Remote Monitoring of Fatigue Sensitive Details on Steel Bridges

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Problem statement and significance

Michigan Department of Transportation performs inspections of over 200 steel bridges with fatigue-sensitive details that are categorized into two groups:

(a) **load-induced fatigue and** (b) **distortion-induced fatigue.**

The details that are prone to load-induced fatigue can be identified using codified methods and basic structural analysis. The distortion-induced fatigue can result in due to many reasons. Identification of these details requires reviewing maintenance records and inspection records, and performing a thorough inspection and refined analysis.

Bridge safety inspection is performed biennially by visual inspection supported by hands-on non destructive evaluation (NDE) (Figure 1). However, real-time structural health monitoring is required to monitor stresses, detect fatigue events, and characterize fatigue cracks (Figure 2). The data acquired can also be used to evaluate the performance of retrofits such as fatigue crack stop drills (Figure 3). Considering the age of existing bridges (Figure 4) and increased traffic, real-time monitoring will facilitate timely inspection and maintenance for early detection and prevention of unexpected failure events.

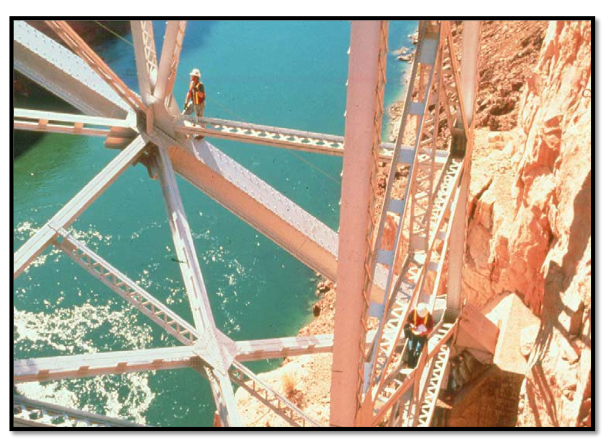


Figure 1. Conventional bridge inspection
(Source: http://www.cedengineering.com)

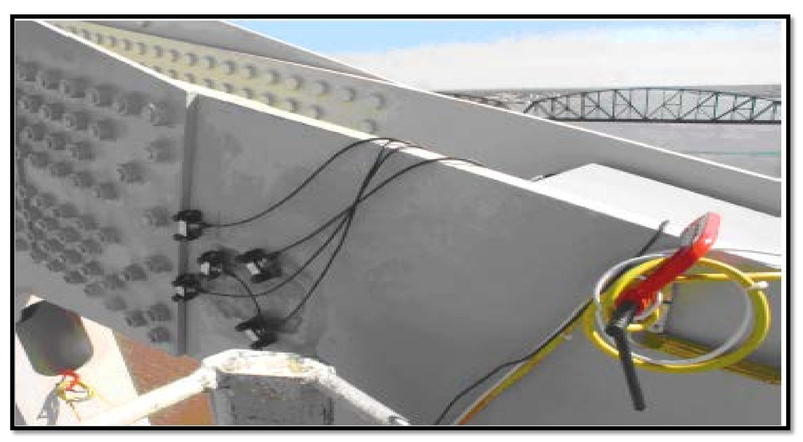


Figure 2. Remote bridge health monitoring for fatigue
(Source: Kosnik 2008)

Figure 3. Retrofitted fatigue cracks
(Source: Zhao et al. 2013)

