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

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

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ABSTRACT

The project, "Parametric Finite Element Analysis (Phase I) and Full-scale Testing (Phase II) of Trunnion-Hub-Girder Assemblies of Bascule Bridges", involves investigating the reasons for failure of the hub during the assembly procedure (prior to installation).

Phase I has analyzed three bridges and put forth plots of stresses and temperature against time. It has also developed a design tool that design engineers can use to analyze existing and new bridges. Phase II of the project involves an experimental stress and temperature analysis of the THG (trunnion-hub-girder) assembly.

Large tensile hoop stresses are developed in the hub at the trunnion-hub interface. These stresses are a combination of structural stresses (due to interference fits) and thermal stresses (due to thermal shock). Furthermore, the cast steel may have some small cracks or voids. These small cracks may grow in size when the hub is cooled in liquid nitrogen because the fracture toughness of the steel decreases with decrease in temperature.

The trunnion-hub-girder can be assembled by two different procedures. The transient stresses and temperatures are measured during both these assembly procedures. These data help in assessing the possibility of hub failure in the each procedure.

Introduction:

A bascule bridge is a type of movable bridge that can be opened or closed to facilitate the movement of water-borne traffic such as ships and yachts. The bascule bridge opens like a lever on a fulcrum. The fulcrum that is fit into the girder of the bridge is made of trunnion and hub as shown in Figure 1. This assembly is called the trunnion-hub-girder (THG) assembly. Power is supplied to the THG assembly by means of a rack and pinion gear at the bottom of the girder to open and close the

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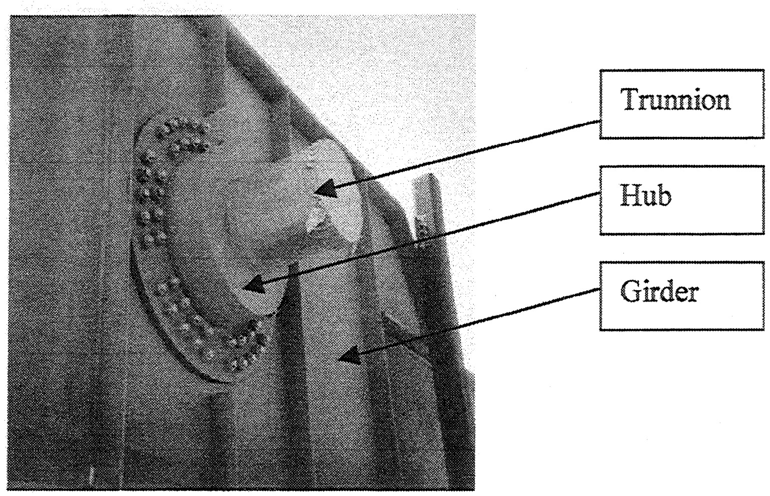

Figure 1. Trunnion-hub-girder (THG) assembly

The THG assembly is generally made via interference fits between the trunnion and the hub, and the hub and the girder. Typical interference fits used in Florida bascule bridges are FN2 and FN3 fits. There are two assembly procedures: the first, called AP#1, involves shrink fitting the trunnion into the hub followed by shrink fitting the trunnion-hub assembly into the girder, and the second, called AP#2, involves shrink fitting the hub into the girder followed by shrink fitting the trunnion into the hub-girder assembly.

In Florida, during the process of assembling the THG, cracks were developed in the hub of three bridges: Christa McAuliffe Bridge, Miami Avenue Bridge and Brickell Avenue Bridge. FDOT officials wanted to carry out a complete numerical and experimental study to find out the reason for these failures, how they could be avoided in the future and to develop clear specifications for the assembly procedure. So, a grant was given to the College of Engineering at the University of South Florida to investigate this problem.

Earlier studies:

There have been two earlier studies conducted as part of this FDOT grant. The first one, conducted by Denninger[1] found that the steady state stresses in the THG assembly are well below ultimate tensile strength (UTS) of the materials used in the assembly. Hence, these stresses could not have caused the failure. These results called for an investigation of the stresses during the assembly process. The stresses during the assembly process came from two sources – thermal stresses due to temperature gradient and mechanical stresses due to interference at the trunnion-hub and hub-girder interfaces.

