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Evaluation of strains and stresses of prestressed girders for Bridge A7957, MO, USA (Field study)

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ABSTRACT: In this contest, bridge A7957 was designed and erected on HWY 50, Missouri State, USA, for in situ investigative studies to evaluate strains and stresses over different stages taken into account the effect of prestress losses. The bridge was designed with a concrete mixture of different mechanical and rheological properties. High strength concrete, high strength-self consolidating concrete and normal strength-self consolidating concrete were used to construct bridge girders. The bridge girders were instrumented with vibration wire strain gages to monitor the strains from concrete casting stage to the service life. The measured stresses (from strain readings) were compared to design limitation adopted by ACI 318-14. Based on the analysis of the test results, the measured compressive stresses at mid-span bottom fiber are higher than design compressive stresses for all the beams at release stage. Also, there are no substantial changes in the compressive strain level after 300 days.

1 INTRODUCTION

Monitoring the stresses within a concrete structure is absolutely necessary for sound design, especially when new concrete [self-consolidating concrete (Daczko (2012), ACI Committee 237R (2007))] is used in the construction. In prestressed concrete girders, stress and strain subject to change over a period of time, during which creep and shrinkage of concrete and relaxation of steel develop gradually. In sequence, concrete modulus of elasticity increases also with its age (Shahawy and Arockiasamy (1996)). Due to the progressive increase of concrete strains with time, considerations should be taken during design members with a new type of concrete.

A limited number of full-scale studies have been conducted to monitor the strain and stress time history of prestressed HS-SCC beams. In a recent study by Myers and Block (2010) at Missouri University Science and Technology, two precast prestressed high-strength concrete (HSC) and HS-SCC bridges were instrumented. The researchers found that the HSC bottom fiber compressive strains at release tended to be about 27% higher than predicted, and the bottom fiber HS-SCC compressive strains at release tended to be about 14% higher than predicted. During erection, they reported that the HSC had an average percentage difference of 60% and the HS-SCC 50% between actual and theoretical strain data (Myers and Block (2010)).

In this study, concrete stresses were not measured directly. Stresses were determined by multiplying measured strains by the measured modulus of elasticity. The objective of this study is to evaluate the strains and stresses developed in the girders with emphasis on types of measurements related to design calculations, as well as measurements that have a significant influence on the overall structural behavior of the bridges and their components. Obviously, strain measurements prior to the release of prestressing strands, immediately after the release of prestressing strand, erection, and service were considered as key stages for this study.

2 BRIDGE DESCRIPTION

A three spans bridge (A7957) with PC/PS concrete girders was utilized in this study. The A7957 Bridge on Highway 50 is located in Osage County, Missouri was designed to be simply supported for dead load and continuous for live load via a CIP deck. The two exterior spans are 30.5 m long and one interior is 36.6 m long. The target 28-day compressive strength of HSC and NS-SCC was 55.2 MPa and the specified release strength was 44.8 MPa. However, HS-SCC had 68.95 MPa target 28-day compressive strength and a release compressive strength of 55.2 MPa. The mixture proportions of each type of concrete are presented in Table 1.

Table 1. Concrete Mixture Proportions

Constituent	Type	Quantity		
		HSC	HS-SCC	NS-SCC
Cement(kg/m^3)	Portland Cement – Type I	475	504	445
Water(kg/m^3)	Potable water	152	166	155
Coarse Aggregate (kg/m^3)	19 mm Crushed stone Grade E Dolomite	1056	---	---
	12 mm Crushed stone Grade E Dolomite	---	795	876
Fine Aggregate (kg/m^3)	Revier Sand	644	850	850
Chemical Admixtures (ml/m^3)	Air Entraining Agent	309	658	658
	Type D Water Reducer and Retard	356	2959	2611
	Type F High Range Water Reducer	665	986	986

3 MONITORING SYSTEM AND STRAIN MEASURMRNTS

HSC, HS-SCC, and NS-SCC girders were produced for spans 1, 2, and 3 of the A7957 Bridge, respectively. They were instrumented to obtain data for the measured strain and temperature. Instrumented girders are named as following: S1-G3, S1-G4, S2-G3, S2-G4, S3-G3, and S3-G4. A total of 86 vibrating wire strain gauges with built-in thermistors (type EM-5) were utilized to measure the strain and temperature for the PC/PS girders. The standard pattern in the mid-span consisted of five gauges over the height of the girder and two more in the slab above the girder. The data from the VWSGs were recorded by a data acquisition system (DAS). The DAS used was Campbell Scientific CR800 box which works wirelessly. Measurements were taken at five-minute intervals. The measuring strain was corrected due to the thermal effect.

