# OPTIMUM ASSEMBLY PROCEDURE OF TRUNNION-HUB-GIRDER ASSEMBLIES IN BASCULE BRIDGES

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## Background

Leafs of bascule bridges are constructed by fitting a trunnion and hub into the main girder (Figure 1). Two distinct methods are used to make the trunnion-hub-girder (THG) assembly:

- Assembly Procedure #1 (AP#1): The trunnion is first cooled down in a bath of liquid nitrogen and then shrink-fit into the hub. Then the trunnion-hub assembly itself is cooled down in a bath of liquid nitrogen and then shrink-fit into the main girder.
- Assembly Procedure #2 (AP#2): The hub is first cooled down in a bath of liquid nitrogen and then shrink-fit into the main girder. Then the trunnion is cooled down in bath of liquid nitrogen and shrink-fit into the hub-girder assembly.

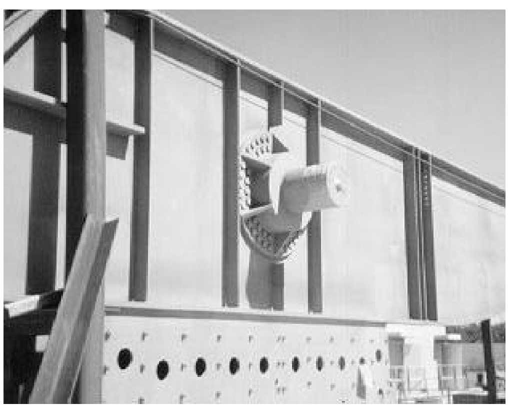


**Figure 1. Trunnion-Hub-Girder Assembly of a Bascule Bridge**

Each of these methods has been used throughout the United States on the construction of Bascule Bridges. Although the steady state stresses caused by both assembly procedures are the same, using the first assembly procedure - AP#1, cracking failure of the hubs of trunnion assemblies occurred during the assembly of three bridges in the state of Florida. The economic losses due to these trunnion-hub failures were of the order of hundreds of thousands of dollars. Florida Department of Transportation (FDOT) is interested in finding the reason of these failures and then use the information thus obtained to develop specifications for the THG assembly.

## Objectives & Research:

Due to the shrink-fits in the THG assembly, radial compressive stresses are developed at the trunnion-hub and hub-girder interfaces. Such radial compressive stresses at the interfaces determine part (other part is due to the bolt assembly between the hub and girder) of the torque taking capability during the opening and closing of a bascule bridge.

In this work, we first develop the formulas for calculating the steady-state radial compressive stresses at the trunnion-hub and hub-girder interfaces based on the interference [1] at these two interfaces. The amount of the interference for the THG assembly is based on two types of standard interference fits – FN2[1] or FN3[2]. More importantly, maximum hoop and Von-Mises stresses are calculated in each of the three components – trunnion, hub and girder. These determine whether the stresses created by interference fits are within tolerable limits.

Note a larger interference at the interfaces creates a larger compressive radial stress at the interface for desirable larger torque taking capabilities. At the same time, larger interference creates larger hoop and Von-Mises stresses in the components that may be more than the safe limits of stress - determined by the yield strength of the material of the components and the factor of safety. Hence, the amount of interference at the trunnion-hub and hub-girder interfaces needs to be optimized.

Following the steady-state analysis that showed all stresses within tolerable limits, a three-dimensional thermal analysis of shrink-fit assembly of selected trunnion-hub-girder configurations using the finite element code, ANSYS™, was done.

Note that in the transient analysis, material properties such as elastic modulus, specific heat, thermal conductivity and coefficient of thermal

1 FN2 designation [1]: "Medium-drive fits are suitable for ordinary steel parts or for shrink-fits on light sections. They are about the tightest fits that can be used with high-grade cast-iron external members."

