FIELD AND LABORATORY STUDY OF PRECAST COMPOSITE SLAB SPAN SYSTEM

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Abstract

This paper describes a field and laboratory investigation of the Minnesota Department of Transportation (Mn/DOT) Precast Composite Slab Span System (PCSSS) implemented for short to moderate span bridges (20-50ft. range). Advantages of the system include accelerated construction, improved quality control, and reduced impact on the environment compared to cast-in-place (CIP) slab span systems. The field study was conducted on one of the early Mn/DOT implementations over a period of 24 months to investigate the performance of the system relative to design assumptions and the susceptibility of the system to developing reflective cracking. In addition, a two-span laboratory specimen was constructed and load tested to investigate effects of variations in flange thickness, bursting reinforcement, horizontal shear reinforcement, and flange surface treatment.

Introduction

The main motive for this study was to develop a robust system for short to moderate span bridges (20-50ft. range) that could accelerate construction and reduce impact on the traveling public. The Precast Composite Slab Span System (PCSSS) implemented by the Minnesota Department of Transportation (Mn/DOT), shown in Figure 1, was based on the French precast Poutre Dalle slab span system that was identified in a 2004 FHWA International Scanning Tour of Prefabricated Bridge Elements and Systems utilized for accelerated construction. The concept consists of a series of precast prestressed concrete inverted tee bridge elements which also serve as stay-in-place formwork for the cast-in-place (CIP) portion of the deck placed in the field. Besides accelerating construction, the system offers additional advantages including improved quality control and safety, and reduced impact on the environment compared to cast-in-place (CIP) slab span systems.

The objectives of this research were to better understand the performance of the system through a combination of field monitoring and laboratory testing, improve design guidelines, and improve standard details for future projects.

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Field Study

One of the first Mn/DOT implementations of the PCSSS is shown in Figure 2. This three-span bridge system, located in Center City, MN, was instrumented, and subsequently, monitored for 24 months to investigate reflective cracking and continuity over the piers since the deck was cast. Longitudinal and transverse load distribution was evaluated by loading the bridge at designated locations with one and two truck combinations. Figure 3 shows the general layout of the instrumentation used in the Center City Bridge which consisted of both spot-weldable and concrete embedment vibrating wire (VW) gages that were attached to the reinforcement or embedded in the concrete, respectively. The instrumentation was located within the CIP portion of the bridge; the precast sections were not instrumented. The primary instrumentation was located over three of the longitudinal joints between the precast panels to monitor the potential development of reflective cracking, and on the longitudinal reinforcement to investigate the continuity of the system for carrying live load moments.

The data obtained from the field study indicated that cracking initiated in the bridge at the locations of some of the transverse gages in the CIP just above the longitudinal flange joints at midspan and some of the longitudinal gages near the support. The cracking was determined to be the result of environmental and shrinkage restraint effects rather than due to vehicular loading. Figure 4 indicates the initiation of the suspected transverse crack above Joint 1 occurred on April 25, 2006, which had the largest thermal gradient experienced by the bridge since its construction in the fall of 2005. A plot of the daily fluctuations in thermal gradients is given in Figure 5 for the time scale corresponding to Figure 4. As the bridge was constructed in the fall of 2005, the increased thermal gradients were associated with the increased effect of solar radiation that occurred in the spring of 2006.

Figure 6 shows the strains measured in the positive and negative moment reinforcement at the centerline of the east pier. These data show a large strain increase observed in one of the spot-weldable strain gages (i.e., SJ1-C1-1) located on the continuity reinforcement provided in the bottom of the reinforcement cage that was placed between the webs of the precast inverted tee elements. These data suggest the development of a positive moment crack at the pier created at approximately the same date as the suspected cracking above the longitudinal joint between the precast panels. Again, this crack was attributed to the thermal gradient effect caused by solar radiation. It was found in the course of this study that the environmental loading effects caused much larger strains than those due to vehicular loading. In addition, the thermal gradient effect had a much larger impact on the magnitude of the restraint moment at the pier than the time-dependent effects due to creep and shrinkage.

Laboratory Study

In addition to the field study, a two-span PCSSS bridge was constructed in the University of Minnesota Structures Laboratory. Figure 7 shows a conceptual plan view of the two-span laboratory bridge which lists the variables that were investigated in the laboratory bridge specimen. The options designated as “original” in the figure indicate the details that were identical to those implemented in the Center City Bridge.