The second study conducted by Ratnam[2] studies the effect of thermal and structural stresses in the THG assembly. It brings forth results, which show that the most critical hoop stresses are generated due to thermal shock when a component or sub-assembly is dropped in liquid nitrogen.

Its hypothesis is that small cracks or voids present in the assembly propagate catastrophically forming cracks once they attain a critical crack length a_c. The critical crack length is determined by the formula below:

$$a_c = \frac{K_{1c}^2(T)}{f_e^2 \pi \sigma_\theta^2}$$

where

a_c = Critical crack length,

$K_{1c}(T)$ = Temperature dependent critical stress intensity factor,

f_e = Edge effects, and

σ_θ = Hoop stress.

The critical crack length is dependent upon the critical stress intensity factor (a_c) and the hoop stress (σ_θ). The critical stress intensity factor (K_{1c}) in turn is a function of temperature. K_{1c} decreases with a decrease in temperature.

This study also states that, "in AP#1 a combination of high hoop stress and low temperature result in smaller values of minimum crack length a_c ultimately leading to crack formation. In AP#2, stresses due to interference never occur together with the cooling process, resulting in larger values of a_c and thereby reducing the probability of crack formation. In short, temperature, hoop stress and critical stress intensity factor (fracture toughness) are not optimized in AP#1 and AP#2 will resolve this problem ".

Present study:

This Paper is based on Phase II of the FDOT Research Grant. The objective of Phase II is to carry out a stress analysis of a Full Scale model of the bascule bridge on 17th Causeway Bridge.

In order to record the stress and temperature data over the entire duration of the test, a data acquisition (DAQ) system is employed which monitors 40 channels, 10 channels of temperature (Type-E thermocouples) and 10 rectangular strain gage rosettes (which take up 30 channels). The data acquisition system also provides excitation and bridge-completion for the strain gages. The DAQ system is connected to a Laptop computer via a PCMCIA card. A slow scan rate of 1 channel/second is used.

Verification Experiments:

The Full scale testing is a non-repeatable experiment, owing to the high costs involved in the machining of the trunnion, hub and girder. Hence, it was important to verify that each and every component of the experimental set-up worked in perfect conditions throughout the temperature range of room temperature (80 ^{0}F) to the temperature of Liquid Nitrogen (-321 ^{0}F). Also, the results produced by the DAQ system needed to be validated. Hence, a few verification experiments were carried out.

The first one involved verification of thermocouples and their cement. Six type E thermocouples were inserted into a steel cylinder (Figure 2).

Radial1, Radial2 and Radial3 were probe type thermocouples that had been inserted radially and were cemented into 17/64" holes with a 120-degree spacing, at depths of ½", 1", and 1 ¼" respectively. Axial1, Axial2, and Axial3 were bare end thermocouples cemented into 1/8" diameter holes with a spacing of 120 degrees, drilled on a 1 1/8" diameter circle located axially on the test sample. These thermocouples reached depths of ½", 1", and 1 ½" respectively.

This cylinder was dropped into liquid nitrogen and then allowed to warm back up to about 55 ^{0}F. The results of this experiment are shown in Figure3.

The second verification experiment was a simple cantilever beam experiment, where two strain gages were mounted on a steel beam. This beam was then loaded with known weights at its free end. Bending stresses were calculated from the strain gage readings and compared with those from theory.

