Monitoring an Interstate Highway Bridge with a Built-In Fiber-optic Sensor System

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ABSTRACT: An optical fiber monitoring system was designed and built into one span of the five span high performance prestressed concrete I-10 Bridge over University in Las Cruces, NM. A total of 72 long-gage (2m long) deformation sensors, along with 36 thermocouples were embedded in the prestressed concrete girders. Sensors were installed along the bottom and top flanges, at mid-span and quarter spans. Pairs of crossed sensors in a rosette configuration were embedded in the webs at the supports. The embedded sensors measured temperature and deformations at the supports, quarter spans, and mid-span. Data was collected from the start of construction thru service. Collected data was analyzed to evaluate the prestress losses and cambers in the girders. Actual losses and camber were compared to the losses and camber predicted using available code methods. The project was funded by the New Mexico DOT and the FHWA under the Innovative Bridge Construction Program.

1 INTRODUCTION

Using High Performance Concrete (HPC) in prestressed concrete girders has enabled engineers to design bridges with longer span lengths and fewer supports, shallower sections, and increased girder spacing, which can decrease the fabrication, transportation, and erection costs of the bridge. However, despite the wide current use of HPC, there are still factors that need to be further considered. The design of a prestressed concrete girder is highly dependent on the amount of prestress loss expected over a period of time. Current methods to empirically estimate these losses are derived for conventional concrete and have not yet been modified for HPC. Those methods need to be reevaluated for HPC.

Another factor that needs further consideration when using HPC is camber. Camber is an important serviceability consideration in the design of prestressed bridge girders. Both material properties and structural parameters influence girder camber. Camber behavior of HPC girders can be significantly different than that of regular strength concrete girders due to the difference in material properties. Current simplified methods of camber prediction, such as the Precast/Prestressed Concrete Institute (PCI) multiplier method and the PCI improved multiplier method (PCI Committee 1997) were developed for regular strength concrete and need to be further evaluated for HPC.

In this project prestress losses and camber were monitored during beam manufacturing, bridge construction and service. Strain measurements were collected for a period of one year and actual prestress losses and cambers were calculated based on the collected data. The prestress losses were then compared to prestress losses estimated by several code methods. Cambers were compared to those calculated using the PCI multiplier methods, and the cambers measured using a self leveling laser on site.

2 BRIDGE DESCRIPTION

The study bridge is located in Las Cruces, New Mexico on westbound Interstate 10 over University Avenue and Main Street. The bridge consists of five spans with lengths of 42.14, 30.94, 40.70, 40.70 and 40.31 meters (138.25, 101.5, 133.5, 133.5, and 132.25 feet). Each span consists of six 1.37 meter (54 inch) tall prestressed concrete spread box-girders. The girders are constructed of high-strength prestressed concrete with minimum 28-day strength of 68.9 MPa (10 ksi). The bridge profile and cross-section are shown in Figures 1 & 2 below.

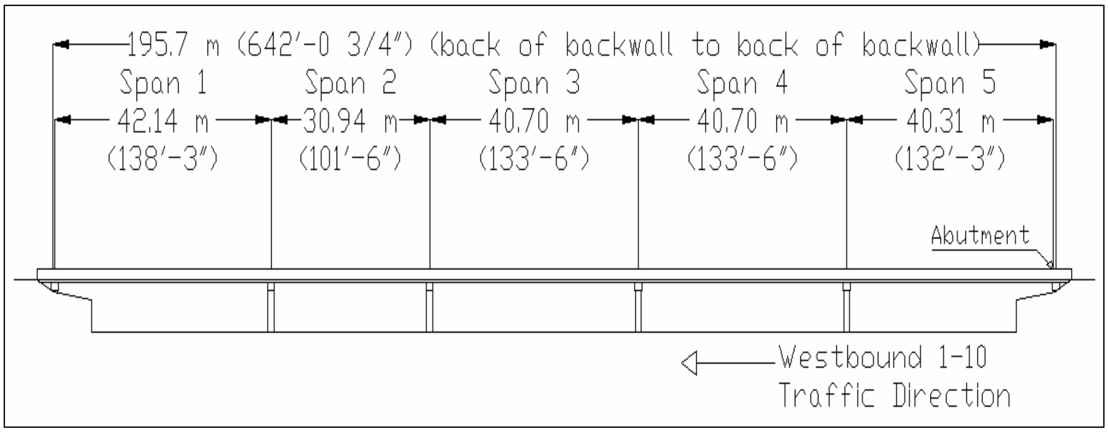

Figure 1. Bridge profile.

