Connecticut Permanent Long-Term Bridge Monitoring Network Volume 6: Monitoring of a Continuous Plate Girder Bridge with Load Restrictions – Route 15 Over the Housatonic River in Stratford (Bridge #761)

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16. Abstract

This report describes the instrumentation and data acquisition system for monitoring of a continuous span steel plate girder bridge with a composite concrete deck located on a limited access highway. The monitoring system was developed and installed on the bridge. The limited traffic loading on the bridge resulted in significant challenges to provide high fidelity measurements of the bridge response. Additionally, lessons learned from the other bridge monitoring installations in Connecticut and around the country and the world were considered here. Issues with low signal-to-noise ratios and aliasing were subsequently identified as needing to be addressed prior to any data collection for vibration-based monitoring of this bridge. Further, the inclusion of temperature sensors is identified to provide a measurement of environmental conditions to correlate measured responses and potential calculated damage measures.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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Monitoring of a Continuous Plate Girder Bridge with Load Restrictions – Route 15 over the Housatonic River in Stratford (Bridge #761)

INTRODUCTION

The Sikorsky Bridge (NBI # 761), located in the towns of Stratford & Milford, Connecticut is so named because of its proximity to the Sikorsky aircraft plant in Stratford, Connecticut. It carries Route 15 over the Housatonic River. Figure 1 shows the aerial view of the bridge. A project to replace the existing structure began in 2000, and the new bridge was opened to traffic in 2003. The total length of this bridge is 548.6 m (1800 ft), which is divided into five continuous spans, supported by structural steel plate girders with a composite concrete deck. The girders are 3.5 m (11 ft. 6 in.) deep except near the piers where they have haunches and are at a maximum depth of 4.8 m (15 ft. 9 in.). The substructure is made up of post-tensioned pier caps, concrete columns (2 columns per pier cap), and concrete footings resting on six-foot diameter drilled shafts which are embedded in rock sockets. The width of a typical span is 40.09 m (131 ft. 6 in.). There are six lanes having left and right shoulders along with a 3 m pedestrian walkway/bikeway. The bridge has a concrete deck with an asphaltic wearing surface.

Figure 1. Aerial View of the Sikorsky Bridge

Route 15 travelling over the bridge is classified as a limited access highway. Commercial vehicles, trailers, towed vehicles, busses, any vehicle that exceeds 7500 pounds, and any vehicle that exceeds twenty-four feet in length, seven feet six inches in width, and/or eight feet in height are prohibited from Route 15 (Connecticut DOT). Thus, traffic excitation on the Sikorsky Bridge is mainly due to cars.

OBJECTIVES AND SCOPE OF STUDY

The objective of this study was to use the initial bridge monitoring system developed for this load restricted bridge to expand the knowledge of the development and implementation of structural health monitoring systems on a series of bridges in Connecticut. The experiences from this particular bridge lead to the development of a set of specifications for highway bridge structural health monitoring data (Trivedi, 2009; Trivedi and Christenson, 2009; Prusaczyk, et al., 2011; Prusaczyk, 2011). This report describes the bridge monitoring system installed and provides an analysis of the data provided by this monitoring system.

INSTRUMENTATION AND DATA ACQUISITION

The bridge monitoring system was installed in 2007. The long term monitoring system consists of 4 LVDTs (linear variable differential transformers) as displacement transducers, 22 accelerometers, 6 tilt-meters and 16 strain gages to measure expansion joint movement, bridge accelerations, pier tilts and beam strains, respectively. These sensors are located along the length of the bridge as indicated in Figure 2.

