The first is to present an easy to and readily perform method for the inspection of trunnion alignment by employing the use of a laser and basic trigonometry. The second is to offer a criteria by which to evaluate the information extracted from the field data.

PAST METHODS

The most common method used for alignment inspections today is the piano wire method. Figure 1 below shows a typical arrangement used for this procedure.

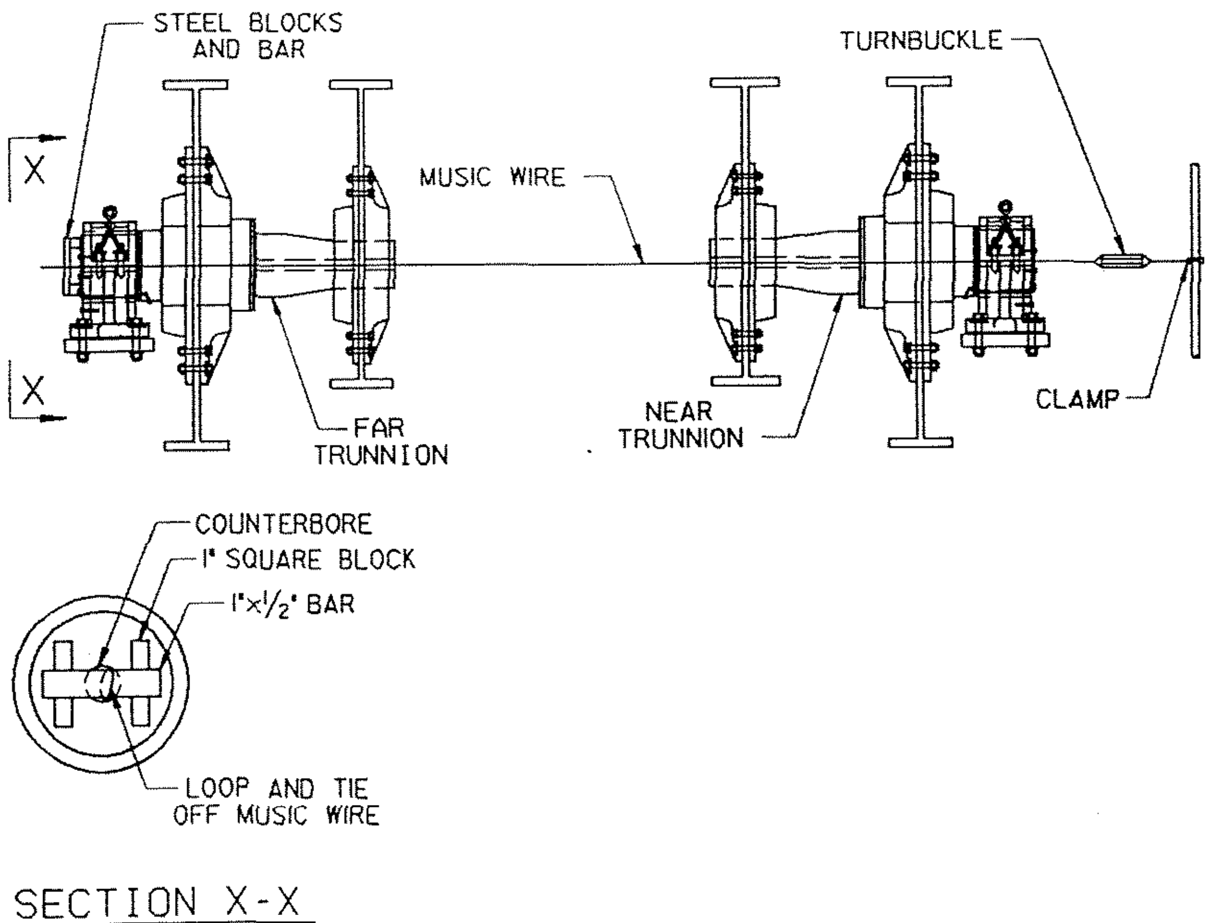


FIGURE 1

The steps required to perform this method are:

1. Attach the end of the piano wire to a short bar on the outboard side of the far trunnion.
2. Lace/string the piano wire through the counterbore of both trunnions.
3. Clamp/fasten a turnbuckle to an object located outboard of the near trunnion.
4. Attach the piano wire to the turnbuckle and tension it loosely.
5. Insert blocks between the bar and the far trunnion, and tension the piano wire as required to hold the bar in place.
6. Measure and adjust the piano wire to the center of the outboard side of each trunnions counterbore.
7. Take measurements of the wire's location relative to inboard side of the trunnion counterbores.

