Full-Scale Testing of Trunnion-Hub-Girder Assemblies for Bascule Bridges

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Introduction

The fulcrum that is fit into the girder of a bascule bridge is made of a trunnion and a hub as shown in Figure 1. This trunnion, hub and girder when fitted together are referred to as a trunnion-hub-girder (THG) assembly.

![Figure 1: Trunnion-Hub-Girder (THG) Assembly.](image)

The THG assembly is generally made by interference fits (FN2 or FN3) between the trunnion and hub, and the hub and girder. The THG assembly can be done in two different ways, called “Assembly Procedure #1 (AP1)” and “Assembly Procedure #2 (AP2)”, respectively. AP1 involves the following four steps:

Step 1. The trunnion is shrunk by cooling in liquid nitrogen.

Step 2. This shrunk trunnion is then inserted into the hub and allowed to warm-up to ambient temperature to develop an interference fit on the trunnion-hub interface.

Step 3. The resulting trunnion-hub assembly is shrunk, by cooling in liquid nitrogen.

Step 4. The trunnion-hub assembly is then inserted into the girder and allowed to warm-up to ambient temperature to develop an interference fit on the hub-girder interface.

Whereas, AP2 consists of the following four steps:

Step 1. The hub is shrunk by cooling in liquid nitrogen.

Step 2. This shrunk hub is then inserted into the girder and allowed to warm-up to ambient temperature to develop an interference fit on the hub-girder interface.

Step 3. The trunnion is shrunk by cooling in liquid nitrogen.

Step 4. This trunnion is then inserted into the hub-girder assembly and allowed to warm-up to ambient temperature to develop an interference fit on the trunnion-hub interface.

During either of these assembly procedures, the trunnion, hub and girder develop both structural stresses and thermal stresses. The structural stresses arise due to interference fits between the trunnion-hub and hub-girder. The thermal stresses are a result of a temperature gradient within a body. This temperature gradient comes into play when either the trunnion or the hub is immersed in liquid nitrogen or when a cold trunnion is inserted into the hub, which is at room temperature.

History

On May 3\textsuperscript{rd}, 1995 during the immersion of the trunnion-hub assembly in liquid nitrogen for the Christa McAuliffe Bridge, a cracking sound was heard. On removing the trunnion-hub assembly out of liquid nitrogen, it was found that the hub had cracked near its inner radius.

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To prevent failures in the future, the Florida Department of Transportation (FDOT) decided to investigate the cause of failure in the THG assemblies. Preliminary investigations done by independent consulting firms and manufacturers gave various reasons for the possible failure including high cooling rate, use of liquid nitrogen as a cooling medium, residual stresses in the cast hub, and the assembly procedure itself.

Experimental Set-Up

The objective of the experimental setup was to measure stresses and temperatures during the two different assembly procedures. This study utilized cryogenic strain gages and thermocouples mounted on the trunnion, hub (see Figure 2), and girder. These sensors monitor strains and temperatures during all steps (cool-down in liquid nitrogen and warm-up in ambient air) during each of the assembly procedures.

Results

The hoop stress on the inner diameter of the hub developed during both these assembly procedures are shown in Figure 3.

In Figure 3 for AP1, Step-1 is trunion cool-down. The hoop stress in the hub remains zero during this step. In Step-2, the cold trunion is inserted into the hub. Consequently, the hoop stress rises to a steady state value of approximately 12.5 ksi. Step-3 is the most critical step in AP1, the trunnion-hub being cooled down results in the peak hoop stress of approximately 25.7 ksi. During Step-4, the trunnion-hub warm-up into the girder, the steady state stress on the hub inner diameter is approximately 12.8 ksi.

The plot for AP2 is also divided into the four assembly steps. Step-1 being hub cool-down results in a peak stress of approximately 19.5 ksi on the hub inner diameter. In Step-2, the
hub warms up into the girder, and the compressive stress on the hub inner diameter is 0 ksi. In Step-3, the trunion is inserted into the hub-girder. This trunion expands within the hub, creating tensile stresses on the hub inner diameter. The steady state value of this stress is approximately 12.1 ksi.

Figure 3 presents a very clear and concise comparison of the hoop stress between AP1 and AP2. It illustrates the peak stress in Step-3 of AP1 to be higher than the peak stress in Step-1 of AP2.

Figure 4 compares the Von-Mises stresses on the hub inner diameter during the two assembly procedures. The peak of 49 ksi in AP1 is observed in Step-3 (trunion-hub cool-down). At this time, the hub has both high radial and hoop stresses that add up to give very high values of Von-Mises stresses. The peak in AP2 is during the cool-down of the hub. It is to be noted that this peak is significantly lower than that of AP1.

![Figure 4 Comparisons of the assembly procedures based on Von-Mises stress.](image)

Conclusions

Table 1 summarizes the comparisons of assembly procedure #1 (AP1) and assembly procedure #2 (AP2) based on all three criterions, hoop stress, critical crack length and Von-Mises stress. Table 1 clearly illustrates that AP2 is significantly better compared to AP1 in terms of all three criterions. Furthermore, the FEA results agree with this conclusion as well.

<table>
<thead>
<tr>
<th></th>
<th>Hoop Stress (ksi)</th>
<th>Minimum Critical Crack Length (inch)</th>
<th>Von-Mises Stress (ksi)</th>
<th>Minimum factor of safety</th>
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<tbody>
<tr>
<td>AP1</td>
<td>25.7</td>
<td>0.3737</td>
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<td>AP2</td>
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<td>0.7610</td>
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