4 MATERIAL PROPERTIES

Material property tests were performed on specimens collected from the same batch of concrete girders to have adequate predictions for the stresses. All the tests follow standard ASTM guidelines. A summary of the tests, test methods, and results are presented in Table 2.

Table 2. Summary of Fresh and Hardened Properties Tests and Results

Tests	Member (Span-Girder)					
	S1-G3	S1-G4	S2-G3	S2-G4	S3-G3	S3-G4
Air Content, %	6.9	6.9	7.5	7.6	6	8.3
Slump or Slump Flow, mm	229	229	686	660	673	673
J-ring, mm	n.a.	n.a.	673	635	648	648
Segregation Column, S (%)	n.a.	n.a.	0	0.56	n/a	0
Compressive Strength, MPa	74	67	77	72	69	63
Modulus of Elasticity, GPa	36	35	39	36	36	33
Coefficient of thermal Expansion, με/°C	8.95		9.92		11.3	

5 RESULTS AND DISCUSSIONS

The VWSGs embedded in the concrete girder were utilized to measure strains in all the stages below. Strains are monitored with the temperature at the same locations. Strains are relative to baseline strain reading taken right after placement of concrete. Compressive strains are defined negative while tensile strains are defined as positive in this study. Since only compressive strains were observed in this paper, the maximum compressive strains at bottom fiber mid-span were discussed and compared with theoretical values and ACI Code limits.

5.1 Concrete Strains after Release of Prestress

The concrete strength is relatively low at this stage and checking the stresses is essential in design. Strain readings were recorded before and after the release of the prestress tendons. The stress values were estimated by multiplying the strain values with the mixture's measured modulus of elasticity and compared to the predicted stress (σ design) values demonstrated in Eq. (1). Figure 1 through Figure 3 illustrate strain data points at mid-span of the HSC, HS-SCC, and NS-SCC beams, respectively. A regression line was fit to the measured release strains for each beam. All HSC, HS-SCC and NS-SCC beams had an R^2 range from 0.96 to 0.99. The values are relatively close to 1 indicated that plane section of the beam remained plane. The average curvature caused by prestressing release at mid-span in the HSC, HS-SCC, and NS-SCC beams were 0.53 με/mm, 0.41 με/mm, and 0.52 με/mm, respectively. It is apparent that both HSC and NS-SCC beams exhibited higher curvature than HS-SCC.

$$\sigma_{design} = -\frac{P}{A} \mp \frac{P.e.y}{I} \pm \frac{M_{self}.y}{I} \tag{1}$$

Where P is prestressing force, A is the cross-sectional area, I is the moment of inertia, e is the eccentricity, y is the distance from bottom or top to the centroid, and M is the moment applied due to self-weight or external load. In addition, ninety percentage of the original load at release was assumed for the prestressing force (Nawy (2009)).

Comparison between measured stresses determined from linear regression with design and allowable stresses limited in ACI code (ACI Committee 318 (2014)) is presented in Figure 5. For all beams, measured compressive stresses at mid-span bottom fiber are higher than design compressive stresses. The differences range between 11-49%. However, when comparing with allowable stresses level, the compressive stresses at mid-span bottom fiber meet requirement for most beams expect beams S1-G3 and S3-G3. The measured compressive stresses for S1-G3 and S3-G3 were 7% and 20% higher than allowable stresses, respectively.