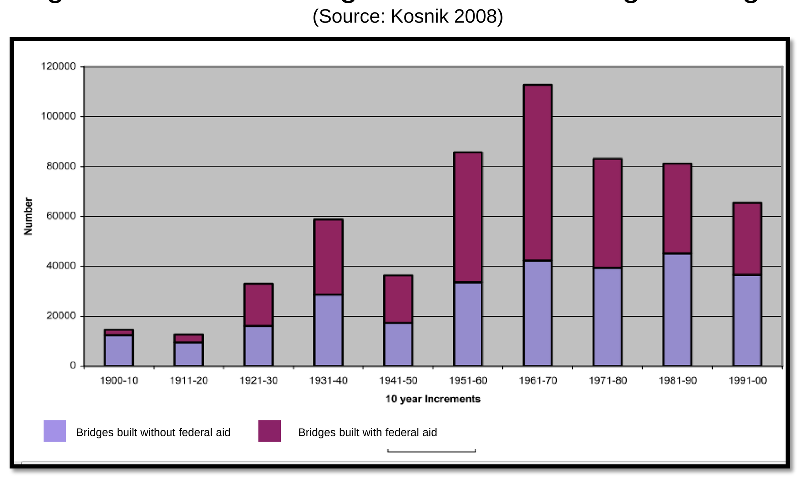
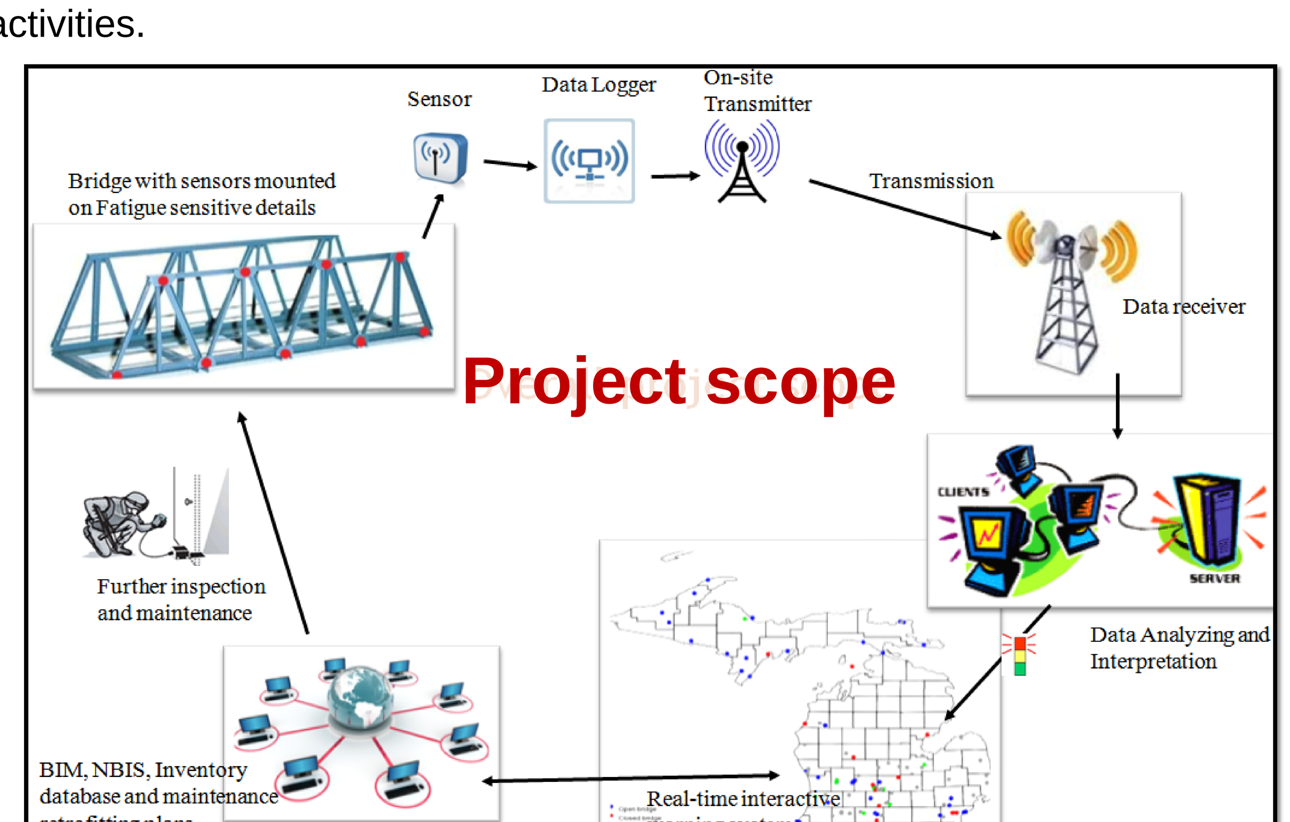


Figure 4. Bridges built since 1900
(Source: http://www.cedengineering.com)