Primary considerations in selecting the modifications to be implemented in the laboratory specimen were improving system performance and easing fabrication to reduce labor cost and fabrication time. Once potential modifications were identified, a parameter study was performed to determine how to lay out the test specimen to facilitate comparison between the original and modified designs. The eleven proposed modifications originally considered are summarized in Table 1 which also indicates the effects which might be impacted by the proposed modification, as well as the potential locations considered for modification. Descriptive images of the proposed modifications are given in Table 2 which shows a comparison of the proposed versus the original details. Figure 7 shows the final parameters chosen for study. As a control, the west end of Beam 2S of the laboratory specimen was identical to the precast sections in the Center City Bridge.

The laboratory specimen was instrumented with 30 vibrating wire (VW) strain gages, 344 resistive strain gages, and 16 linear variable differential transformers (LVDT’s). This included the 80 resistive strain gages in the precast sections that were read at the precast fabrication plant. Primary behaviors investigated with the laboratory bridge specimen included reflective cracking, transverse load distribution, continuity over the pier, restraint moment, and prestress losses. Other issues including bursting, effects of cyclic loading, and composite action were investigated as part of an NCHRP companion study (NCHRP 10-71 *Cast-in-Place Concrete Connections for Precast Deck Systems*).

The precast elements incorporated in the laboratory bridge specimen were 7-days old when the CIP was cast to simulate what was considered to be the situation that would produce the largest positive restraint moments due to time-dependent effects. Such restraint moments are caused by differential shrinkage and creep between the precast and CIP. When the CIP is cast on the precast at an early age, the creep of the precast concrete dominates the time-dependent response causing shortening of the precast concrete section which promotes an upward deflection. This deformation causes positive moments to develop at the pier to provide continuity across the support. The younger the precast concrete is at the time of casting the CIP, the larger this effect. A precast age of 7-days was deemed to be the youngest feasible age at which the CIP could be placed. If the CIP is cast when the precast concrete is at an advanced age (e.g., 3 months old), the differential shrinkage between the CIP and precast concrete produces the opposite effect (i.e., downward deflection and development of negative restraint moments).

Load cells were used to monitor the end reactions in the two-span laboratory bridge specimen over a period of approximately 250 days. The changes in end reactions were used to determine the positive restraint moments developed at the pier. The results were compared to two models from the literature, the PCA method (Freyermuth 1969) and the P-method (Peterman and Ramirez 1998). The PCA method was used by Mn/DOT in the designs of the PCSSS bridges in the field. Both the PCA and P-methods overestimated the positive restraint moment measured in the laboratory specimen. However, when the creep and shrinkage models used in these methods were corrected using the measured creep and shrinkage strains from concrete samples, the P-method provided a good estimate of the observed positive restraint moment while the PCA method predicted a large, negative restraint moment. This indicated that the assumption of CIP shrinkage restraint assumed by the P-method (neglected by the PCA method) was valid as the unrestrained CIP shrinkage resulted in the predicted negative restraint moment. Also, strains from companion creep cylinders showed that the creep charts from the PCA method over-predicted the creep strains by 294% compared to 185% for the equations in the AASHTO LRFD Specifications (2004).

After the monitoring period was over, the load cells were removed to allow for larger loads to be placed on the laboratory specimen during actuator loading. Both spans were tested at midspan with four loads. Three patch loads of 35.5 kips were used, one at the center of each of the two precast sections (not simultaneously) and one over the longitudinal flange joint. The fourth load was applied with two actuators and a spreader beam to give a line load across the width of the specimen with a load of 140 kips as shown in Figure 8.

Comparison of Selected Results from the Laboratory and Field Studies

In the laboratory specimen, loading of the longitudinal joint with the patch load resulted in negligible midspan transverse strains of only 15 and 25 με in Spans 1 and 2, respectively, which were consistent with the small transverse strain magnitudes observed in the truck tests of the field bridge (i.e., transverse strain of only 7 με was measured directly under the wheel load in Joint 2 during the truck test at the Center City Bridge). No tensile stresses were observed over the web corners in the field or laboratory study with either chamfer condition, indicating that reflective cracking from the web corners did not appear to be a concern for the Mn/DOT PCSSS.