The are many drawbacks with this method. A few are listed below:

1. It almost certainly is a two person task due to "blocking" operation. (Magnetic blocks could be used to avoid this problem, but be sure to bring a ruler along which will not be affected by the magnetic field when taking measurements.)
2. Wire sag due to long span widths.
3. The difficulty (and almost impossibility) of finding an object to which the turnbuckle can be clamped which permits the centering of the piano wire with respect to the trunnion counterbore.
4. Many times the inboard side of a trunnion is difficult to view perpendicularly, leading to parallax errors when taking measurements.

Another method which receives mention in "The Bridge Inspectors Manual For Movable Bridges", is that which utilizes optical instruments such as a theodolite or transit. While the equipment arrangment used in this method is similar to that used with a laser, it has numerous disadvantages not associated with the laser method. The following is a brief list of these disadvantages.

1. If the outboard trunnion bearings are mounted on an elevated platform or built up support, the center of the counterbores will be only 2-4 inches higher than half of the trunnion diameter. This is too low to correctly mount and level a theodolite or transit.

2. Typically the lighting on a bascule pier produces an insufficient amount of light to read the "crosshairs" of the optical instrument, or makes the reading of them difficult at best.

3. The cost of quality optical equipment ranges from $5000 to $7000. (The prices for new state-of-the-art digital theodolites start at $14,000!). This is

a costly investment if you use it for nothing more than alignment inspections.

NEW LASER METHOD

In an attempt to overcome the problems associated with these and other past methods, a new procedure has been developed for the inspection of trunnion alignment. At the core of this method is the utilization of a laser. Figure 2 below shows a typical arrangement used for this procedure.