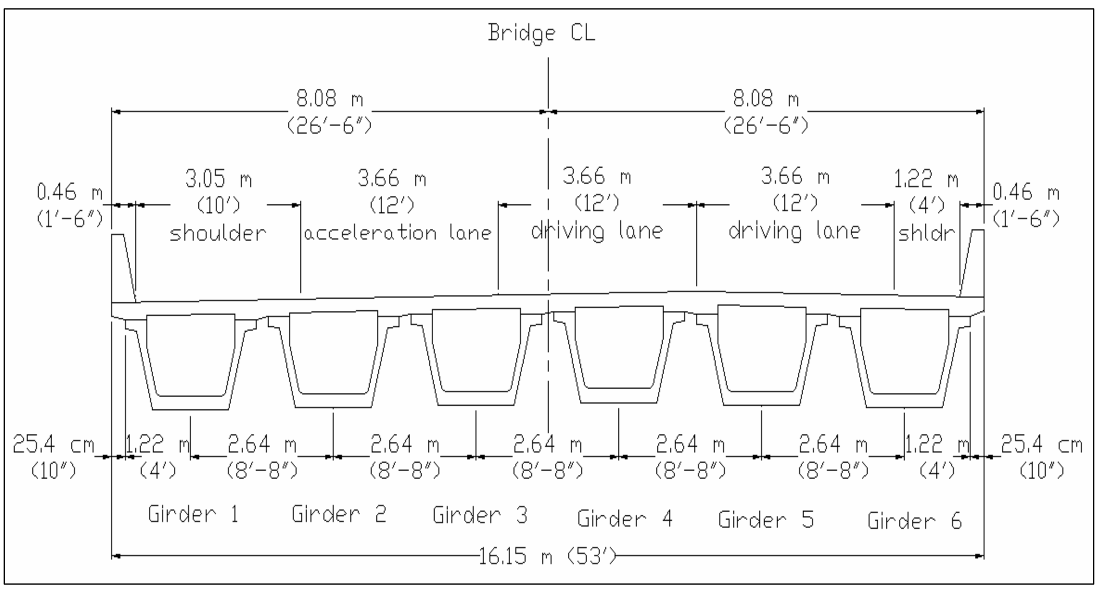

Figure 2. Deck cross-section.

3 INSTRUMENTATION

Long-gage (2m length), fiber optic sensors were installed in Spans 5 of the bridge. The sensors were used to measure girder camber, as well as the short and long-term losses in the prestressing cables throughout beam manufacturing, bridge construction, and service (Liang 2004). In another portion of the project, the bridge was tested under truck loading and the sensor data was used to evaluate shear and moment girder distribution in the bridge (Hughs 2004).

A SOFO monitoring system was used for this bridge. The monitoring equipment and deformation sensors were manufactured by the Swiss company SMARTEC. The system is based on a low-coherence interferometry in long-gage optical fiber sensors. The fiber optic sensors perform measurements by passing light from a laser through the sensor fibers. Any change in the fiber (e.g. temperature, deformation) will cause a change in the light properties. Changes in light properties passing through the sensor fibers can be calibrated and the strain in the structure being monitored can be measured. Figures 3& 4 below show the sensor layout used for monitoring of this bridge.

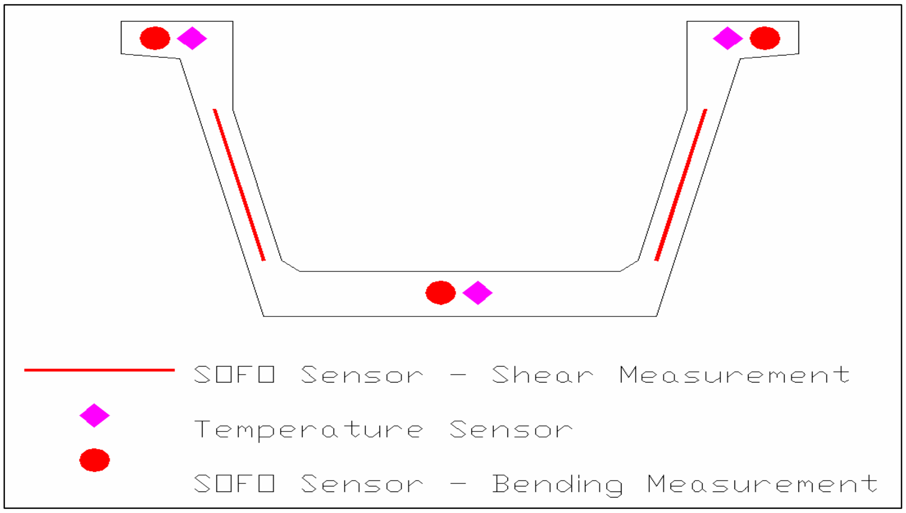

Figure 3. Girder cross-section and sensor layout.