Curvatures across the width of the laboratory specimen during the patch load tests were more uniform in Span 1 with the 3 in. flange thickness than in Span 2 with the 5 ¼ in. flange thickness, indicating that the reduced flange thickness improved system performance with respect to transverse load distribution. However, the transverse curvature distribution measured from the truck test at the Center City Bridge, where all precast sections had the original 5 ¼ in. flange thickness, fit well with a simple isotropic plate model, indicating that the assumption of a monolithic slab superstructure used to obtain distribution factors for the original design was valid. Both the field and laboratory study found that the distribution factor used by Mn/DOT in the original design was conservative and that a wider effective width participated in carrying the loads to the supports. This included the case at the Center City Bridge when the two trucks were side by side at midspan of the center span where the Mn/DOT design assumption was both conservative and reasonable.

Recommendations

Although the Center City Bridge and Span 2 of the laboratory specimen with the original 5 ¼ in. flange performed well, the test results indicated that the reduction in flange thickness to 3 in. improved transverse load distribution. Also, there was no indication that the reduced flange was not durable enough for transportation and construction. Therefore the 3 in. flange is recommended in future implementations of the Mn/DOT PCSSS.

It was difficult to determine the effects of the smooth flange surface on reflective cracking, considering that the reduction in flange thickness would have a larger effect. Also, the smooth flange surface did allow for easier removal of the forms during fabrication, as expected. However, the effect of the smooth flange surface on composite action as the bridge is loaded to ultimate should be considered when that research is concluded at which point a recommendation can be made.

As transverse tensile strains over the web corners were not observed under any conditions, no change the original chamfer that was specified at ¾ in. by ¾ in. and as built at 1 in. by ½ in is recommended.

The equation used to obtain distribution factors for the original design from the AASHTO LRFD Specification (2004) 4.6.2.6 was reasonable and conservative and it is recommended that its use be continued.

The original design assumptions of full continuity over the pier and of a monolithic slab superstructure for load distribution appeared to be valid, and it is recommended that their use be continued.

The P-method better predicted positive restraint moments in the laboratory specimen than the PCA method, so it is recommended that the P-method replace the PCA method in future designs or that the PCA method be modified such that CIP shrinkage restraint is considered and another method for creep and shrinkage prediction, such as AASHTO LRFD Specifications (2004) 5.4.2.3, replaces the charts in the PCA method paper (Freyermuth 1969).

In all, the results of the field and laboratory study confirmed the durability of the Mn/DOT PCSSS, which has been shown to be a practical, economical accelerated construction alternative to cast-in-place slab construction. It has also been shown to be a viable alternative for retrofit of existing bridge systems as shown in Figure 9. This retrofit was performed by maintenance crews on Bridge 6679 in the summer of 2006.

Acknowledgments

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References

American Assoc. of State Highway and Transportation Officials. 2004. AASHTO LRFD Bridge Design Specifications, Third Edition. Washington, D.C.: American Assoc. of State Highway and Transportation Officials.

Freyermuth, C.L. 1969. Design of Continuous Highway Bridges with Precast, Prestressed Concrete Girders. Journal of the Prestressed Concrete Institute 14(2), 14-39.

Peterman, R.J., and Ramirez, J.A. 1998. Restraint Moments in Bridges with Full-Span Prestressed Concrete Form Panels. PCI Journal 43(1), 54–73.

Unit Conversion

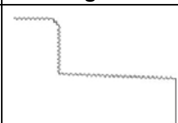
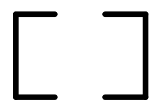
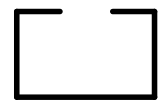
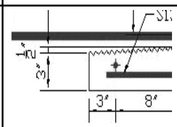
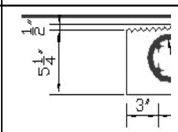
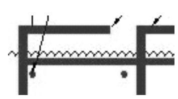
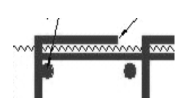
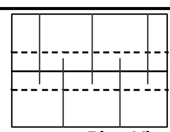
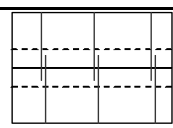
1 in. = 25.4 mm
1 k = 4.448 kN