Objectives and scope

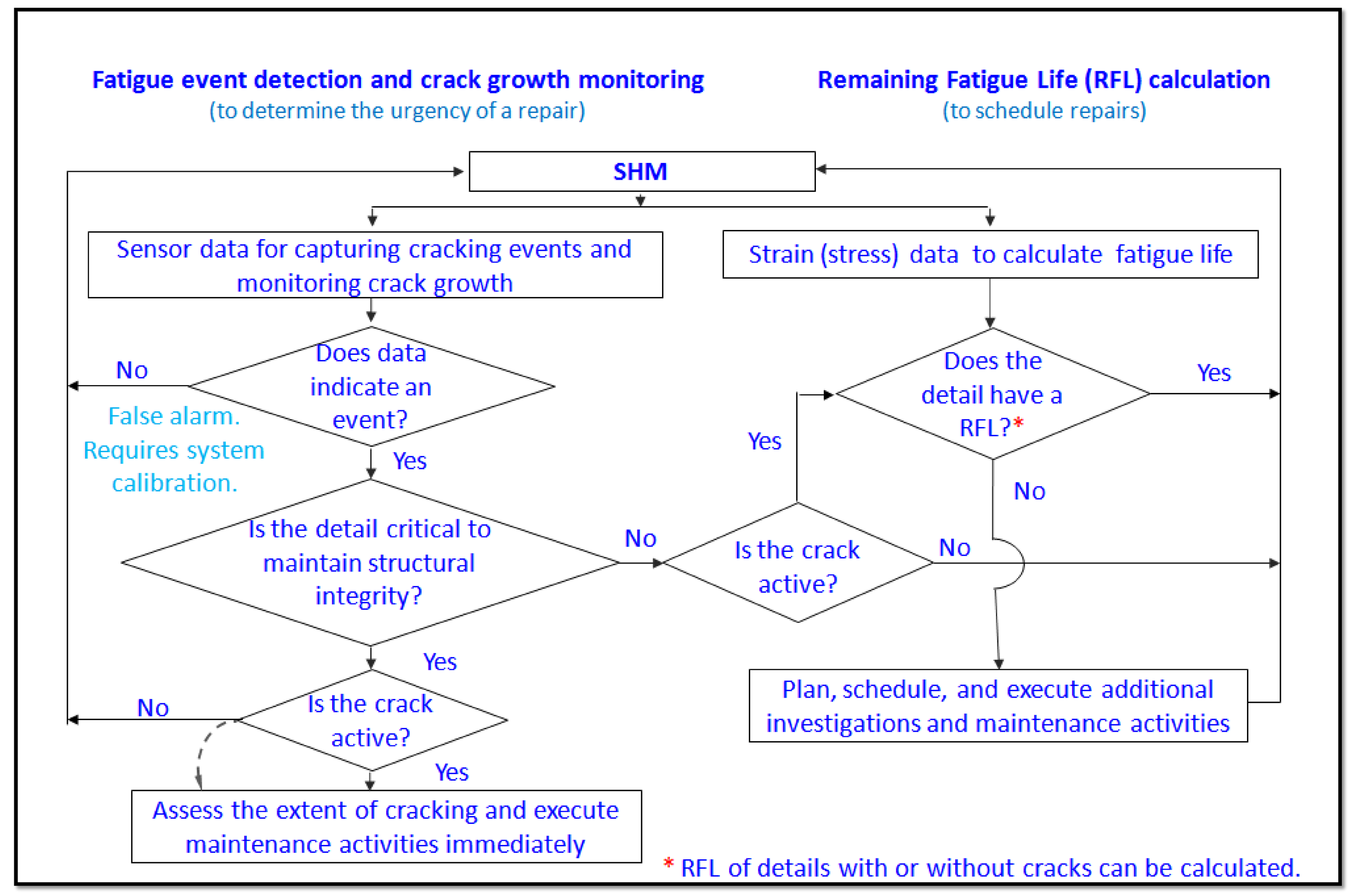
1. Review and identify commercially available technologies for remote monitoring of steel bridges having fatigue sensitive details.
2. Select an appropriate bridge with fatigue-sensitive details for monitoring.
2. Identify fatigue-sensitive details and stress concentrated areas using finite element (FE) modeling and analysis.
3. Design sensor network arrays with multiple sensors to capture damage events and to monitor stress states at such details in short and long term to gather real-time data.
4. Perform sensor data acquisition and analysis.
5. Calculate/predict remaining fatigue life of such details to streamline maintenance activities.



Methodology

Technology selection → FE modeling and analysis → Structural health monitoring (SHM)

SHM flowchart



Technology selection

Table 1. Commercially available technologies for fatigue monitoring

Fatigue event detection (crack initiation or crack propagation monitoring)	**Acoustic emission sensors**
	Electro chemical fatigue sensor
	Ultrasonic guided wave sensors
Existing fatigue crack detection	Ultrasonic testing method
	Eddy current method
Strain measurement	**Strain gauges**
	Fiber optic sensors

Acoustic emission (AE) sensors for fatigue event detection

Working principle:

- Detect rapid release of energy in the form of transient elastic waves

Applications:

- Crack initiation detection
- Crack growth detection

Capabilities:

- Surface and subsurface (hidden) crack monitoring
- Inspection of inaccessible area
- Do not require access to the cracked area once mounted in a effective array network
- Nature of the origin of the damage/crack can be obtained with the location (need to design an array of sensors within the range of detection based on the AE signal attenuation)
- Continuous remote monitoring
- Sensor data can be combined with external parametric sensors such as strain, displacement, temperature, etc.

