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Structural Health Monitoring of Bridges Using Smart Sensing Techniques

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Abstract

The subject of structural health monitoring, or SHM, is expanding quickly and offers a platform for ongoing evaluation of civil engineering structures to guarantee their serviceability and safety. Over the past few decades, a variety of SHM tactics have been put forth. However, applying them to civil infrastructures presents minimal difficulties. In order to evaluate the structure's performance, the majority of SHM strategies currently in use basically call for measuring the number of loads that are applied to it. Nevertheless, it is frequently challenging to quantify the loads acting on the structure (bridges), or more often, it is more challenging to apply such pressures to the structures in order to obtain answers. The application of current SHM techniques for evaluating the condition of civil engineering structures—which necessitate load measurement—has been restricted by this challenge. Methods for monitoring and evaluating the health of structures that use ambient vibrations caused by loads have grown in popularity. However, further study is needed to create methods for evaluating health that take into account the ambient vibration of structures. The fact that damage is a local phenomenon presents another challenge to using the current SHM technique. When compared to sensors located far from the damage, those located close to the damage record the highest reactions. Consequently, sensors need to be widely spaced across a structure in order to identify deterioration in that structure.

Keywords: Structural Health Monitoring, Smart Sensing, Monitoring.

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Introduction

For a number of reasons, including the need for rehabilitation and aging infrastructure, structural health monitoring, or SHM, has been a growing field of study in recent years (Basharat et al., 2005). The method of evaluating a structure's state by analysing how it responds to loading while accounting for the location and extent of damage is known as SHM (Nagayama et al., 2007). There are four steps in the damage identification procedure. In the first stage, a structural damage occurs; in the second stage, the geometric location of the damage is determined; in the third stage, the extent of the damage is quantified; and in the fourth stage, the remaining service life of the structure is predicted. (Rice et al., 2010). The process of creating a technique for detecting damage to engineering structures is known as SHM. Data acquisition, fusion and cleaning, feature extraction and information condensation, statistical model development for feature discrimination, and operational evaluation are all parts of a SHM process. Economic and/or life safety concerns, damage definition, operational and/or environmental constraints, and data management are all included in operational evaluation. Sensing and collection concerns are taken into account in data acquisition, fusion, and cleaning. Extraction techniques include local, ambient, and forced excitation. Information and Feature Extraction Resonant frequencies, frequency response functions, mode shapes, mode shape curvatures, modal strain energy, dynamic flexibility, damping, nonlinear features, and time-frequency analysis are some of the parameters and techniques found in condensation (Cho et al., 2010). Structural damage monitoring systems contain a sensor and microprocessor, a system for transmitting and collecting data, and methods for diagnosing damage. Modern developments in global positioning systems, wireless communication, micromachined sensors, and processing power provide the means for potentially novel answers to many of the issues these systems raise (Sun et al., 2010; Sony et al., 2019). A data processor receives the data from the sensor unit. Nowadays, the majority of sensors provide raw data that hasn't been processed at the structural location. Although they are not always employed as processors, site master units are typically used as data collectors. All monitoring system structures' damage data can be received and processed by the central monitoring facility (Jang et al., 2010; Sofi et al., 2022).

Methodology

A large portion of India's current infrastructure has been operational for a long time. Despite aging and the resulting buildup of damage, many structures are still in service. Therefore, it is now vitally crucial for our society to keep an eye on the state of these structures in order to offer the required maintenance. A new area of civil engineering called structural health monitoring, or SHM, offers the possibility of ongoing and recurring evaluations of the integrity and safety of the infrastructure (Jang et al., 2010). The use of techniques based on ambient vibration has grown in significance in the fields of damage detection and SHM. The use of a dense array of sensors for SHM is now possible because to recent advancements in wireless sensors. The quality of the SHM may be enhanced by dense arrays of inexpensive wireless sensors. To further understand the performance of the wireless sensor platforms, a number of laboratory-level experimental investigations were conducted. Following successful laboratory calibration and validation tests, wireless sensor systems were installed on two railroad bridges to examine how well the devices functioned in actual field settings. This chapter provides a detailed explanation of the research done on assessing these railway bridges' performance using the created wireless sensor network system. The experimental investigations were conducted as a component of a study aimed at assessing railway bridge performance. By installing the created wireless sensor system at the bridge, the performance of a steel plate girder railroad bridge was assessed in Fig 1. Conventional sensors were also placed at the bridge to examine how well the wireless sensor system performed in actual field settings. The following sections provide an explanation of the specifics of the experimental experiments.