Table 1 Proposed modifications to the laboratory bridge specimen

			Effects						Locations	
			Reflective Cracking	Transverse Load Distribution	Longitudinal Flexural Behavior	Composite Action	Bursting	Constructability/ Economy	Potential	Recommended
Parameter	A	Smooth Flange Surface	+	?	-	- -		+ +	1 vs. 2 or 1W vs. 1E	1 vs. 2
	B	Increased Stirrup Spacing			-	- -		+ +	1 vs. 2 or 1 and 2N vs. 2S	1 vs. 2
	C	Decreased Flange Thickness	+ +	+ +	+	+			1 vs. 2	1 vs. 2
	D	Increased Clear Spacing Under Hooks			+	+ +			1 vs. 2 or 1 and 2N vs. 2S	1 vs. 2
	E	Staggering Hooks over Flanges	?	?					1 vs 2	None
	F	Separating Reinforcement into Two Pieces						+ +	1 vs. 2 or All	1 vs. 2
	G	Decreased Bursting Reinforcement					-	+	Each End	Each Beam
	H	Decreased Longitudinal Deck Steel			?			+	N vs. S	N vs. S
	I	Decreased Transverse Deck Steel	?	?				+	1 vs. 2	1 vs. 2
	J	Increased Chamfer	+	?					N vs. S	N vs. S

Expected Change in Performance			
+ +	**Greatly improve performance**	- -	**Greatly impair performance**
+	**Improve performance**	-	**Impair performance**
?	**Unknown change in performance**	(blank)	**No expected change**

Table 2 Descriptive images of proposed modifications

		Proposed	Original			Proposed	Original
A	Smooth Flange Surface			F	Separating Web Reinforcement into Two Pieces		
B	Increased Stirrup Spacing	24 in.	12 in.	G	Decreased Bursting Reinforcement	#4 Stirrups @ 2 in. or #3 Stirrups @ 2 and 4 in.	2 #5 Stirrups @ 2, 4, and 6 in.
C	Decreased Flange Thickness			H	Decreased Longitudinal Deck Steel	#6 @ 6 in.	#7,#7,#8 @ 12 in.
D	Increased Clear Spacing Under Hooks			I	Decreased Transverse Deck Steel	#4 @ 12 in.	#5 @ 12 in.
E	Staggering Transverse Hooks over Flanges	 Plan View	 Plan View	J	Increased Chamfer @ Web Corner	1-1/2 in.	3/4 in.

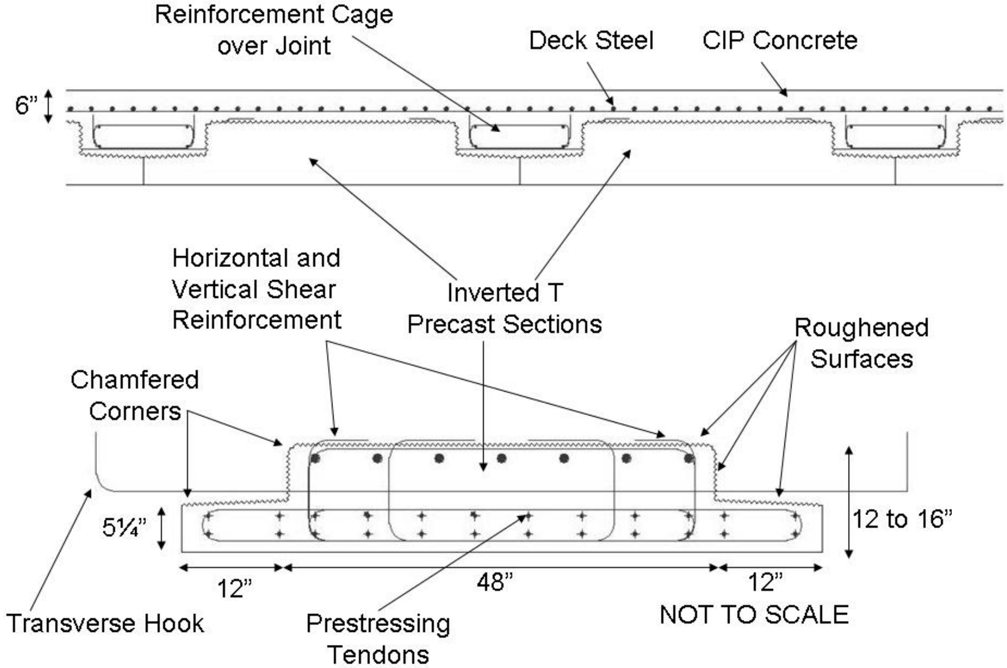


Figure 1 Conceptual cross section of Mn/DOT Precast Composite Slab Span System (PCSSS)