Technology implementation plan

The field monitoring system for this project comprises of acoustic emission (AE) and strain sensors that are selected after reviewing capabilities and limitations of the state-of-the-art technologies for fatigue monitoring.

Technology implementation involves installing these sensors at fatigue-sensitive locations, which are identified from inspection and confirmed by the preliminary finite element (FE) analysis of an I-girder bridge with partial depth intermediate diaphragms, to monitor stresses, detect fatigue events, and characterize fatigue cracks.

FE modeling and analysis

The objective of the analysis is to identify the stress levels at the potential fatigue-sensitive details of the selected I-girder bridge superstructure. The bridge details are as follows:

- Located in Stevensville, Michigan, and carries I-94 over Puetz Road.
- Bridge was built in 1961.
- 1996 Traffic: ADT 33,500 (Truck: 27%), 2015 Traffic: ADT 48,500 (Truck: 30%).
- The superstructure consists of steel I-girders (wide flange section) with a cast-in-place concrete deck.
- Potential fatigue-sensitive detail : partial depth intermediate diaphragms.

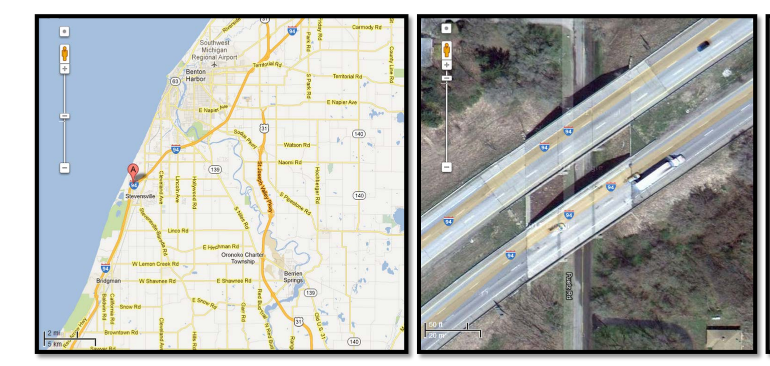


Figure 5. Bridge location map (Source: Google map)