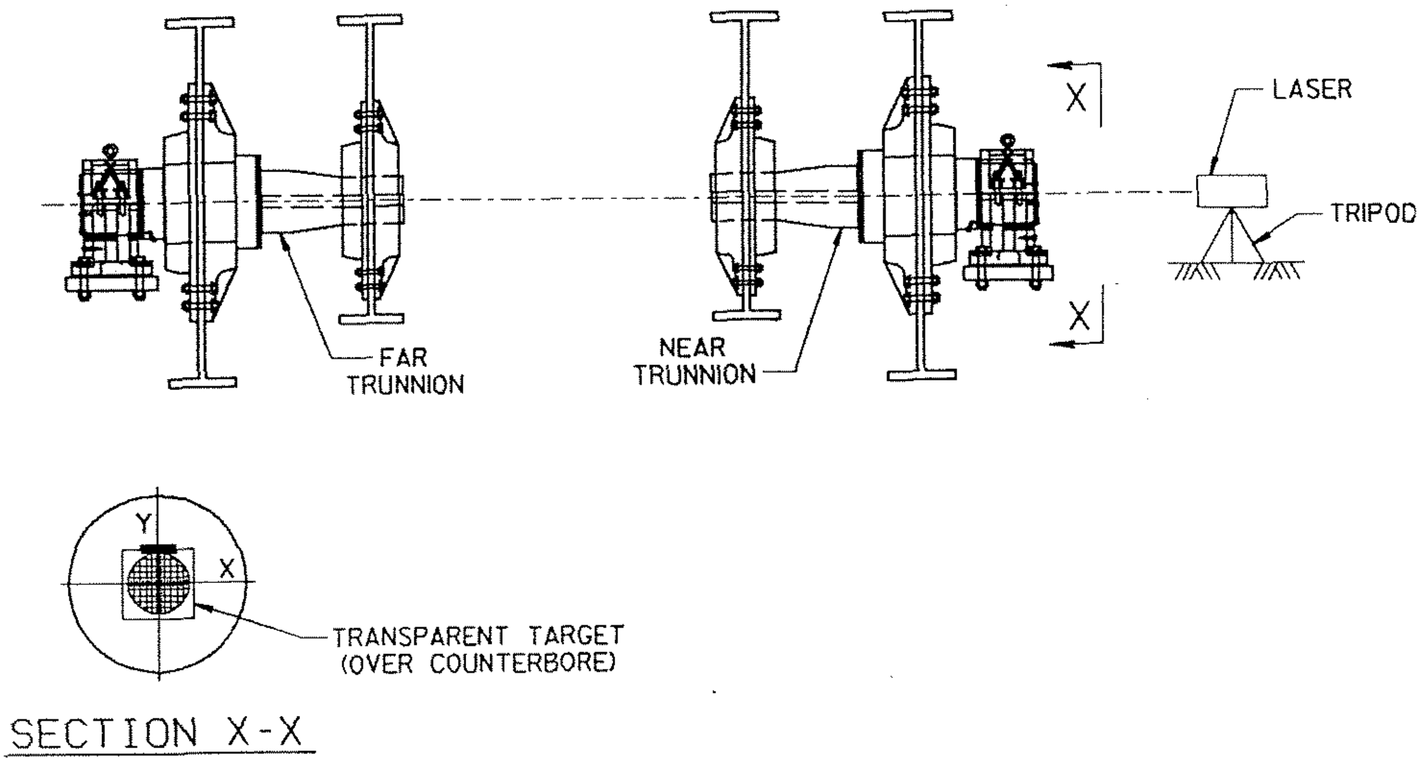


FIGURE 2

The steps required to perform this method are:

1. Prior to traveling to the site, generate a set of mylar (transparent) targets. The target field should be identical to the diameter of the trunnion counterbore, with divisions of 1/16 or 1/8 inch.
2. Set the laser on the outboard side of the near trunnion and direct its beam through the counterbores of both trunnions.
3. Level and mount a mylar target over the ends of each trunnion's counterbore (using heavy duty tape works well for this).
4. Record the beam location on each target with a dot or some other mark.
5. Repeat step #4 for the bridge raised to its halfway (approximately) and fully open position's.

6. Cleanup!

Note: Make sure to label the location of each target and also each data point.

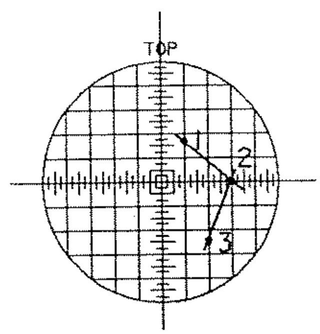
This may not seem adequate at first glance but the laws of mathematics insist that it is! We'll now look at the analytical procedure used to evaluate the data.

Either on site, or preferably back at your office, the following steps are required to analyze the data:

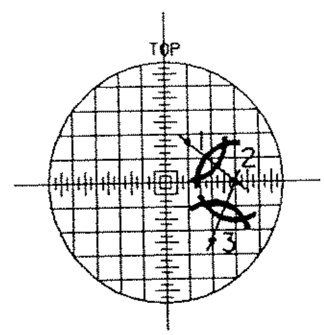
1. Using geometric relationships and principles, locate the center of the circle defined by the three data points for each of the targets. (Ideally this will be the exact center of the target and counterbore). The center of each of these circles defines a point located on the true axis of rotation for the trunnions.

This procedure is illustrated below:

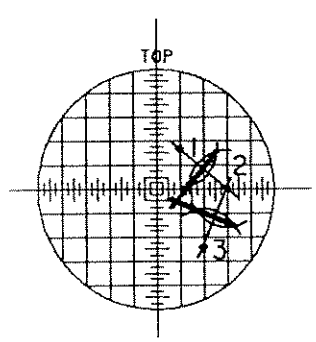
a) Connect the data points with two straight lines.



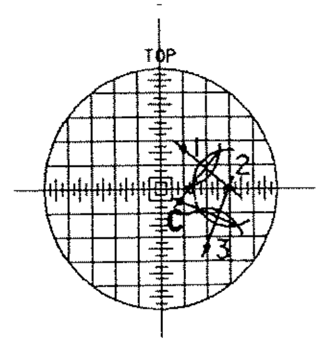
b) Draw arcs to locate two points on the lines which are perpendicular to the midpoints of the lines from step a).



c) Draw two straight lines through the intersection of the arcs.



d) The intersection of the lines drawn in step c) is the true center of rotation.



