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PARAMETRIC FINITE ELEMENT MODELING AND FULL-SCALE TESTING OF TRUNNION-HUB-GIRDER ASSEMBLIES FOR BASCULE BRIDGES

PROBLEM STATEMENT

Failures during the fabrication of trunnion-hub-girder (THG) assemblies of bascule bridges can result in losses of hundreds of thousands of dollars. Crack formation in the hubs of the Miami Avenue, Christa McAuliffe, and Brickell Avenue Bridges during assembly led the Florida Department of Transportation (FDOT) to commission a project to perform a complete numerical and experimental study to investigate why the assemblies failed.

Two different procedures are currently utilized for assembly of the THG. Assembly procedure 1 (AP1) involves cooling the trunnion and shrink-fitting it into the hub, and, then cooling the trunnion-hub assembly to shrink-fit it into the girder. Assembly procedure 2 (AP2) involves shrink-fitting the hub into the girder, then cooling the trunnion and shrink-fitting it into the hub-girder assembly. Several problems can occur during the assembly, including the development of cracks on the hub and improper assembly due to insufficient cooling of the parts.

OBJECTIVES

Researchers conducted this research study in three stages:

1. A preliminary study of the steady state stresses in the THG assemblies.
2. Phase 1: parametric finite element modeling of the THG assemblies.
3. Phase 2: full-scale testing of THG assemblies.

FINDINGS AND CONCLUSIONS

The **preliminary study** of steady state stresses revealed that the stresses are well below the yield strength of the material and could not have caused failure.

At the outset of **phase one**, researchers hypothesized that AP2 resolves the problems associated with AP1. The results broadly agree with this hypothesis. However, each bridge is different and needs to be analyzed separately. In certain situations, AP1 is nearly identical to AP2 with regards to problems associated with assembly. A problem common to these assembly processes is thermal shock. In AP1 and AP2, the sharp thermal gradient sometimes leads to very low values of critical crack length (CCL). In AP1, a combination of high thermal and interference stresses results in potential crack formation. A lower thermal gradient can improve both assembly processes. Researchers recommended the following:

1. Before choosing the assembly procedure for a bridge, the THG Testing Model (THGTM) should

be run and the following questions answered:

a. What are the CCL values during the critical steps in the assembly process? During which process does a lower CCL value occur?
b. How long do the CCL values remain low? Are there indications of crack arrest?
c. What are the highest values of hoop stress? When do they occur?
d. What are values of CCL and hoop stress during the two warming-up processes?

2. To reduce thermal stresses, avoid sharp thermal gradients. Part of the cooling process, prior to dipping a part into liquid nitrogen, should be done in a medium with a lower convective heat transfer coefficient and boiling point than liquid nitrogen (e.g., immersion in liquid nitrogen could be preceded by immersion in a dry ice/alcohol mixture).

3. In general, it is better to cool parts of the assembly until there is a reasonable gap (i.e., clearance) between the male and the female part before insertion, particularly if the THGTM indicates low CCL values during the process.

Phase 2: The table below summarizes the comparisons of AP1 and AP2, based on hoop stress, CCL, and Von-Mises stress. It clearly illustrates that AP2 is significantly better than AP1. However, these results may or may not change by altering the geometry or interference values in the THG assembly. The FEA results agreed with this conclusion as well.

PROCEDURE	HOOP STRESS (ksi)	CRITICAL CRACK LENGTH (CCL) (inches)	VON-MISES STRESS (ksi)	FACTOR OF SAFETY (FOS)
AP1	25.7	0.3737	49.2	2.95
AP2	19.5	0.7610	30.9	3.29

The numbers for CCL were calculated at the locations of the strain gages at different times, and the smallest numbers provided the critical crack length for the whole assembly.

The maximum hoop and Von-Mises stresses were calculated, throughout the assembly procedure, at the strain gage locations. The factor of safety (FOS) was calculated by finding the minimum of the ratio between the yield strength and hoop stress at the strain gage locations. Since yield strength is a function of temperature, maximum hoop stresses do not necessarily result in lower FOSs. Further, the maximum Von-Mises stress does not coincide with the time at which the maximum hoop stress occurs in AP2. The maximum Von-Mises stress occurs when the whole assembly reaches steady state, while the maximum hoop stress occurs when the trunnion is placed in the hub-girder.

Researchers suggested the following **overall recommendations**:

- Lay down inspection specifications for determining whether voids or cracks in the cast hub are bigger than 0.3 inch. (CCL for AP1 was found to be 0.3 inch)

- Specify tight machining tolerances for the inner diameter of the hub, indicating true position and perpendicularity tolerances. A taper along the depth could also contribute to chances of the trunnion getting stuck in the hub during assembly.

- Consider heating the outer component as an alternative to cooling the inner component. Heating has two distinct advantages over cooling in liquid nitrogen. First, it is a slow process which would not create large thermal stresses. Second, heating the steel does not make it brittle. Cooling the steel casting makes it more brittle and more susceptible to crack propagation.

- Consider gradual cooling, whenever the hub is being cooled by itself (AP2) or as a trunnion-hub assembly (AP1), in a convection-cooling chamber using liquid nitrogen rather than cooling by immersion in liquid nitrogen. The same shrinkage can be obtained for carrying out a successful assembly. The advantage is that the trunnion or hub does not get a thermal shock associated with direct immersion. The disadvantage is that the process would be slower.

- Consider staged cooling wherein the trunnion or hub is first cooled from room temperature to 0˚ F, then further cooled to -109˚ F using dry-ice/alcohol, and finally cooled to –321˚ F using liquid nitrogen. Staged cooling is better than immersing the trunnion directly in liquid nitrogen since in any given stage the temperature change is smaller, resulting in significantly lower thermal stresses.

The FDOT has implemented the recommendations of this research, the most significant of which is the heating of the outer component of the assembly. This method, compared to the method of cooling the inner component, has a significant effect on the assembly process in that relatively high clearances are obtained with reduced thermal gradients and stresses.

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