

# Evaluating Sensors for Bridge Health Monitoring

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**Abstract** – Sensors for infrastructure monitoring and evaluation utilizes different types of sensors which are placed at strategic locations to monitor the behavior of structures and provides valuable data such as strain, temperature, and vibration. A sensor network helps in identifying structural problems at early stages, prolonging the life of these structures, and improving public safety. This paper will discuss the experimental evaluation of two types of sensors commonly used in bridge applications.

**Index Terms** - Sensor network, structural health monitoring, sensors evaluation.

## I. INTRODUCTION

Various techniques have been used to assess the degradation in the transportation infrastructure. Current techniques such as visual inspection, ground penetrating radar (GPR), acoustic emission, and chain drag are time consuming, expensive, and depend on human interpretation. One method to overcome the shortages of the current methods is to use the concept of structural health monitoring (SHM). SHM is a way to monitor the structure integrity for either long term or short term purposes by using remotely located sensors, such as strain gauges. SHM system can be used to monitor the condition of a bridge in order to determine where and how much stress is being applied. The use of embedded sensors for health monitoring can provide real-time data for bridge condition assessment. Sensors can be linked to satellites or internet in order to monitor a bridge's performance from a remote location. The most common types of sensors used in bridge health monitoring are strain sensors. Strain sensors are measuring elements that convert force, pressure, tension, etc., into strain readings [1]. Various types of sensors have been successfully used in bridge health monitoring applications, such as electrical resistance strain sensors, vibrating wire strain gauges, and fiber optic strain sensors. The emphasis in this paper will be on two types of these sensors found to be reliable and effective for bridge applications,

namely vibrating wire strain gauges and fiber optic strain sensors.

## II. BACKGROUND

The sensing mechanisms are based on variety of principles connected to physical, chemical and electrical properties. They collect and modify the input signal to produce an output that is used to measure strain, temperature, electrical or magnetic fields. Vibrating Wire Strain Gauge (VWSG) and Extrinsic Fabry Perot fiber (EFPI) optic sensor interference principle is more suited for the measurement of strain. The VWSG has a body composed of a steel tube with flanges attached to either end. Inside, a steel wire is held in tension between the two plates. Strain in concrete causes the plates to move relative to each other, decreasing or increasing the tension in the wire. This tension in the wire is measured by plucking the wire with electromagnetic coils and measuring the resonant frequency of the resulting vibration [2] and [3]. EFPI fiber optic sensor consists of two optical fibers that are placed in the front of each other, with air gap in between inside a glass capillary tube. When light arrives at the lead fiber end-face, a portion is reflected off the lead fiber interface and the remaining light propagates through the air gap with a second reflection occurring at the reflecting fiber interface. Lead fiber reflection is the reference reflection and reflecting fiber is the sensing reflection. These reflective signals interfere constructively or destructively based on the optical path length difference between the reference and sensing fibers. Small movements in the capillary cause a change in the gap length, which changes the phase difference between the sensing and reflecting waves producing fringes [4], [5], [6], and [7]. Figure 1 shows a schematic of EFPI fiber optic sensor working principle. Table 1 summarizes the comparison between different parameters of fiber optic and vibrating wire sensors. Figure 2 shows the sensors used in this research project.

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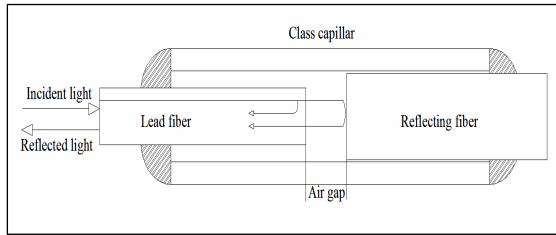


Fig. 1. Schematic of EFPI fiber optic sensor working principle

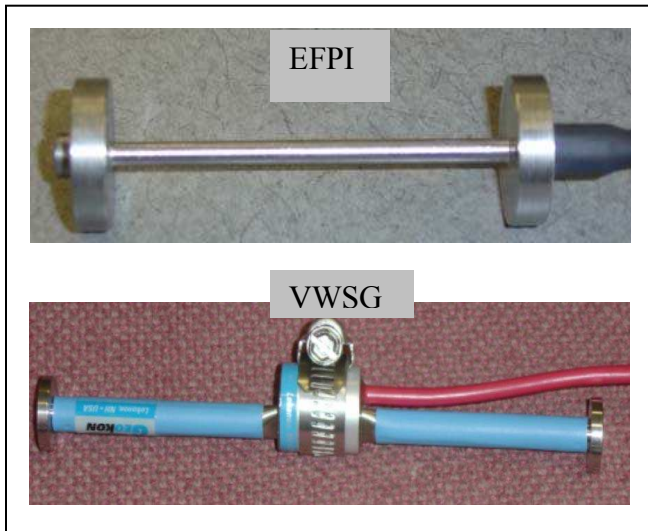


Fig. 2. EFPI and VWSG sensors used in this research project

### III. OBJECTIVE OF THE STUDY

The main objectives of this study can be summarized as follows:

- Study different types of sensors which can be used for structural health monitoring purposes.
- Select the most applicable and most promising sensor for strain monitoring.
- Develop test specimens to validate and verify the reliability of the selected sensors.

Table 1: Comparison between the Parameters of Fiber Optic and Vibrating Wire Sensors [8, 9, 10, 11]

Parameters	Fiber optic sensor	Vibrating wire gage
Gage length	1 to 500 mm	50 to 300 mm
Resolution	1 Microstrain	1 Microstrain
Measurement range	±5000 to ±10000 Microstrain	±2000 to ±3000 Microstrain
Sensor corrosion resistance	Very good	Moderate
Sensor long term stability	Very good	Good
Remote operations possibility	Yes	Yes
Structural response capabilities	Static and dynamic loads	Just static loads
Temperature range	- 20 to 55 °C	-20 to 80 °C
Ability to multiplexing	Yes for long and short term monitoring	Yes for long term monitoring

### IV. EXPERIMENTAL PROGRAM

Evaluation of sensors for the strain measurement is conducted to assess the performance criteria which include measurement range, resolution, accuracy, power consumption, etc, of the sensor when embedded in concrete structures. The test involves embedding strain sensors in concrete specimen, applying test loads and measuring the outputs. First, the two sensors (EFPI Fiber optic sensor and VWSG), are placed along the same axis inside a concrete cylinder, maintaining equal distance from each other and from the edges of the cylinder mold. Once dried, the concrete cylinder is placed on the compression machine and the initial measurements are taken. Next various loads are applied along the vertical axis of the concrete cylinder and strain values are measured. Then, the measured strain is compared with the theoretical one. The experimental setup of the test specimen is shown in Figure 3. Placement of sensors inside the concrete mold is shown in Figure 4, while Figure 5 shows the actual experimental setup inside the compression machine.

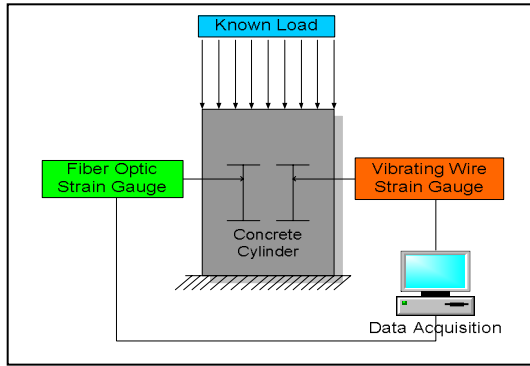


Fig. 3. Experimental setup

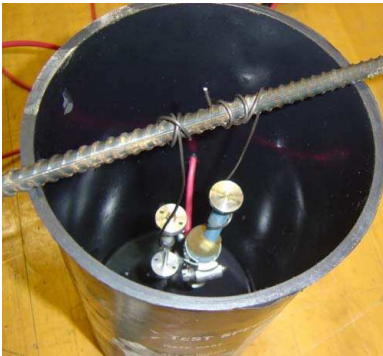


Fig. 4. Placement of sensors in the mold



Fig. 5. Specimen during testing

## V. PARAMETERS INCLUDED in the STUDY

Different parameters were included in this study such as sensor accuracy, thermal effect, creep at load and recovery time, and repeatability. A brief discussion of these parameters is included in the following subsections

### A. Sensor Accuracy

Sensor accuracy can be defined as the degree of conformity of the measured quantity to its actual or true value [12]. Compression test was conducted to investigate the strain behavior of the two sensors embedded inside the concrete. In order to conduct this test, elastic modulus as well as the ultimate load values were obtained according to ASTM standards. The ultimate load is the load for which the cylinder crushes. To prevent any plastic deformation, the maximum load applied to the cylinder was 40% of the ultimate load.