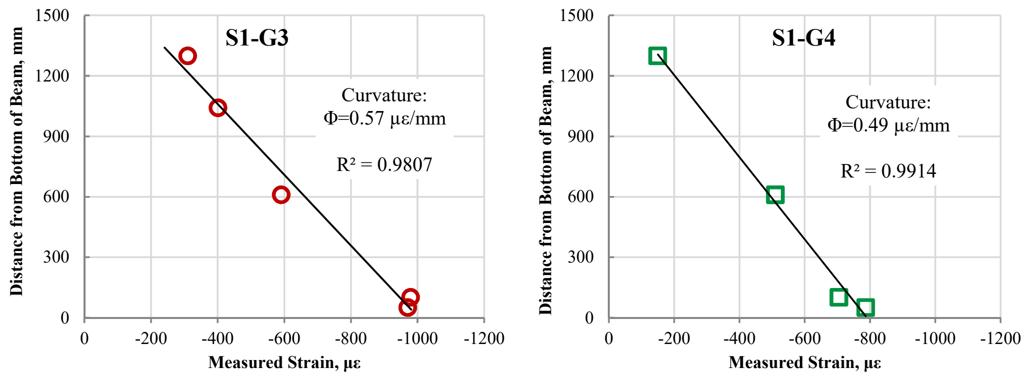
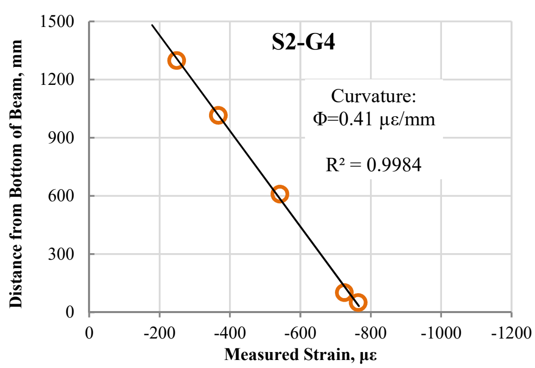


Figure 1. Measured strains at mid-span of HSC girders at release.



* Initial reading for S2-G3 girder was not recorded.

Figure 2. Measured strains at mid-span of HS-SCC girder at release*.

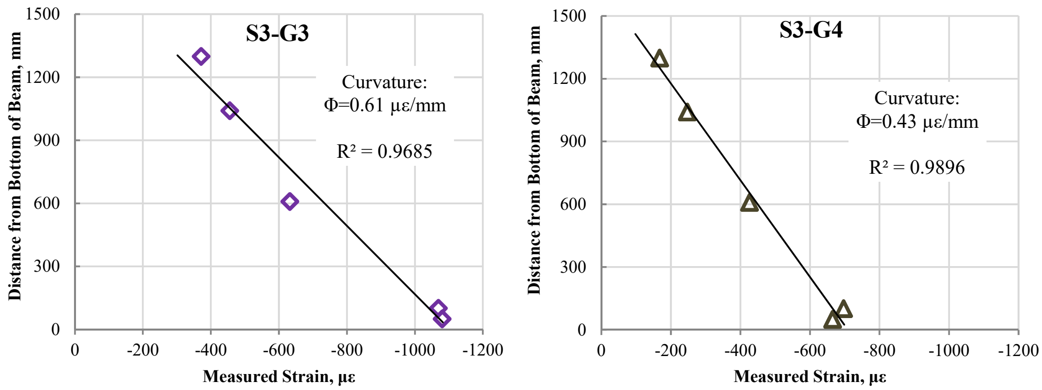


Figure 3. Measured strains at mid-span of NS-SCC girders at release.

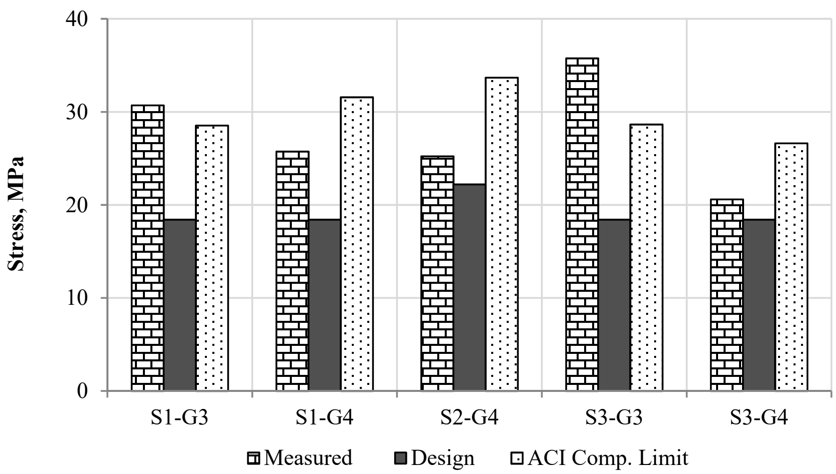


Figure 4. Comparison of stresses at release for bottom fiber mid-span.