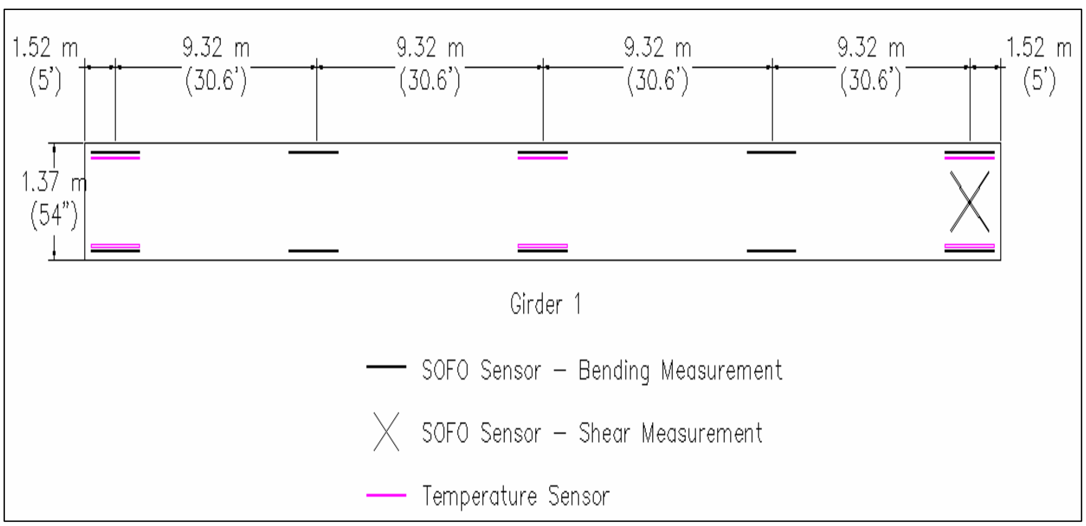

Figure 4. Elevation view of sensor layout for Girder 1.

4 PRESTRESS LOSSES

Prestress losses were calculated using the sensor measurements (Liang 2004). Several methods were used to calculate the prestress losses: the PCI general method (PCI Committee 1975), the ACI-ASCE method (ACI-ASCE Committee 1979), the LRFD method (AASHTO 2004), and the LRFD lump sum method (AASHTO 2004). None of these methods were developed specifically for high-performance concrete. The PCI method is a time-stepped method for predicting the prestress losses in which incremental prestress losses can be calculated at different time intervals. Unlike the PCI general method which divides the life history of a prestressed concrete member into several time steps, the ACI-ASCE committee method and the AASHTO LRFD methods use overall total loss estimates.

The prestress losses calculated using the sensor measurements were compared to the estimated losses as shown in Figures 5. We can see that overall, all four methods largely overestimate the prestress losses of HPC girders. This can be partially attributed to the fact that HPC creeps much less than conventional concrete (Mindess et al.2003). As shown in Figure 5, a large portion of the estimated losses by the PCI general, the ACI-ASCE and the LRFD method is due to creep.