### B. Thermal Effects

Test was conducted to investigate the response of the sensors to temperature variations. The temperature effect produces a significant strain in the concrete cylinder. In order to evaluate the performance of the sensor, the linear thermal expansion coefficient of the concrete cylinder is calculated based on strain reading from each sensor. The calculated value of that coefficient is then compared to the typical value of the thermal expansion coefficient of normal concrete, which is around (10). A total of 7 cycles of this test were conducted.

### C. Creep at Load and Recovery Time

A strain sensor will take some time to adjust to a change in the stress applied. Creep at load for a strain sensor is usually defined as the change of output with time following a step increase in stress from one value to another. Figure 6 shows an example of a creep curve where the sensor exhibits a change in the output from S1 to S2 over a period of time from t1 to t2 after a step change between 0 and t1. Creep at recovery, when the applied stress is nullified usually the sensor exhibits a step change from S2 to S3 over period of time t2 to t3 but takes some more time to reach the zero value. For both creep at load and creep at recovery, the results will depend on how long the applied strain has been at zero or the rated value respectively before the change in strain is made [13].

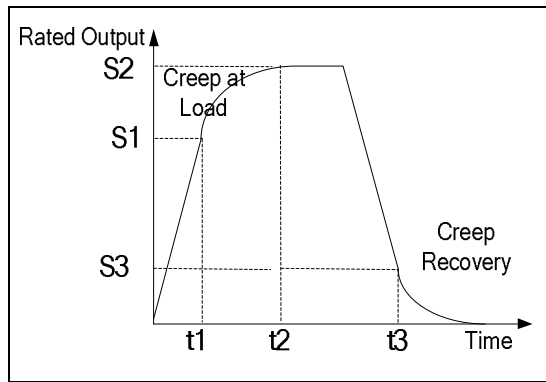


Fig. 6. Creep at load and recovery

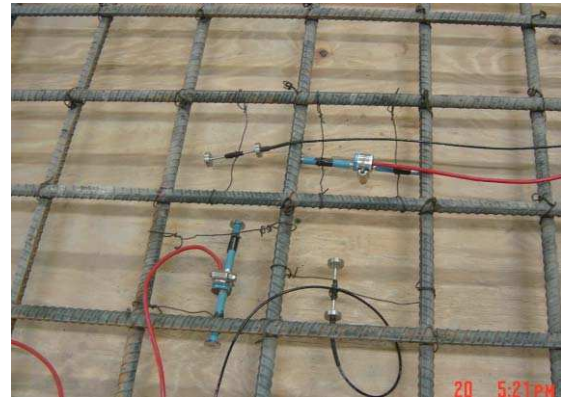


Fig. 7. Instrumentation in the slab form

#### D. Repeatability

Repeatability is defined as the measure of agreement between the results of successive measurements with the same conditions [13]. The test was carried out using the same set of equipment and the timing intervals between two successive repeated measurements.

### VI. PRELIMINARY RESULTS

The preliminary results are summarized as following:

- The accuracy results indicate that the vibrating wire gauge data correlates better with the theoretical calculation than the fiber optic sensor data.
- The thermal test results show that vibrating wire strain gauge after temperature correction and appropriate calculations gives a value around 10, where as the fiber optic sensor does not correlate with the expected value of linear thermal expansion coefficient of concrete.
- Both sensors show similar behavior during the creep at load and recovery tests.
- The repeatability test results show that the vibrating wire sensor correlates with the expected value better than the fiber optic sensor.
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### VII. FUTURE WORK

After verifying the sensor reliability and performance. Different mechanical properties of concrete will be assessed in the future using these sensors, such as, creep, shrinkage, modulus of elasticity, and flexural strength. Figure 7 shows the forms intended for the flexure test on a reinforced concrete slab, while Figure 8 shows the sensor in creep and shrinkage molds.



Fig. 8. Sensors suspended in creep and shrinkage forms

### VIII. CONCLUDING REMARKS

The work presented in this paper is part of an ongoing research at Western Michigan University. One of the research objectives is to evaluate different types of sensors to validate their usage, reliability, and performance inside concrete structures. Sensor technology is considered a powerful way to assess the condition of concrete structure. However, the performance of the sensors has to be evaluated in the laboratory before using them in real structures. Characterizing the performance of the strain gauge embedded in concrete is based on a number of different physical principles including the deviation from the known value or true value, the effect of temperature changes, the ability to measure consistently and the time taken to adjust fully for a change in the strain.

## ACKNOWLEDGMENT

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