2. Derive the degree of misalignment between the trunnion counterbores.
   a) Calculate the distance between the true center of rotation and the center of the counterbore/trunnion in both the x-plane and y-plane for each target.
   b) Write the equation which defines the centerline of each trunnion with respect to the true center of rotation.
   c) Calculate the alignment of the trunnions with respect to each other.

The analytical procedure presented in Step 2 may appear lengthy, but actually consumes little time in practice. The following pages will attempt to illustrate the analytical procedure presented above. Figure 3 below is presented for reference and orientation purposes.

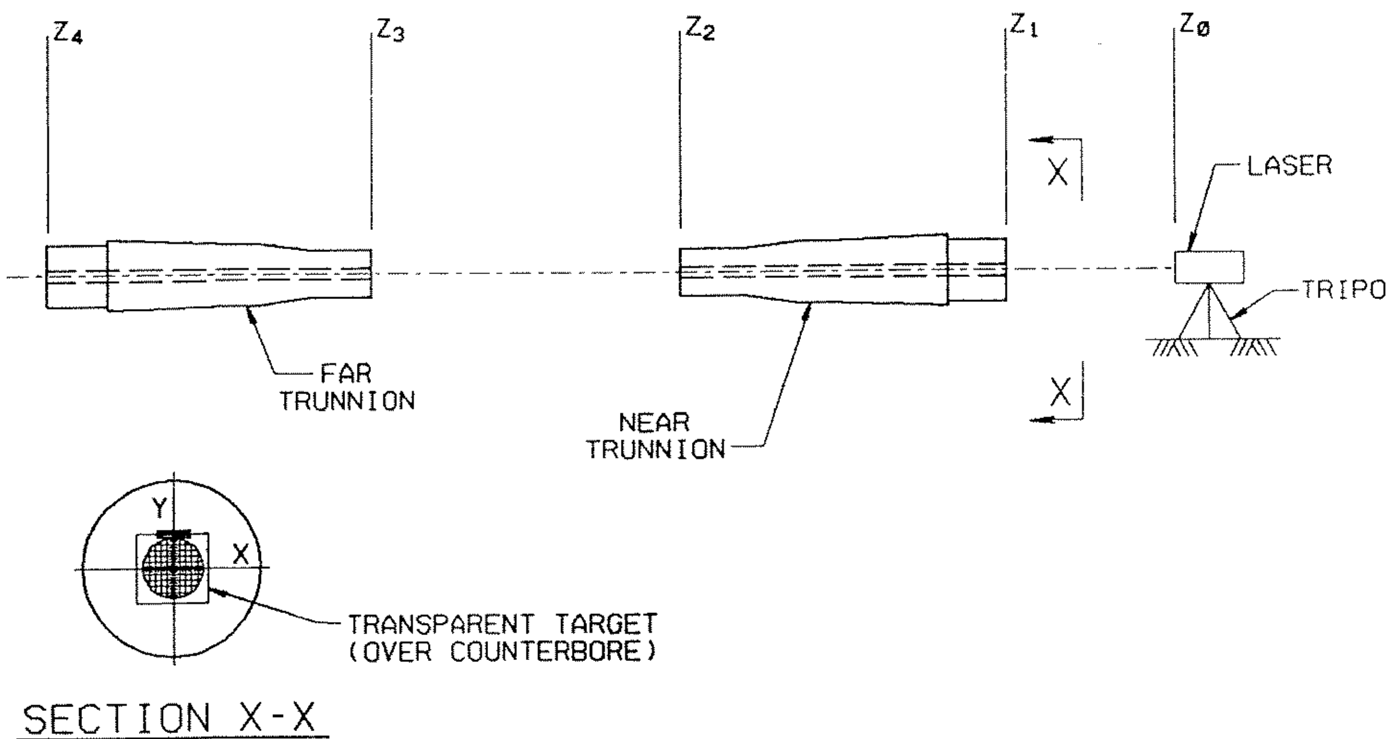


FIGURE 3

a) These calculations are straightforward. Read the distance from the centerline of the trunnion/counterbore to the true center of rotation directly from each target. (Be consistent in your sign convention when reading each target).