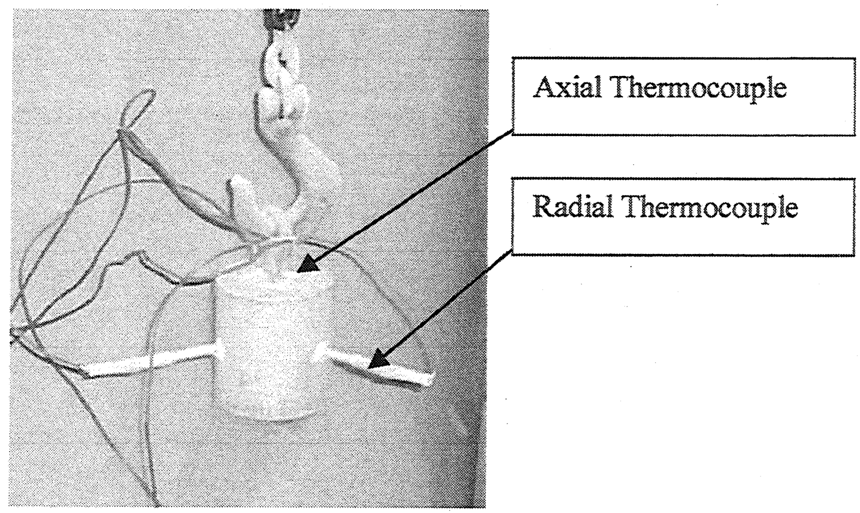

Figure 2. Steel cylinder with six thermocouples, pulled out of liquid nitrogen

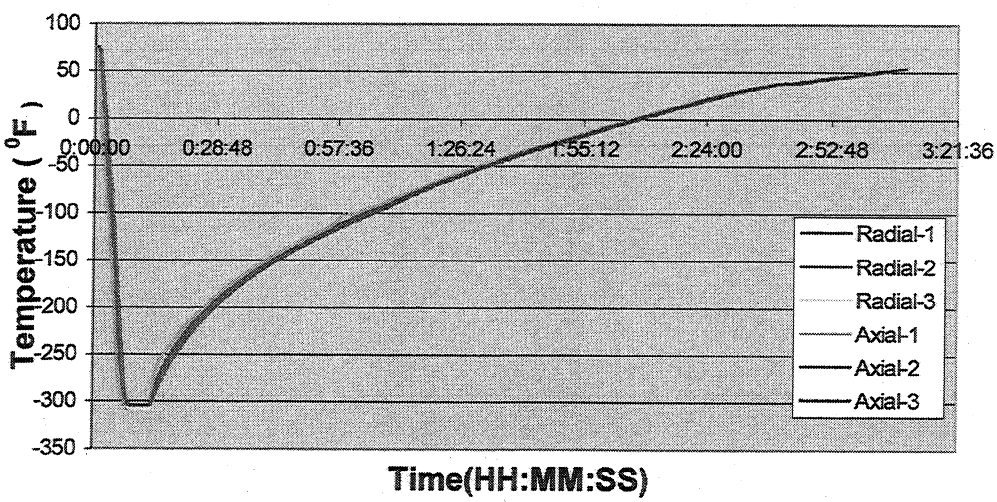

Figure 3. Cool down in Liquid Nitrogen and warm up in ambient air

The third experiment was done in order to verify whether the strain gages performed well when immersed in liquid nitrogen. The theory underlying this experiment was differential expansion between a steel sleeve and a brass bolt. The sleeve was constrained at its two ends by brass nuts (mounted on the brass bolt). This sleeve-bolt assembly was immersed in liquid nitrogen, and the stresses developed in the steel sleeve were compared to their theoretical values.

The fourth experiment was a simplified version of problem being studied, in that it involved shrink fitting one cylinder into another. Liquid nitrogen was employed as the cooling medium for obtaining the shrink fit.

A quarter scale model will also be run before the full-scale model. The shrinkage obtained by cooling in liquid nitrogen and the actual interference required are both very close to each other (both are of the order of thousands of an inch). This results in very close time limits for inserting the shrunk male part into the female part before it expands out due to warming up. The objective of carrying out a quarter scale model is to get a better understanding of these time issues and all other similar minute details involved in the assembly procedures.

The full-scale model:

Ten crucial points will be monitored on the full-scale model, three points on the trunnion, six points on the hub and one point on the girder. Each "square" on the hub/trunnion (Figs. 4 & 5) represents one rosette and one thermocouple. The focus of this experiment is the hub, since this is the component that has failed in the assembly procedures. These ten points have been decided so as to get the maximum information out of the full-scale model. (An effort has been made to try and capture stresses at both the interfaces and in each component.)