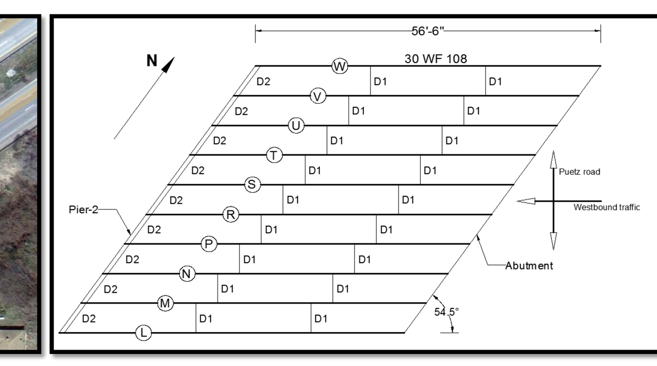


Figure 6. Superstructure details

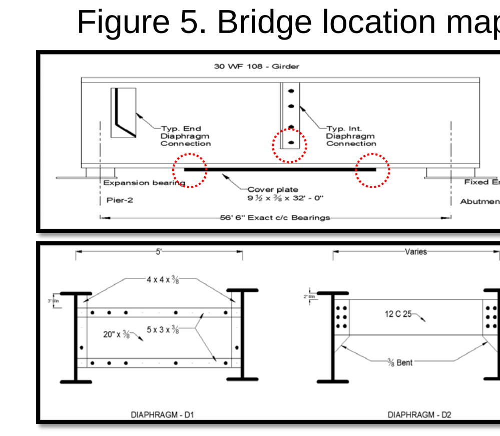


Figure 7. Girder and diaphragm

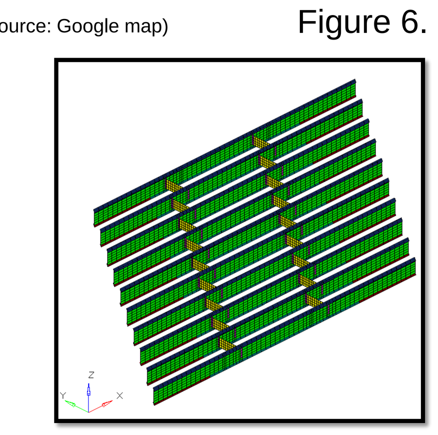


Figure 8. FE Model

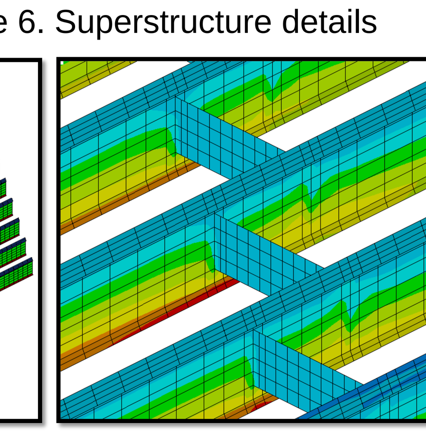
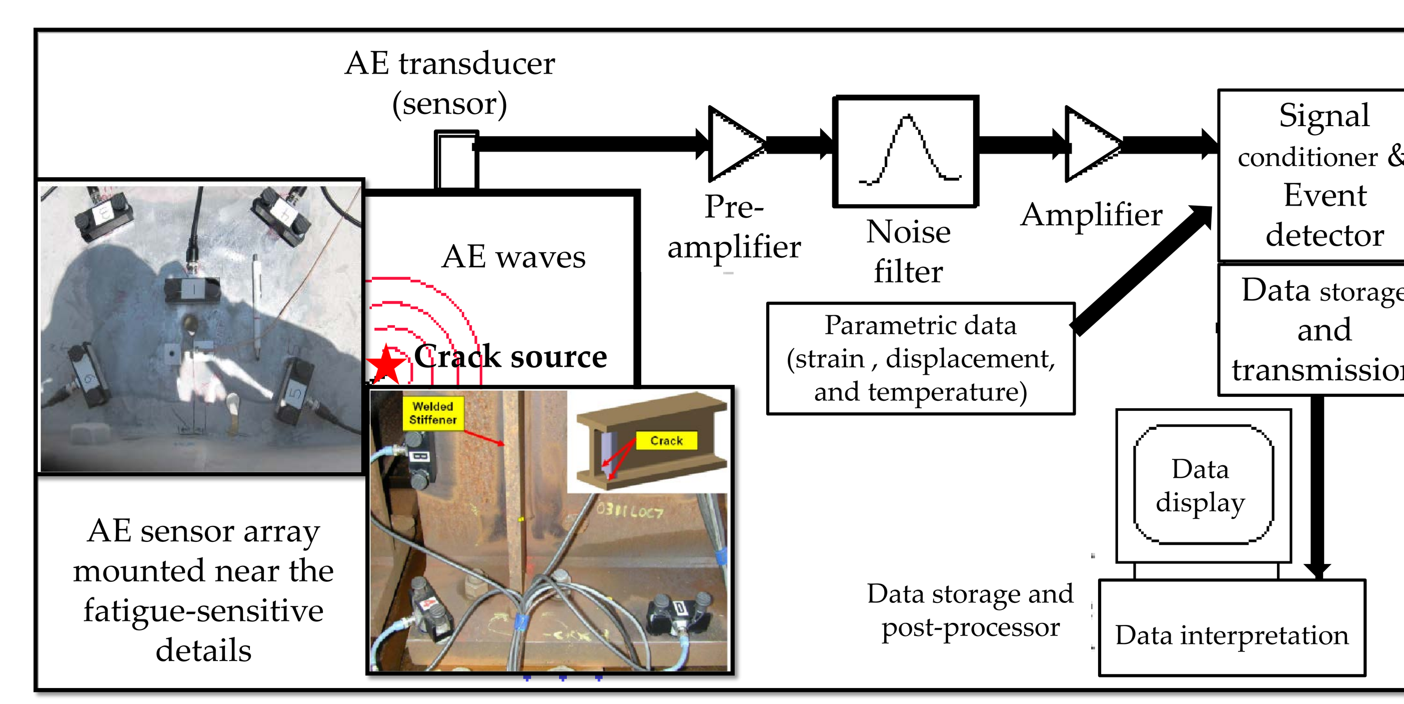


Figure 9. Stress XX contours

Structural health monitoring

The objectives of this SHM are as follows:

1. Monitor the stress state of fatigue-sensitive details to calculate the remaining fatigue life so that the inspection and maintenance can be scheduled as needed.
2. Detect fatigue events and characterize the cracks to schedule additional inspection and maintenance activities.
3. Evaluate the performance of retrofits.



Schematic of AE system
(Source: Kosnik 2008, TISEC, Huang 1998)

Future tasks

1. Field inspection of the selected bridge
2. Global and local refined finite element (FE) analysis
3. Design of monitoring system and sensor arrays
4. Field implementation and data acquisition, analysis, and interpretation

Acknowledgement

This project is funded by the Michigan Department of Transportation.