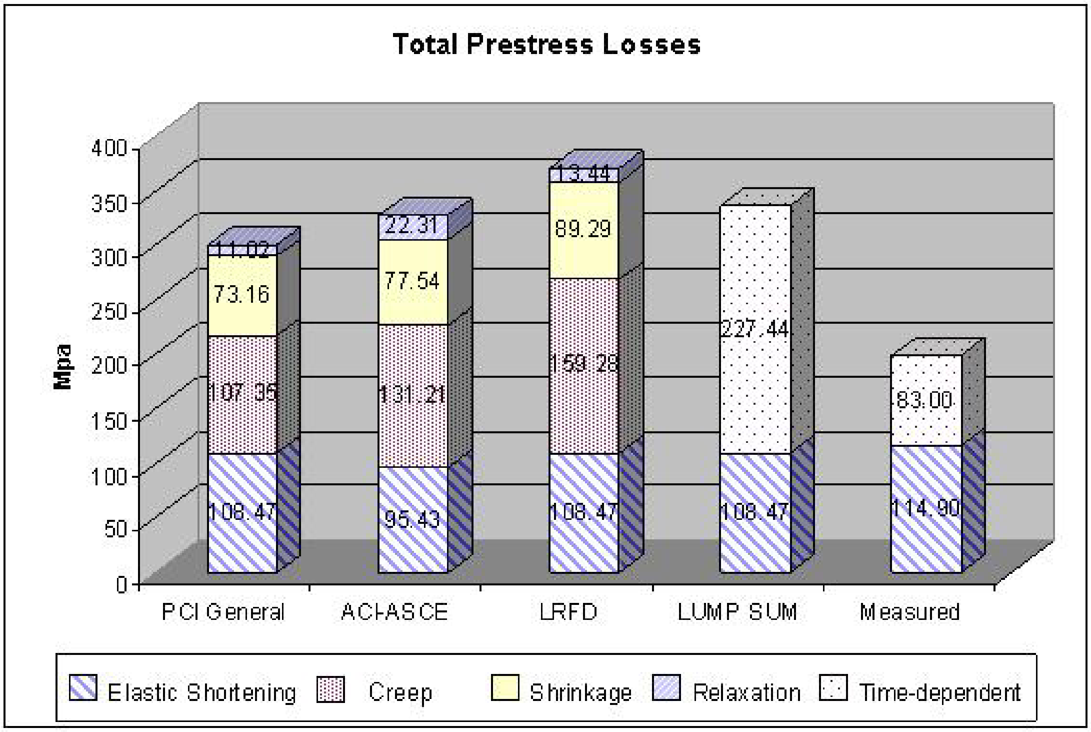

Figure 5. Comparison of the total prestress losses by all methods

5 CAMBER

The camber calculations were done using SOFO SPADS 6.0 software. The software allows the calculation of the vertical displacement with a resolution in the order of 0.1 mm for short-term measurement (e.g. during a load test) and 1mm in the long term. The sensor measurements are used to calculate the average curvature of the cells, which in turn are used to construct the curvature function of the whole girder. The deflection of the girder can then be produced by double integration of the curvature function (Vurpillot 1999). Figure 6 shows a typical camber plot for a girder.

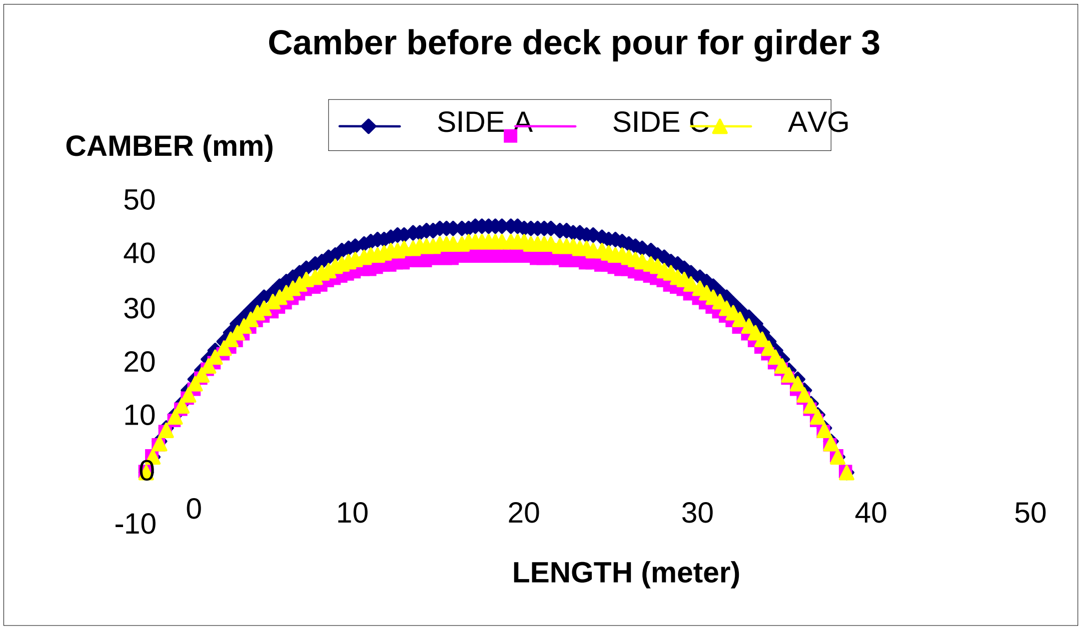

Figure 6. Typical camber plot using sensor measurements

Along with the cambers obtained from sensor measurements, cambers were also calculated using the PCI bridge design manual multiplier and improved multiplier methods (PCI Committee 1997). At transfer both PCI methods closely agree with the results based on sensor measurements as shown in figure 7.