Figure 2 Photograph of the Center City Bridge

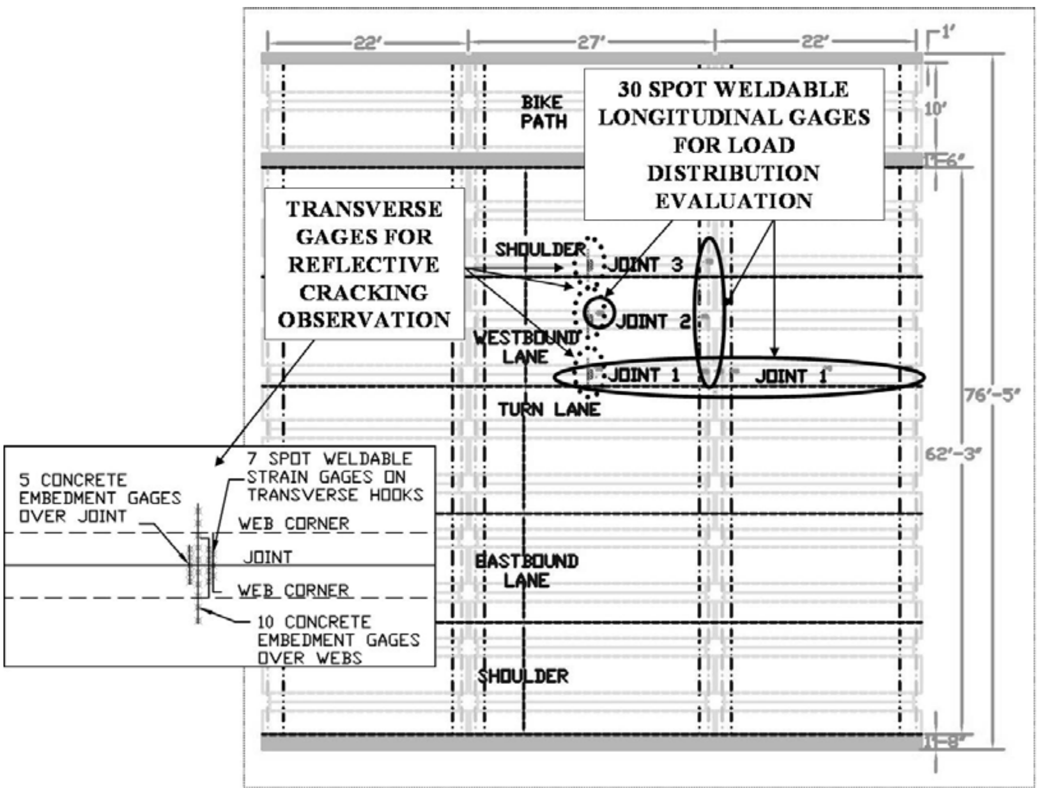


Figure 3 General layout of Center City Bridge instrumentation

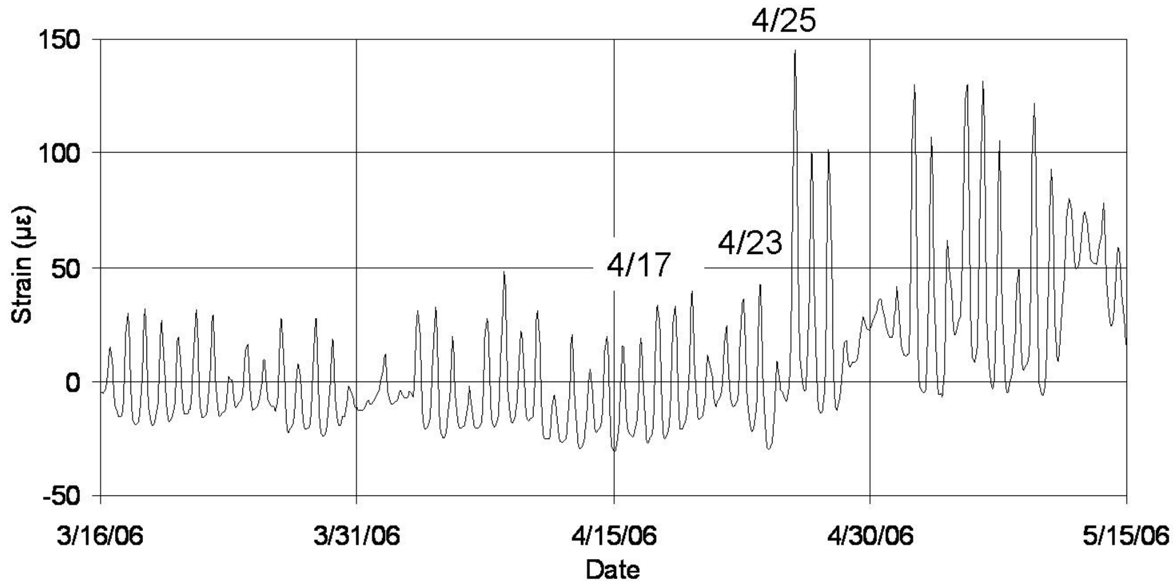