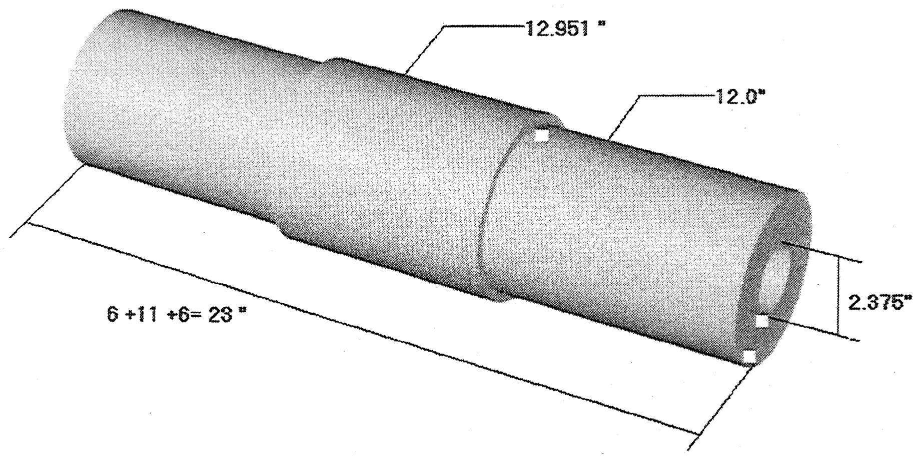

Figure 4. Trunnion of the full-scale model of the 17th Causeway bascule bridge

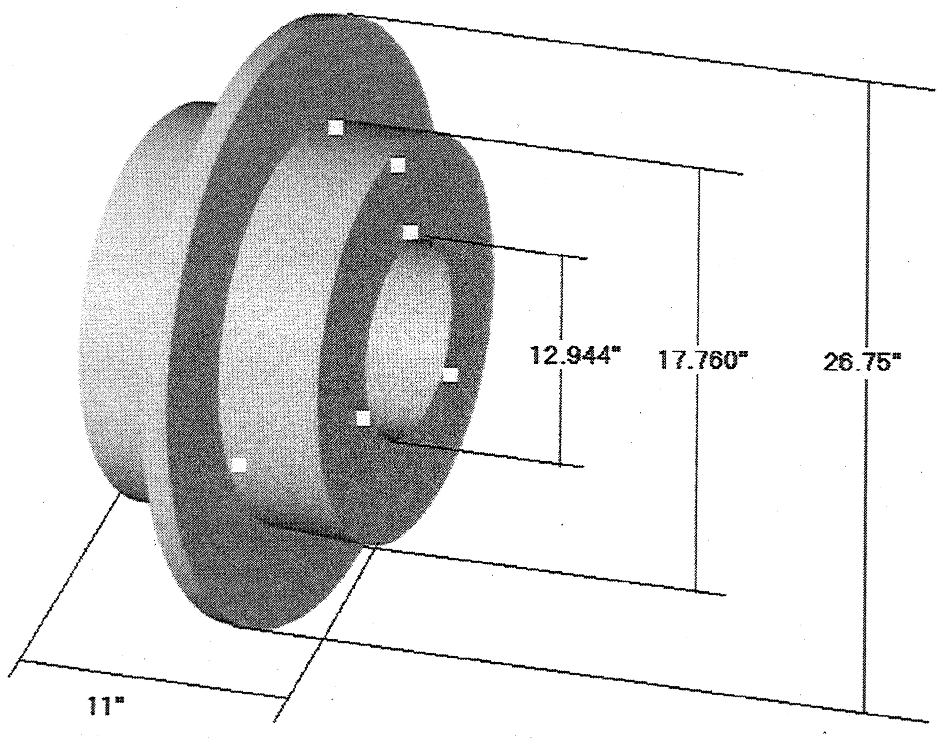

Figure 5. Hub of the full-scale model of the 17th Causeway bascule bridge

The hub has been sent for an x-ray inspection. This has been done so as to detailed information about the cracks or voids that exist in the cast hub. This information will be of great value during the analysis of the data obtained from the full-scale test, since "critical crack length" is an important parameter for determining the chances of hub failure.

The quarter scale model will be run in late august and the full scale testing will be run in early September.