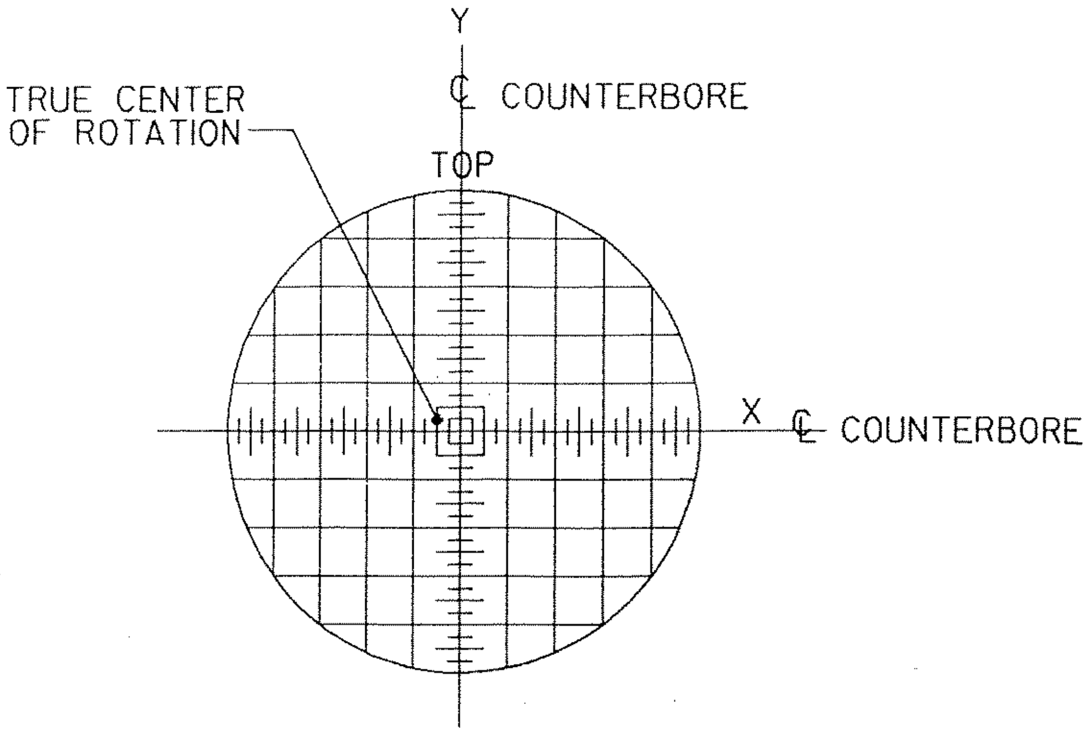


FIGURE 4
SCALE: FULL

In the sample target shown in Figure 4 above, the distance from the true center of rotation to the center of the counterbore in the x-plane is +1/8", and the corresponding distance in the y-plane is -1/16".

b) After completing step a) for each target, you will have compiled a table which resembles Table 1 shown below.

TABLE 1

DATA POINT	X	Y	Z
1	-1/8	+1/16	+8
2	-1/16	+1/8	+92
3	-1/16	-1/8	+272
4	+1/16	-1/8	+356

The equation of the line from data point 1 to data point 2 (which defines the centerline of the near trunnion) is:

$$(-\tfrac{1}{16} - -\tfrac{1}{8})i + (\tfrac{1}{8}-\tfrac{1}{16})j + (92-8)k = +\tfrac{1}{16}i + \tfrac{1}{16}j + 84k$$

Similarly, the equation of the line from data point 3 to data point 4 (which defines the centerline of the far trunnion) is:

$$+\tfrac{1}{8}i + 0j + 84k$$

For two lines that intersect, the angle between the two lines can be found from the equation:

$$\cos\theta = \frac{|a \cdot b|}{\|a\|\,\|b\|} \quad \text{,where } 0<\theta<\pi/2 \text{ (in radians)}$$