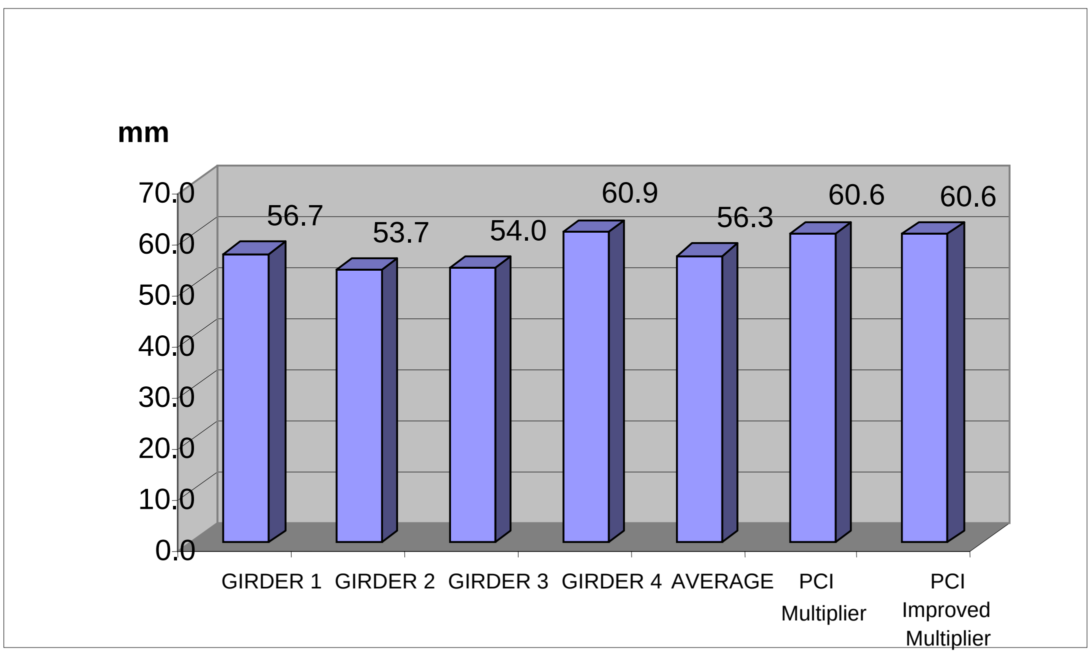

Figure 7. Girder camber right after transfer.

As shown in figure 8, both PCI methods overestimated the camber at erection. In the PCI methods creep of the concrete is primarily responsible for the long term camber growth. HPC creeps much less than regular strength concrete (Mindess et al. 2003). This can explain why the girders had much less camber growth than what was expected by the PCI methods. Figure 9 is a typical plot of the camber history for a girder. We can see that little camber growth occurred between transfer and deck pour. The daily fluctuations in camber are due to daily temperature fluctuations.

