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"Vertical Lift Bridge Trunnion Replacement"

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Bridge Trunnions

In July of 1978, the Shippensport Bridge at La Salle-Peru over the Illinois River experienced a trunnion fatigue failure. The Shippensport Bridge had been in operation for about 55 years when this failure occurred. It had seen many thousands of openings, as this stretch of waterway was and is a busy navigation channel. The trunnions were of a more or less "standard" design, with a large step down in diameter from the center section, that was shrunk into the sheave hubs, to the journals. There was a fairly generous fillet between the two diameters.

Of course, since then there have been several fractures detected, and many trunnions replaced. Combining trunnion concerns with rope durability difficulties, the vertical lift bridge is now looked at as not quite the invincible type of movable bridge that it was once thought to be. Not too long after the Shippensport failure, the Illinois Department of Transportation disseminated a very informative paper on trunnions, written by Mr. Floyd K. Jacobsen of their Bureau of Materials and Physical Research in Springfield. If any of you wish to receive a copy of it, I suggest you contact them. It was available directly from them, and also from the FHWA. The paper presents a lengthy discussion on fatigue, which is what the culprit was at Shippensport, and good guidelines for dealing with it. After the La Salle Incident, IDOT inspected the trunnions of all their vertical lift bridges, and found that many had to be replaced. They performed several trunnion replacements in the field, which as you can imagine, is no mean feat. In fact, they found that merely replacing the trunnions was no guarantee to an end to their problems.

A few years after the Shippensport incident, I was inspecting the machinery at the Hardin Vertical Lift Bridge over the Illinois Waterway for IDOT, and noticed some strangeness at the sheave trunnion area. Sure enough, some quizzing of the district engineer led to the revelation that the trunnions had been replaced shortly after the LaSalle failure, as cracks were suspected. Unfortunately, the new trunnions were not properly fitted into the sheave hubs, and were actually loose as opposed to having the shrink fit that should have existed. Not having been involved in the trunnion replacement process for this bridge, I could only assume that the trunnion diameter was incorrectly determined, or that an allowance was made to make the field fitting process easier. The sheaves were exhibiting a tendency to walk off the trunnions, being restrained only by the bearing housings.

Of course, vertical lift bridges aren't the only ones with trunnion problems, and the IDOT study refers to bascule bridges as well as vertical lifts. The majority of bascule bridges have trunnions, and their only saving grace in many cases is the fact that they do not go through complete stress reversal during operating cycles, or they wouldn't last as long as they have. I know of no actual fatigue failures at bascule bridge trunnions. Some bascule bridges have suffered from loose trunnions, however, due to incorrect fits between the trunnion and collar or between the collar and the bascule girder.

Many of you are familiar with the failures that are becoming more frequent at counterweight trunnions on old Strauss type articulated trunnion bascules. These are not failures of the trunnions themselves, but rather the undesired and improper movement of the unstiffened hanger plates which carry the counterweight load to the trunnion. These failures are traceable to the fact that it is almost completely impossible to properly lubricate these trunnions, due to the fact that they are located under the approach deck in the tail end of the bascule girder, between the counterweight and the main approach girder. Increased journal friction, plus corrosion at the trunnion and hanger eventually build up to the point where they are too strong for the usually underdesigned fasteners for the trunnions and the hangers, resulting in one of the hangers sliding off the end of the trunnion. This results, inevitably, in the counterweight dropping and the bridge becoming inoperable and unuseable.

The only real trunnion fatigue area is, then, at vertical lift bridge counterweight sheaves. A typical vertical lift bridge will make about 2-1/2 turns at the counterweight sheaves every time it opens or closes. Some may make as many as four turns. These are full stress reversals, with maximum bending tensile stress followed by maximum bending compressive stress at every surface point along the line where the journal diameter meets the fillet to the hub. There are very few other applications in engineering where this stress condition exists. In a gearbox for an automotive or other application, the shafts will be made greatly oversized for the bending stress they actually see, so that fatigue at the shaft is not a real consideration. Stiffness considerations are more important for these and other machinery arrangements, so that stress levels in the shafts are brought far below the critical.