In our example this angle is:

$$\cos\theta = \frac{\left|(\tfrac{1}{16})(\tfrac{1}{8}) + (\tfrac{1}{16})(0) + (84)(84)\right|}{\left|((\tfrac{1}{16})^2 + (\tfrac{1}{16})^2 + (84)^2)^{1/2}\right|\left|((\tfrac{1}{8})^2 + (0)^2 + (84)^2)^{1/2}\right|} \Rightarrow$$

$$\theta = .0603 \text{ radians} = 3.455 \text{ degrees}$$

If the two lines (the centerlines of the trunnions) do not intersect, we can still find the angle between them. However, there will also be an **offset**, which is defined as the shortest distance between the two lines. We can find this offset by calculating the distance from one line to the other along the vector which is normal to both lines. This normal vector can be found by taking the cross-product of the two lines. This procedure is illustrated below:

Given the following two non-intersecting lines:

$$a = 0i + \tfrac{1}{8}j + 80k$$

$$b = \tfrac{1}{16}i + \tfrac{1}{16}j + 80k$$

The vector normal to both lines is:

$$a \times b = \begin{vmatrix} i & j & k \\ 0 & 1/8 & 80 \\ 1/16 & 1/16 & 80 \end{vmatrix} = 5i + 5j - 1/128\ k$$

We need to calculate the equation of the plane which wholly contains the line which defines the centerline of the near trunnion. The equation for our example is:

$$A(x-x_o) + B(y-y_o) + C(z-z_o) - D = 0 \Longrightarrow$$

$$5(x-1/16) + 5(y-1/8) + 1/128(z-8) - D = 0 \Longrightarrow$$

$$5x + 5y + 1/128z - 1 = 0$$

*Where (x_o, y_o, z_o) is a point on the centerline of the near trunnion (we can use one of our data points for the near trunnion).

The normal distance from a point on the centerline of the far trunnion to this plane is the offset. We can now calculate the offset as follows:

$$\text{OFFSET} = \frac{|Ax_1 + By_1 + Cz_1 - D|}{(A^2 + B^2 + C^2)^{1/2}} \Longrightarrow$$

$$\text{OFFSET} = \frac{|5(-1/32) + 5(-1/16) + 1/128(292) - 1|}{((5)^2 + (5)^2 + (1/128)^2)^{1/2}} \Longrightarrow$$

$$\text{OFFSET} = .1149 \text{ in}$$

*Where (x_1, y_1, z_1) is a point on the centerline of the far trunnion (again we can use one of our data points for the far trunnion).

We also need to find the angle between theses two lines. The angle which corresponds to the angle previously calculated for two intersecting lines is the angle seen when the two non-intersecting lines are viewed along their coincident normal vector (the normal vector we calculated from their cross product). This angle can be obtained by the same method as that used to find the angle between two intersecting lines.

We now have two values, the angle and the offset, which together completely define the relative alignment of two trunnions with respect to one another.

EVALUATION STANDARDS

Regardless of the inspection method used, the field data can be quantified into a managable form by the procedure outlined and presented above. Step 1 is unique to the laser method, but Step 2 can be universally applied to all methods. The question that arises at this point is "What standard can we compare our data and calculations to in order to make a sound judgement regarding the adequacy and quality of the trunnion's alignment?".

Current AASHTO Standards state that "Trunnion bearings and counterweight sheave bearings shall be aligned with the utmost accuracy." AREA Codes on this topic reiterate the same statement. The result is that each individual engineer is left to rely on his or her own judgement for evaluating what proper trunnion alignment is, and what the limits of deviation from that are before corrective measures are required.

Other sections of the AASHTO Standards indirectly imply criteria for some permissible misalignment. These implications are found in the following areas:

1. The clearance and misalignment tolerances accomodated by the trunnion bearings used.
2. The intrinsic and allowable deflections of the bearing supports (and bridge superstructure for eccentric trunnions).

Attempts to quantify these alignment allowances would be difficult. The misalignment they will permit is likely to be insignificant, and would provide too stringent a standard. A more plausible method for establishing an alignment criteria may be to follow the example of many other industries. That would be to establish a committee to gather data from both existing bridges and scaled test models, and then derive the "real world" laws which govern the results. We've seen this done time and again by associations such as AGMA and AFBMA. This may be the best option available toward developing a meaningful and reliable standard on acceptable trunnion alignment.

As a relatively young society, we are still defining the scope of our involvement, and the roles we will play in the future of movable bridges. We should consider it our responsibility to assist in and promote the research and development of standards which further this field.