Figure 4 Transverse strains immediately over Joint 1 at midspan of the center span of the Center City Bridge

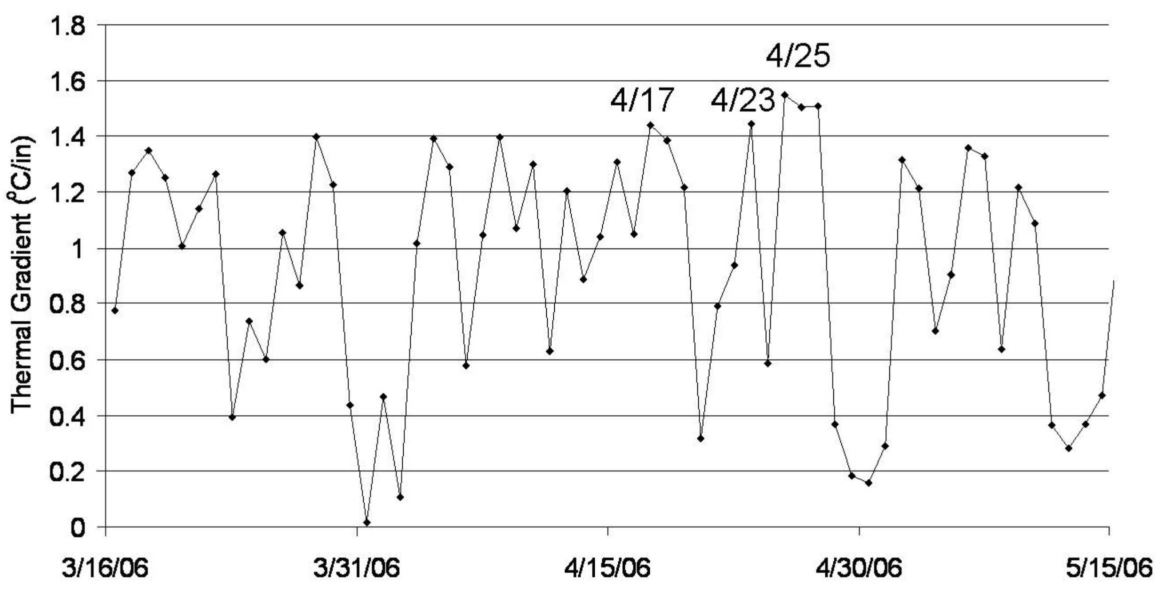


Figure 5 Daily fluctuations in thermal gradients at midspan of the center span of the Center City Bridge