There are two basic paths to determining the susceptibility of a particular bridge's trunnions to fatigue failure: analytical and empirical. The analytical method requires absolute knowledge of the following things:

1) Number of rotations the trunnions have experienced

2) Precise geometry of the trunnion

   a) radius at fillet

   b) diameter of hub and journal

   c) surface finish at stressed area

3) Bending stress limits, maximum and minimum

For the empirical method, the entire fillet area must be exposed for inspection, or as much as possible. There are several specific procedures that can be used:

1) Ultrasonics - if the ends of the trunnion are smooth, and there are no large pin or key discontinuities, a clean output from a good test means it is unlikely that cracks have developed

2) Dye penetrant - this is a good absolute test for cracks, provided that the surfaceof the entire fillet area and adjacent journal

can be exposed for testing

3) Visual - if there are serious cracks that may indicate impending failure, they may be visible by the naked eye, providing they can be exposed

4) Sound - suspicious noises may be a clue to a trunnion crack, but so many vertical lift bridges have faulty trunnion-hub fits, or faults in their bearing support superstructures, that it is very difficult to show that a particular noise results from a trunnion crack

When we began a project in Cleveland to replace a vertical lift bridge's machinery, we suggested that, although the original scope did not call for replacement of any tower equipment other than the ropes, the trunnions be checked for possible fatigue cracks. Our investigation became expanded to cover all the City-Owned vertical lift bridges on the Cuyahoga River. Out of a total of four bridges on the main river channel and one, newer span, on the Old River Bed, two were found to have cracks, including the one we were rehabilitating. The fifth bridge on the other channel was much newer. All four bridges on the main river were roughly the same age; the oldest was built in 1931 and the newest in 1940. All four had to be opened for almost every large lake boat that came up the river, as most of the heavier industry using the boat transportation was upstream from all bridges. Of these four, two exhibited no sign of fatigue and one was so severely cracked that it was strongly suggested it not be moved again. The last time I was in Cleveland, earlier this year, that bridge was still in exactly the same position as when the cracks were found. We recommended closing the third, the one that was to be put under rehab, but it was kept in operation for a while with cracks in the fillets of the trunnions, and eventually closed when the cracks began to increase in size. Both these bridges were left in the raised position, so as not to block river traffic, resulting in a substantial traffic problem for the Flats area of the City of Cleveland.

The two bridges of these four that had failed trunnions had a few things in common. They both had bronze bearings, so frictional torsion stress could have been a factor, and abrasive wear could affect the surface finish and even the geometry of the fillet. They both had trunnions forged of carbon steel which was barely adequate for the stresses under consideration, with no allowance for fatigue. The bridges were located near each other, in an area that was highly industrialized, where it is possible some concentrated pollution source could have attacked the steel trunnions. The oldest of the two, which was also the oldest of all the vertical lift bridges in Cleveland, had severe scoring along the fillets between the cylindrical journal surface and the cylindrical portion that was pressed into the cast steel sheave.

Out of these four frequently-operated, middle-aged vertical lift bridges, we came to the conclusion that one of them did not experience trunnion failure because it had roller bearings, reducing the stress in the trunnions because of lower friction, and preventing scoring at the surface. The other bridge that did not have cracks in its trunnions had them forged of nickel alloy 3340. This material is particularly resistant to fatigue, but it is not popular because it is difficult to weld. I do not believe it is still commercially available.

A possible solution to catastrophic failure on an existing structure is a retrofit that prevents the counterweight sheave from dropping more than a very small amount. While this detail would not necessarily allow operation of the bridge after a trunnion failure, it would make trunnion replacement relatively simple, and would avoid additional damage to the structure during a failure event. The retrofit would be simple and relatively inexpensive, so that it could be installed readily on any bridge that was suspected of imminent fatigue failure.

When designing a new movable bridge, it can be easy to eliminate fatigue. The most foolproof way is to eliminate the rotation of the trunnion. We prepared a design for the Cleveland bridge that was being replaced that called for stationary trunnions at the counterweight sheaves. The design called for a straight trunnion shaft with no steps or other stress risers, suported on pedestals in place of the old bearing housings. Large spherical roller bearings are mounted on the shaft, with the outer races of the bearings pressed into the hub of the new sheave. The bearings are substantially oversized from what would be chosen strictly on a load-speed-life basis, and are conservatively selected based on the AREA vertical lift bridge bearing design parameters. The selection of the specific bearing size was actually made by the Torrington company after a great deal of study. You will note that the stationary shaft supports the rotating sheave, so that the loaded friction surface is at the top of the shaft rather than the bottom, as is the usual case. I don't know of any other vertical lift bridges that have fixed trunnions, but there are many bascule bridges that do. Just north of here, the old U.S.1 bridge at Stuart has trunnions fixed onto pedestals supported on the masonry, and bronze bushings that are fitted into the bascule girders. There are several other bascule bridges of this arrangement, although I doubt that trunnion fatigue was an important consideration at any of the ones I am aware of.

An alternate solution is to design rotating shafts so that they do not approach their endurance limit. Ferrous materials have the property of being able to withstand cyclical stresses for an infinite time if the stress levels are low enough.

In conclusion, metal fatigue need not be an insurmountable problem with trunnions of movable bridges, either existing or proposed, as long as we are able to take a scientific approach to the issue.