Fig. 1: General View of The Steel Plate Girder Bridge

In order to assess the bridge's performance, metrics such as strain and acceleration are measured while trains are passing over it. This allows for the measurement of structural parameters like bending moment, shear force, acceleration, and frequency. The strain gauges that were attached to the NI wireless sensor nodes and instrumented on the bridge girder provided the strain responses. The Imote2 wireless sensor nodes are fixed to gather acceleration responses from the bridge girder. Fig 2 and Fig 3 depict the wireless sensors that will be installed at the location before instrumentation.

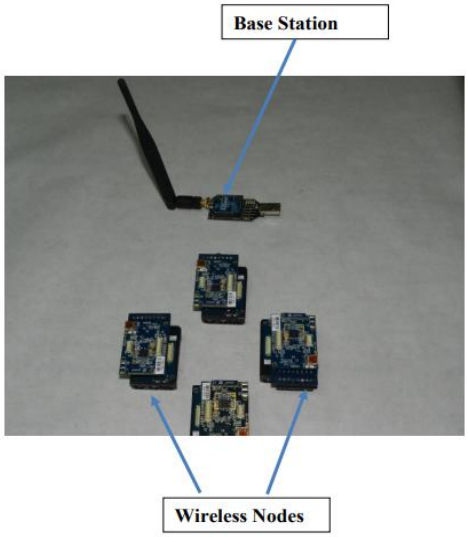


Fig. 2: Imote2 Wireless Sensor Node Along with the Base Station

The midspan will experience the greatest strain reaction because the bridge is only supported by the bridge piers. As a result, the midspan section was equipped with an accelerometer to measure accelerations during train passing and strain gauges at the top and bottom flanges to determine the bending moment. Additionally, one-fourth sections were instrumented with strain gauges at the top and bottom to obtain the change of the bending moment along the span. Imote2 wireless sensors were firmly affixed to the girder's flange at every four positions in order to better comprehend the vibration in the bridge. To determine how the shear force in the girder changed as the trains passed by, strain gauges were installed on the girder at the two support ends. In order to compare the wireless sensor system's performance, the girder was also equipped with a traditional sensor system at the same positions as the wireless sensor system.



Fig. 3: Wireless Sensor System for Strain Measurement

Fig 4 and Fig 5, displays a typical instrumentation plan. Strain gauges are used to measure the bending moments at sites B1 through B6. Strain gauges have been installed at S1 and S2 to measure the shear forces. Accelerometers are installed at sites A1 through A3 to measure the bridge's vibrations while trains are passing. Additional accelerometers and strain gauges were installed next to these sites in order to measure the strains using a standard data collection system. The performance of the installed wireless sensor system was compared using these measurements.

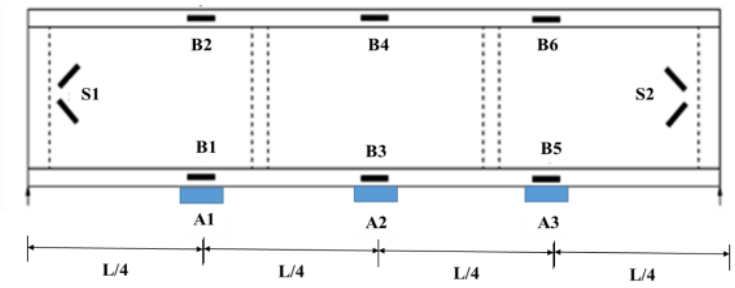


Fig. 4: Typical Instrumentation Plan for Performance Evaluation of The Bridge Girder

Experimental Results

The loco and heavily loaded carriages were positioned at specific points along the span to perform three static tests. By comparing the maximum static strain values recorded at different parts with the corresponding theoretical bending moment, calibration factors were determined.