5.2 Concrete Strains before and after Deck Placement

Due to time-dependent effects, prestressed concrete girders continue to deform after strand release (Alghazali and Myers (2015), Alghazali and Myers (2015)). The time-dependent losses included creep, shrinkage, and relaxation losses. Concrete strains were measured before and after deck placement using vibration wire strain gauges and the readings were corrected for thermal effect.

The time-dependent strains behaviors at mid-span section for all monitored girders are shown in Figure 5 through Figure 7. It is clear that from the strain profiles there is a significant decrease in the compressive strains for all girders after deck placement. Also, it can be inferred from strains profiles that HSC experienced more curvature growth than HS-SCC and NS-SCC after release and before deck placement.

The casting of the bridge deck and placement of precast deck panels are applied additional load to prestressed concrete beams (Myers and Yang (2005)). Measuring the stresses in this stage is essential for the design of highway bridges under service loads, which it is generally desired to prevent cracking (Gross (1999)). As shown in Figure 5 through Figure 7, the plane sections remained plane in all beams. HS-SCC beams exhibit significant curvature change than HSC and NS-SCC beams because the HS-SCC beam has a length 20% longer than HSC and NS-SCC beams.

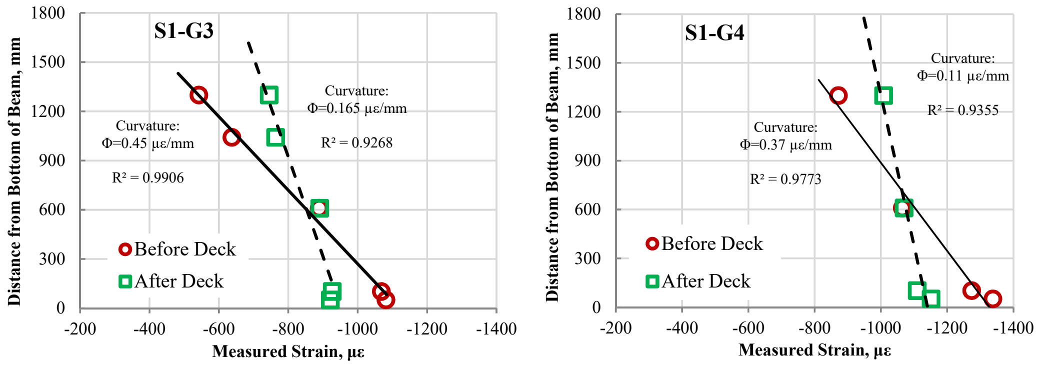


Figure 5. Strain profiles before and after deck placement HSC girders.

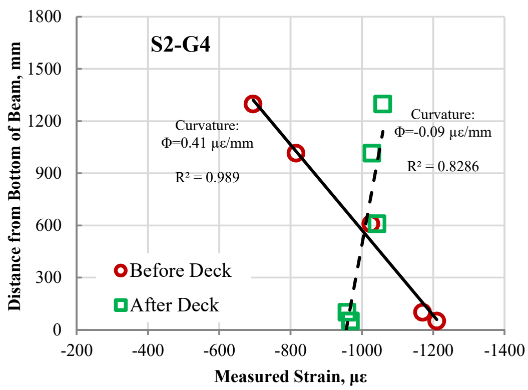


Figure 6. Strain profile before and after deck placement HS-SCC girder.