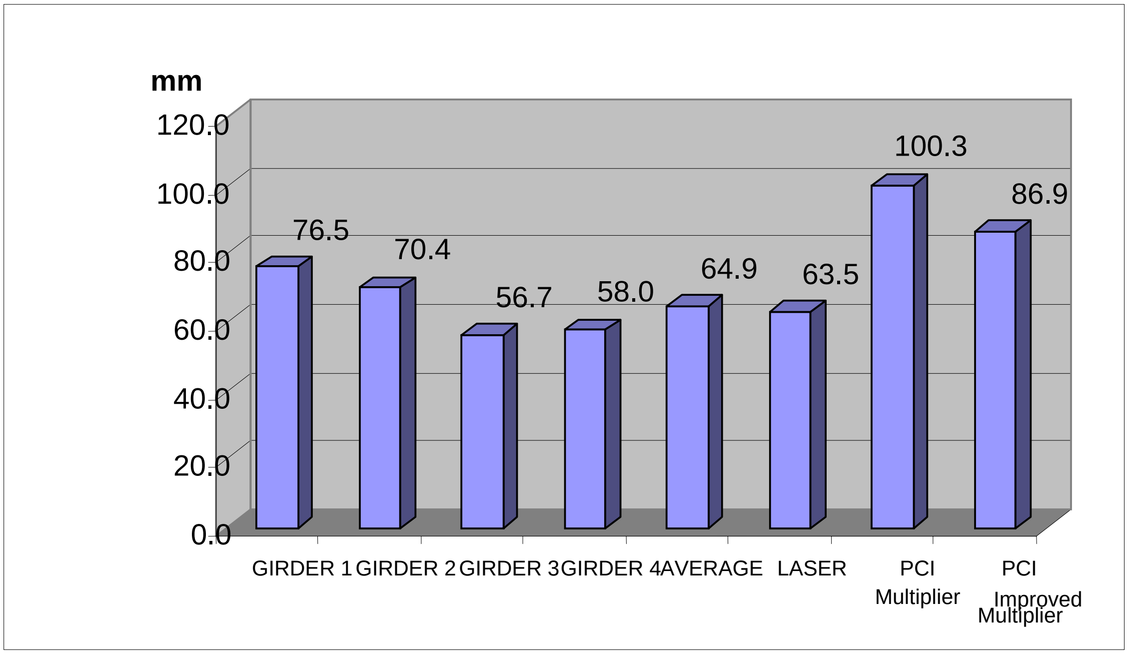

Figure 8. Girder camber at erection.

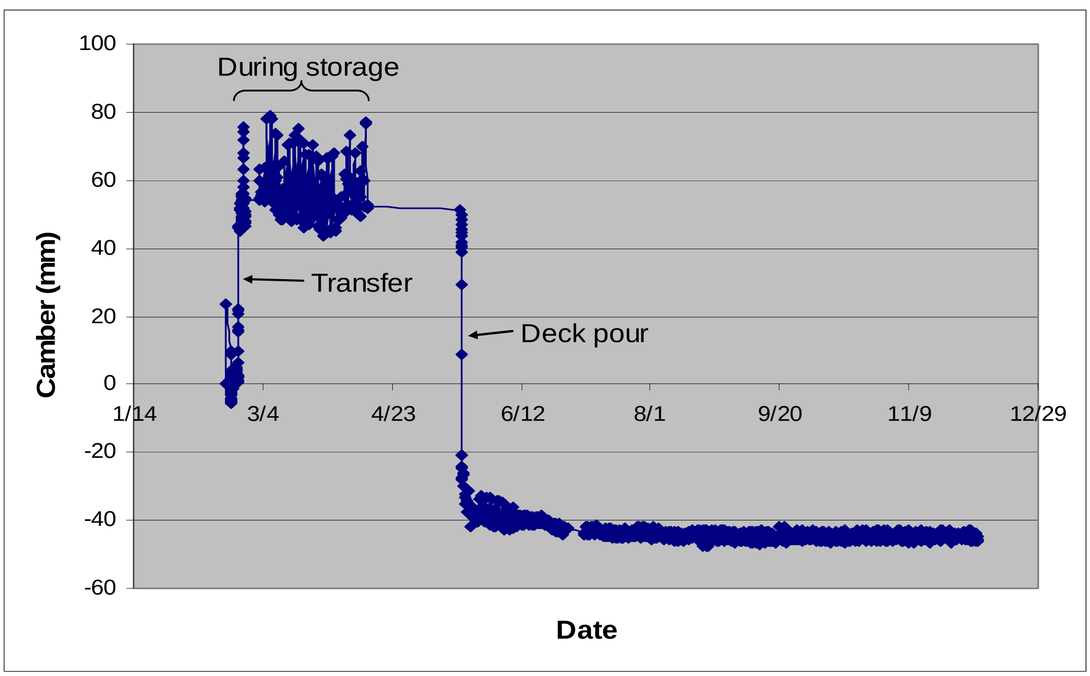

Figure 9. Typical camber history for one girder

6 CONCLUSIONS

The research leads to the following conclusions:

- The PCI general, ACI-ASCE, LRFD, and LRFD lump sum methods are all very conservative in estimating the prestress losses of HPC girders. This can be partially attributed to the lower creep property of HPC.
- The PCI multiplier method and the PCI improved multiplier method over-predicted the camber at erection. Both methods factor in camber growth due to creep. The lack of actual camber growth can be attributed to the lower creep exhibited by HPC.
- Equations need to be developed to better estimate camber and prestress losses for HPC girders.
- A monitoring system can yield very valuable information on material properties as well as structural behavior.

ACKNOWLEDGMENTS

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