2 FN3 designation [1]: "Heavy drive fits are suitable for heavier steel parts or for shrink-fits in medium sections".

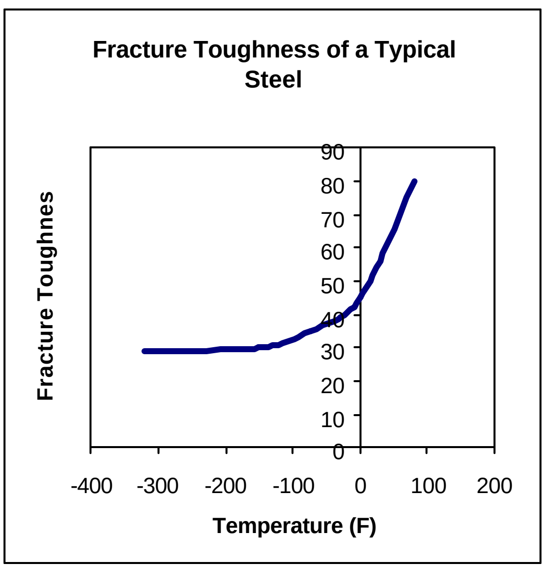
expansion are nonlinear functions of temperature. This is the reason that even if the trunnion, hub and assembly are of the same grade of steel, their properties will be different to make it essentially a *composite cylinder problem*.

Hoop and Von-Mises stresses were calculated for the two assembly procedures to show which procedure develops less stress.

The maximum transient hoop stresses in AP#2 are 12% lower than the maximum transient hoop stresses in AP#1. However, these transient stresses are about 1/3rd of the yield strength of 36 ksi, and hence do not predict failure due to stress.

So, what can be the reason for failure? The answer is that the fracture strength of steel decreases as a function of temperature. For body-centered cubic steels, the yield strength increases rapidly with decreasing temperature that it becomes greater than the fracture strength. Hence, below certain temperatures, these materials fracture before they reach stresses of the order of yield strength. For typical steel, the fracture toughness can reduce from 80 ksi-in$^{1/2}$ at room temperature to 30 ksi-in$^{1/2}$ at –321F (boiling temperature of liquid nitrogen) as shown in Figure 2.

**Figure 2. Fracture Toughness (ksi-in$^{1/2}$) vs.**




**Temperature ($^o$F) for a Typical Steel**

However, one may argue that both assembly procedures go through low temperatures and hence have the same possibility of cracking due to low fracture strengths. But, fracture strengths are more critical where large tensile stresses exist and hence smaller crack lengths are enough to exist to create catastrophic failure[3]. This is true in AP#1, where low temperatures exist in the hub when the tensile hoop stresses are the large and hence making the crack length needed for catastrophic failure to be low. Conversely, in AP#2, low temperatures also exist in the hub but when the tensile hoop stresses are either low or even not existing (that is , the hoop stresses are compressive). Clearly, AP#2 is hence more optimum.

The only drawback in AP#2 is the manufacturing sequence. Generally, one manufacturer makes the trunnion-hub assembly and then ships it to the next manufacturer that puts the trunnion-hub assembly in the girder. This is easy to follow with AP#1. However, if one follows the other procedure, the whole assembly needs to be done at one site or one manufacturer. We are recommending AP#2 to Florida Department of Transportation as well as checking all components of the THG assembly before assembly by nondestructive techniques to see if there are any pre-existing cracks that are larger than the critical crack lengths.

## References

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## Acknowledgements

Florida Department of Transportation funded this research. The monitor for the grant is Mr. Chris Smith; the technical monitor is Mr. Tom Cherukara, P.E. of the Florida Department of Transportation.

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[3] For a crack of length '2a' in an infinite plate under a uniform stress, s, the stress intensity factor is defined as

$$K_1 = s\sqrt{pa}$$

If $K_1$ is greater than the fracture toughness of the material (note it varies with temperature) $K_{1c}$, then the crack will progress catastrophically. Hence, the smallest half-crack length that will progress catastrophically is

$$a_c = 1/p(K_{1c}/s)^2$$

Now, the critical crack length is defined as the smallest crack length that can be detected/allowable during manufacturing or service. So, if this critical crack length is larger than $a_c$, the component is considered unsafe.