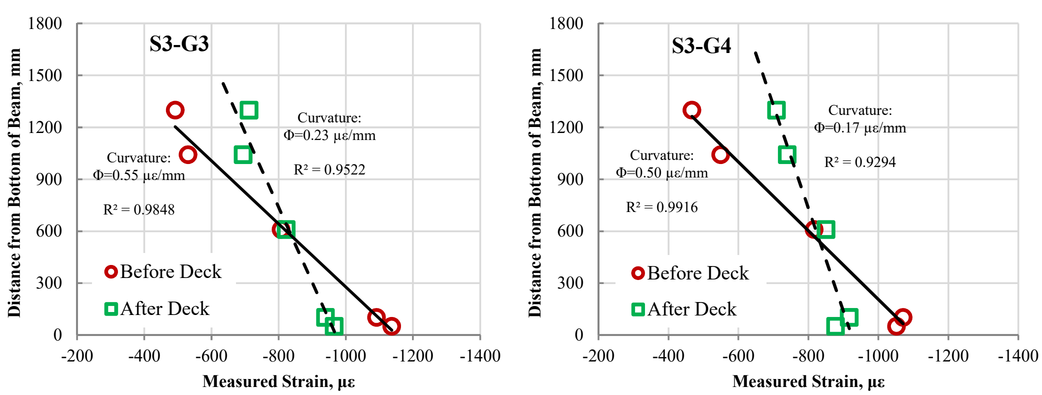


Figure 7. Strain profiles before and after deck placement NS-SCC girders.

5.3 Concrete Strains during Service

Concrete strain history of the bridge girders is illustrated in Figure 10. Since monitoring of the bridge is ongoing, two ages were picked up to evaluate the concrete strain in service life (after 300 days and 900 days) to see the effect of long-term losses on strain change. As shown in Figure 8, there is an increase in compressive strain for all beams due to the creep effect. HSC and NS-SCC beams exhibited higher strains increase than HS-SCC. The stress increase for all beams ranges between 10 to 25%. Obviously, there are no substantial changes in the strain levels after 300 days.

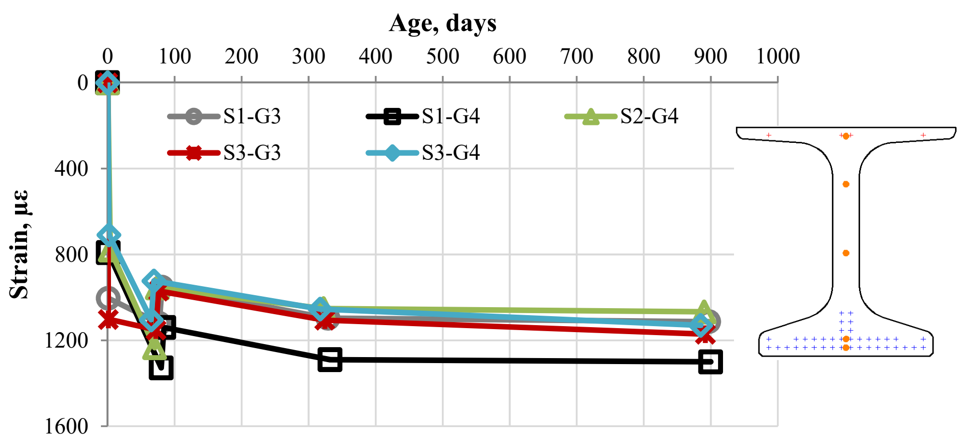


Figure 8. Strains versus time in the concrete in prestressed concrete girders.

6 CONCLUSION

This full-scale study was conducted to monitor strain behavior of prestressed concrete beams constructed with different concrete type. Based on this research, the following conclusions can be drawn:

1. Monitoring system is successfully recording the strains and temperatures in the girders of bridge A7957;
2. Measured strains due to release were fitted linearly. The R^2 values range from 0.96 to 0.99, which exhibits plane sections prior to the release of prestressing remain plane after release;
3. At release, measured compressive stresses at mid-span bottom fiber are higher than design compressive stresses for all the beams. The differences range between 11-49%;
4. HSC beams experienced more curvature growth than HS-SCC and NS-SCC beams after release and before deck placement;
5. In general, there are no substantial changes in the strain levels after 300 days.

7 ACKNOWLEDGEMENT

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