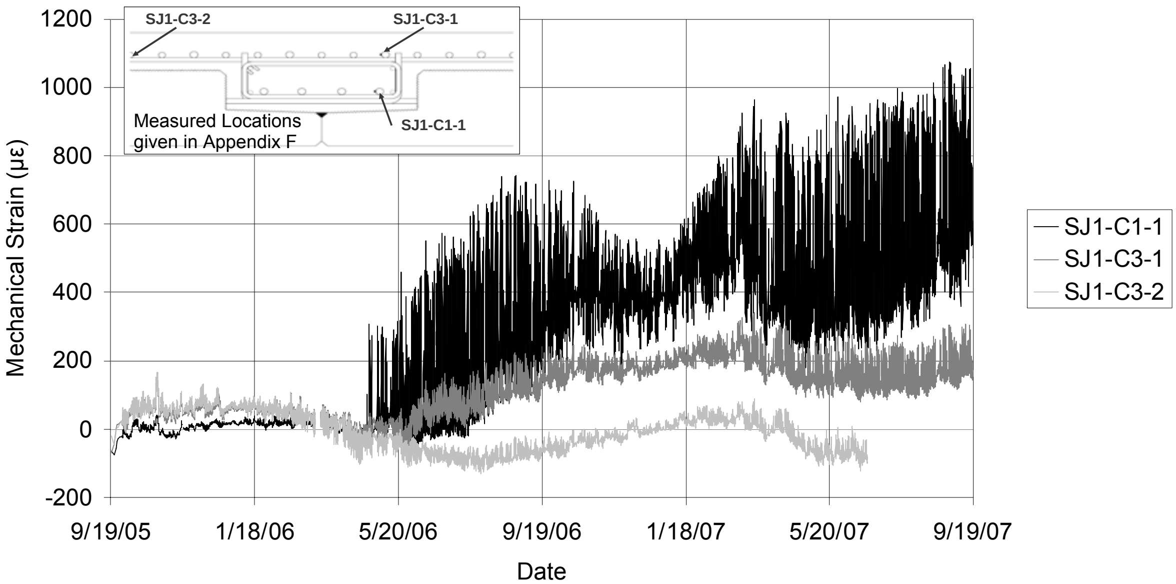


Figure 6 Strains in the positive and negative moment reinforcement at the center line of the east pier

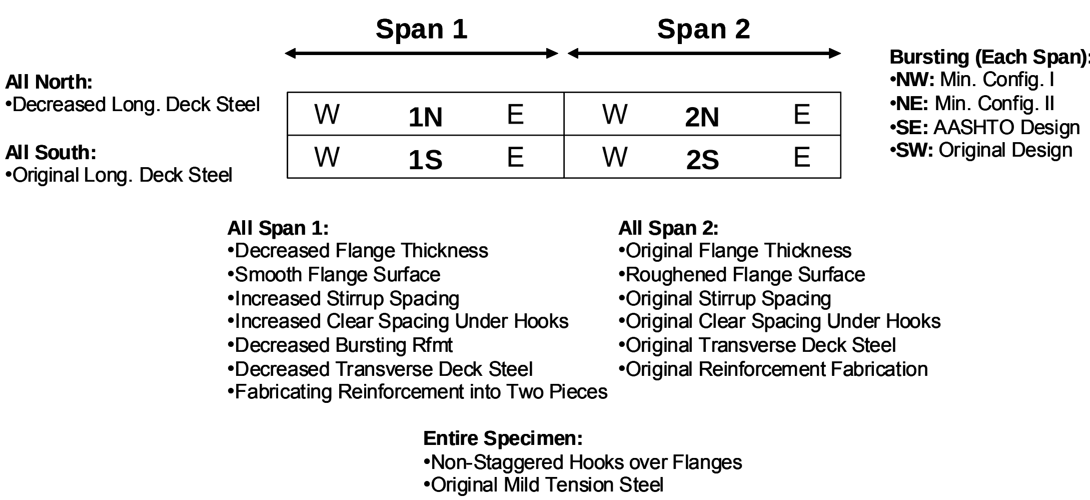


Figure 7 Conceptual layout of laboratory bridge specimen

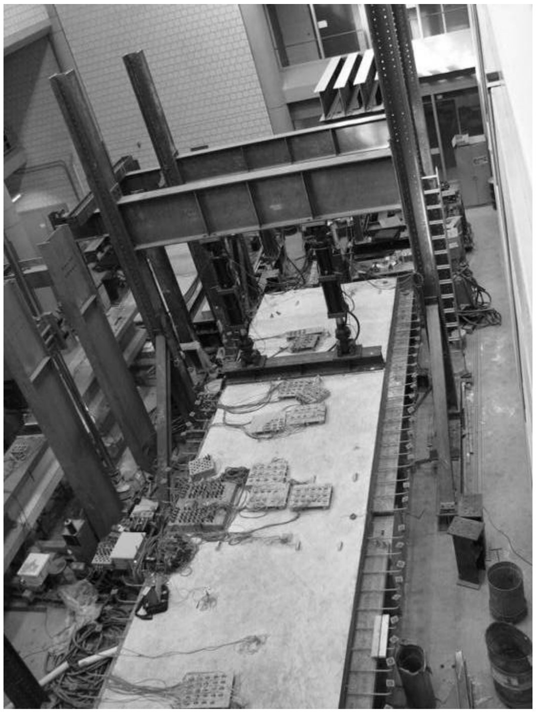


Figure 8 Laboratory bridge specimen during spreader beam test of Span 1

Figure 9 Maintenance crews retrofitting Bridge 6679 with PCSSS panels