Fig. 5: Test Train Formation Running on the Bridge Span

Similar to the traditional system, the wireless accelerometers were able to record accelerations and wirelessly send the data to the base station without any data loss. It is clear from the Fig 6 that there were no losses during the wireless transmission of the acceleration reactions to the base station. Filters in the software code were used to remove signal noise.

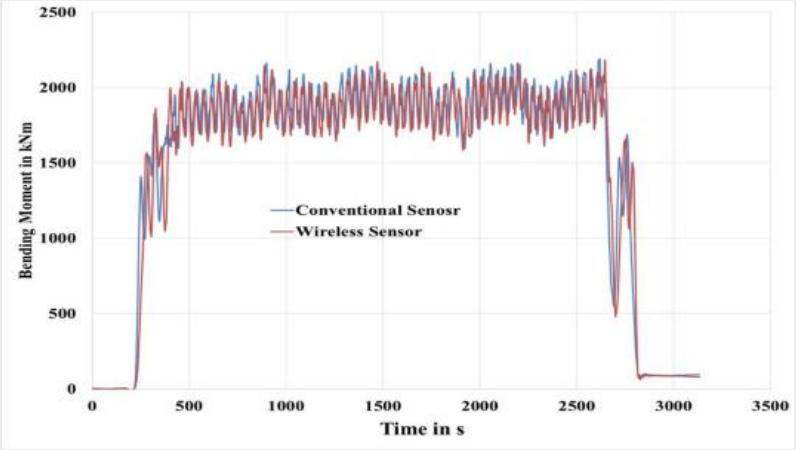


Fig. 6: Typical Variation of Bending Moment During Passage of Train for Dynamic Load Case 2 Midspan Location

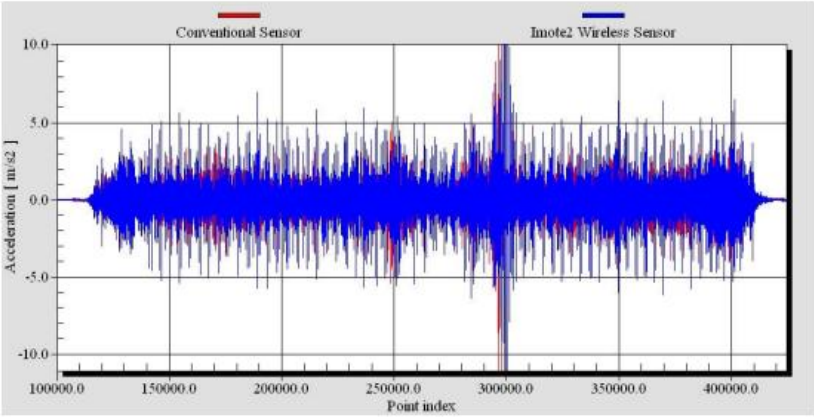


Fig. 7: Typical Variation of Acceleration During Passage of Train for Dynamic Load Case 2 Midspan Location

The developed wireless sensor system was deployed at the bridge site to evaluate the performance of a prestressed concrete girder railway bridge which is shown in Fig 7. Conventional sensors were also employed at the bridge site to examine the wireless sensor system's performance. The following sections provide an explanation of the specifics of the experimental experiments.

Conclusions

By performing the required maintenance and repair work, the structure's service life can be extended based on inputs gathered from SHM, preventing any failure. As a result, the majority of developed countries are spending more money to evaluate the state of their main civic infrastructures. Over the course of the structure's life, the SHM framework provides a chance to lower maintenance, repair, and retrofit costs. Damage to civil engineering structures can be broadly defined as modifications to the way materials, connections, boundary conditions, etc. perform., because of degradation. For example, aging materials have a negative impact on the structural performance, and excessive loading typically results in loads that are far different from the design loads, which lowers the structure's safety and may even cause it to fail. Numerous factors, including aging, corrosion, and repeated or fatigued loads, can cause damage to civil engineering structures. Bridge structures may sustain damage from loads brought on by wind, overloaded

vehicles, and vehicle movement. However, extreme loads brought on by earthquakes, storms, and cyclones can severely harm the structures. There are two types of damage to civil engineering structures: linear damage and nonlinear damage. When linear damage occurs, the structure continues to behave elastically after the harm has occurred, but non-linear damage causes the structure to behave non-linearly after the damage has occurred.

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