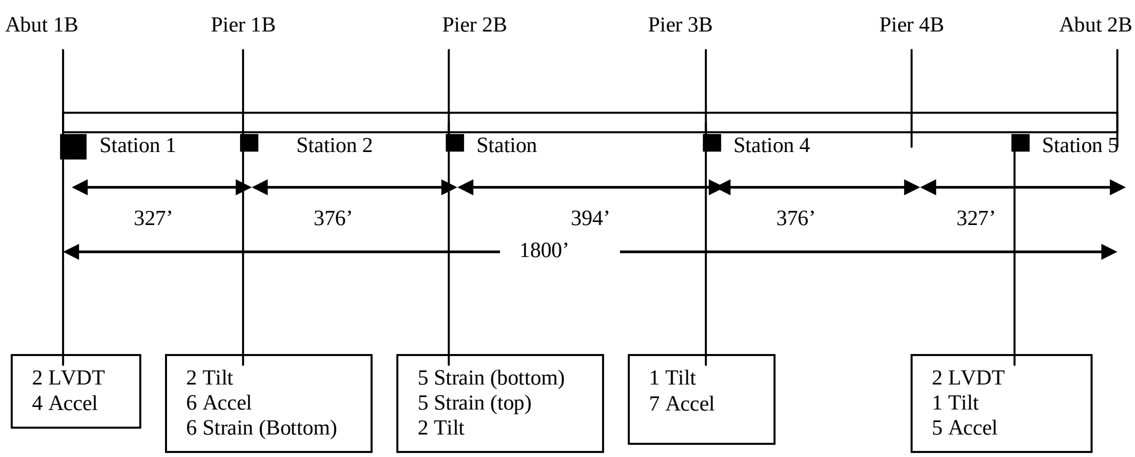

Figure 2. Sensor Locations along the Sikorsky Bridge

The accelerometers installed are PCB Inc. model 392c, which are integrated circuit piezoelectric (ICP), seismic, and uniaxial. Their measurement range is 2.5 g peak with a bandwidth of 0.01 Hz to 1200 Hz. The full bridge strain gages are manufactured by Hitec Corporation and have a

350 Ohm gage resistance. The LVDTs have a measurement range of 7.11 cm (2.8 inches) and are intended for static measurements. They are manufactured by Unimeasure. The uniaxial tilt meters have a measurement range of ± 3 degrees and are also intended for static measurements. Applied Geomechanics manufactures these tilt meters.

There are five data acquisition boxes located along the length of the bridge collecting signals from a number of sensor channels post any signal conditioning of these sensors. The signal conditioners are DI-75B 5B module expanders manufactured by DATAQ. No anti-aliasing (AA) filters are present, and gain settings are in steps of 10, 5, 2.5 & 1.25 V. The 14-bit data acquisition units (DI-720 by DATAQ) digitize the analog signals. The data acquisition units are connected to the main computer through Ethernet Data and are accessed and analyzed remotely.

ANALYSIS OF MONITORING SYSTEM

Prior to monitoring of the bridge, an analysis of the bridge monitoring system was conducted. It was identified that the as-built system has various issues needing to be addressed. These are summarized below.

- Anti-aliasing filters are not present on any of the accelerometers' measurements. Aliasing is observed on these measurements. As a result, the acceleration data is corrupted and not useful for any monitoring purposes. Anti-aliasing filters should be installed prior to digitizing the acceleration signals.

- All measurements are characterized by low signal-to-noise ratios. This is a result of the long cable lengths required prior to digitizing the sensor signals, coupled with small measured responses and a 14-bit analog-to-digital converter in the data acquisition module. Multiple data acquisition modules were initially used to minimize the cable lengths as best as possible, and this cannot likely be further improved from the original design. The sensors, in particular accelerometers, can potentially be switched out for more sensitive accelerometers, with a smaller range. Additionally, the 14-bit analog-to-digital converter could be upgraded to a 16-bit or 24-bit converter.

- Temperature measurements on the bridge are not available. While the full-bridge strain sensors have temperature compensation, the displacement measurements of the abutment would be further enhanced with a temperature measurement. Further, it has been shown that environmental conditions, mainly temperature, can affect various calculated damage measurements in bridge health monitoring. Surface mounted temperature transducers are suggested to enhance the existing monitoring system.

CONCLUSIONS

A bridge monitoring system was successfully installed on a continuous span steel plate girder bridge with a composite deck and load restrictions. An analysis of the bridge monitoring system identified issues with aliasing, low signal-to-noise ratios and no temperature measurements. Prior to monitoring the performance and structural health of the bridge, these issues will need to be resolved.

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The U.S. Government and the Connecticut Department of Transportation do not endorse products or manufacturers.

REFERENCES

Prusaczyk, S., Christenson, R. E., DeWolf, J. and Jamalipour, A. "Proposed Data Specifications for Bridge Structural Health Monitoring Sensor Data," Structures Congress & Exposition, Las Vegas, NV, May 2011.

Prusaczyk, S. (2011). "Data Qualification for the Connecticut Bridge Monitoring Network," thesis presented to the Graduate School, University of Connecticut, Storrs, Connecticut, in partially fulfillment of the requirements for the Master of Science Degree.

Trivedi , H. (2009). "Development of a Data Qualification and Error Quantification Procedure for Bridge Monitoring Systems in Connecticut," thesis presented to the Graduate School, University of Connecticut, Storrs, Connecticut, in partially fulfillment of the requirements for the Master of Science Degree.

Trivedi, H. and Christenson, R. E. "Data Qualification and Error Quantification for Bridge Monitoring Systems in Connecticut," International Workshop on Structural Health Monitoring, Stanford University, Stanford, CA, September 2009.