Joint Transportation Research Program

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Determining Optimal Traffic Opening Time Through Concrete Strength Monitoring: Wireless Sensing

Introduction

Construction and concrete production procedures are time sensitive and fast paced. As such, it is crucial to monitor the strength of concrete in real-time. Existing concrete strength testing methods, such as traditional hydraulic compression method specified by ASTM C 39 and the maturity method specified by ASTM C 1074, can be inaccurate, labor intensive, and cumbersome for field implementation. For example, the curing condition of samples for ASTM C 39 testing can be distinct from the realistic curing condition of in-place concrete, which will cause a discrepancy of the cylinder strength and in-place concrete strength. The maturity method collects the in-place temperature data; however, the correlation between the temperature profile and strength profile varies with concrete mixtures, which makes the maturity calibration process time-consuming and expensive. The PI's previous research (SPR-4210) on the Electromechanical Impedance (EMI) technique has approved the feasibility of monitoring in-situ concrete strength to determine the optimal traffic opening time. Specifically, a polymer-coated piezoelectric square disk was used as the EMI sensor and the Root Mean Square Deviation (RMSD) was used as the metric to interpret the compressive strength ofconcrete. However, limitations of the data acquisition and communication systems have significantly hindered the technologies adoption for practical applications; furthermore, the packaging of piezoelectric sensor needs to be improved to enable robust performance and better signal quality.

In this project, a wireless concrete sensor data transmission system was developed, comprised of the innovated EMI sensor and miniaturized impedance analyzer datalogger with both a wireless transmission and USB module. A cloud-based platform for data storage and computation was established, which provided real-time data visualization access to general users and data research access to machine learning and data mining developers. Furthermore, field implementations have been performed to prove the functionality of the sensor and wireless sensing system in field conditions. This project will benefit the DOTs in many aspects, including maintenance scheduling and asset management, by delivering practical concrete strength monitoring solutions.

Findings

In this project, the research team conducted a systematic and comprehensive study to develop a concrete strength monitoring solution that can be deployed in real concrete projects. Both lab and field experiments were implemented to investigate the performance of the sensing system. The proposed sensor was tested in concrete made of Ordinary Portland Cement (OPC) and Portland Limestone Cement (PLC) containing various water-cement ratios and various curing conditions. The data transmission performance of the datalogger was evaluated through field testing. The major findings of this project are presented as follows.

1. Findings related to the wireless concrete EMI data transmission system.
   - Wireless technologies such as Bluetooth, Low Power Long Range (LoRa), Wi-Fi, and LTE were explored. The research suggests that LoRa has challenges transferring EMI spectrum because of the limits on unit

packet size for data transmission, and Wi-Fi has challenges with the accessibility of routers on the construction site. Bluetooth and LTE were found to be effective considering their data transmission capability and network accessibility. In this project, Bluetooth was used for wirelessly transmitting EMI spectra data packets in short-range from sensors to a centralized on-site hub. LTE was used for long-range distance transmission directly from sensors to the carrier towers.

2. Findings related to the cloud platform for data storage and computation.
   - A cloud computing platform with the capacities of data storage, computation, and AI-assisted data processing was built to make better use of collected data and process abundant information. Such a platform includes the database, the website front-end user interface, and the back-end computation database. The database stores EMI spectrum data received from dataloggers. The website provides the general users with visualized concrete data display, such as the strength and temperature profile. The computing backend processes the data from the database using machine learning models and sends results to the website for displaying.

3. Findings related to the sensor and packaging.
   - In this project, the sensor is improved in terms of durability and quality. A larger piezoelectric element is used to achieve higher signal to noise ratio. Finite Element (FE) simulation shows that the developed sensor can measure the resonant frequencies of concrete and such frequencies shift according to the change of concrete dynamic elastic modulus. The simulation results also show a wave filed distribution pattern surrounding the sensor can be used to describe the sensing region.

4. Findings related to the concrete experiment.
   - Concrete experiments were conducted for OPC and PLC concrete, along with various water cement ratio (0.42, 0.45, 0.50, 0.55) and various specimen shapes (beam, slab). Field tests were implemented at paving projects of Bass Road, Fort Wayne, IN, Indianapolis Airport Runway, IN, and I-35E Highway in Hillsboro, Texas.

5. Field Implementation.
   - The wireless sensing system, including the sensor and the datalogger are found to be applicable for real time and in place of concrete strength monitoring. The sensor is disposable whereas the datalogger is re-usable, so this product is affordable compared with the cost of traditional compressive cylinder testing. The datalogger provides users with convenient features such as wireless data transmission, which enables remote monitoring, and the USB cord data pulling, which serves as a backup solution when a network is not available in a distant area. This project has proved that an EMI sensor can be a promising alternative to traditional strength testing, such as cylinder testing and maturity testing.

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