Finite Element Analysis for the 17th Causeway Bridge:

Fig 6 shows a graph of hoop stress, temperature and CCL (critical crack length) of AP#1 (first assembly procedure) of the 17th causeway bridge. For plotting them together on one graph, the hoop stress has been expressed in Ksi, CCL (in inches) has been multiplied by ten, and the temperature (in ^{0}F) has been divided by ten. The hoop stress peaks to values close to 30 Ksi at two points; once, when the "trunnion-hub contact" begins, and then due to "thermal shock" when the trunnion-hub is dropped into liquid nitrogen.

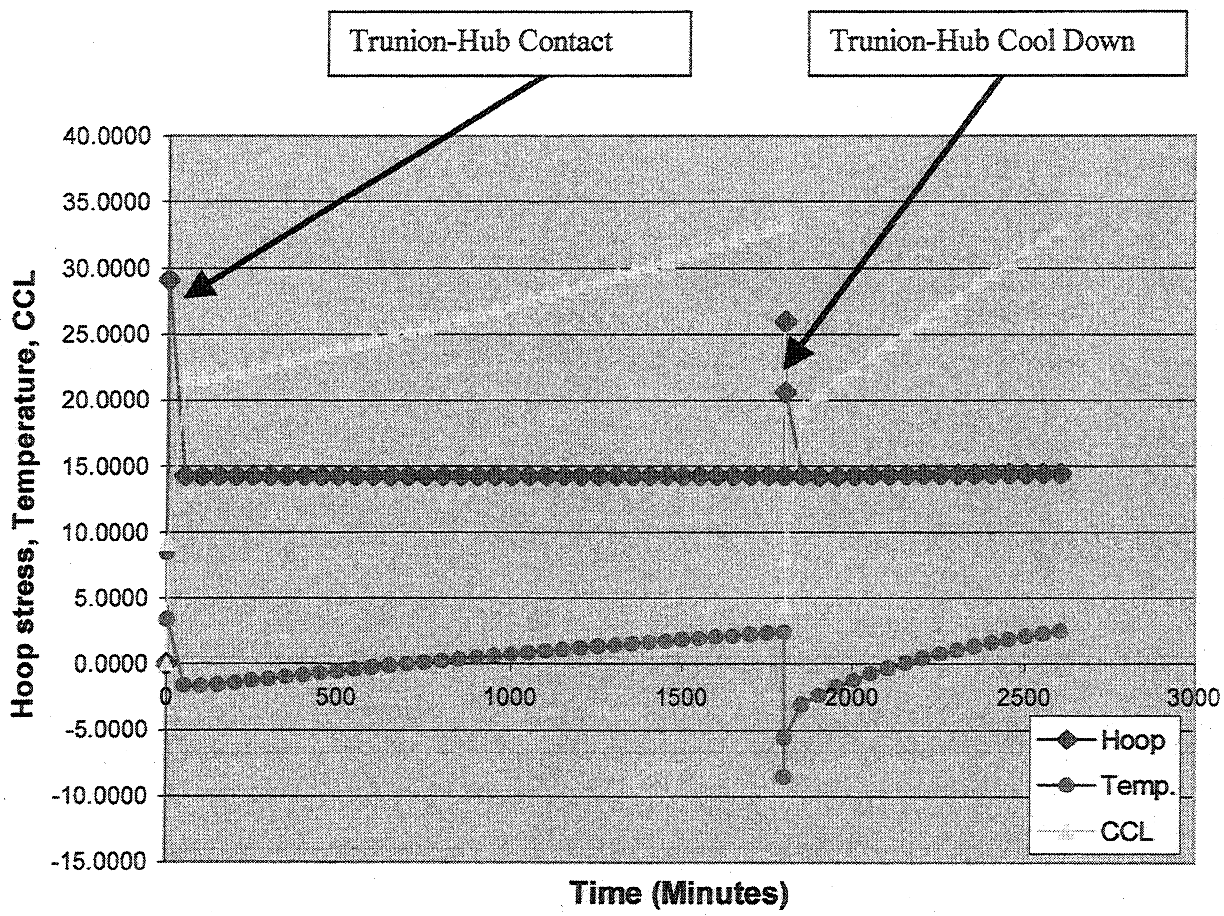

Figure 6. Variation of Hoop stress, Temperature and Critical crack length over AP #1

These results obtained from the finite element analysis study for 17th causeway bridge will be verified by the results of the full scale testing.

References

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