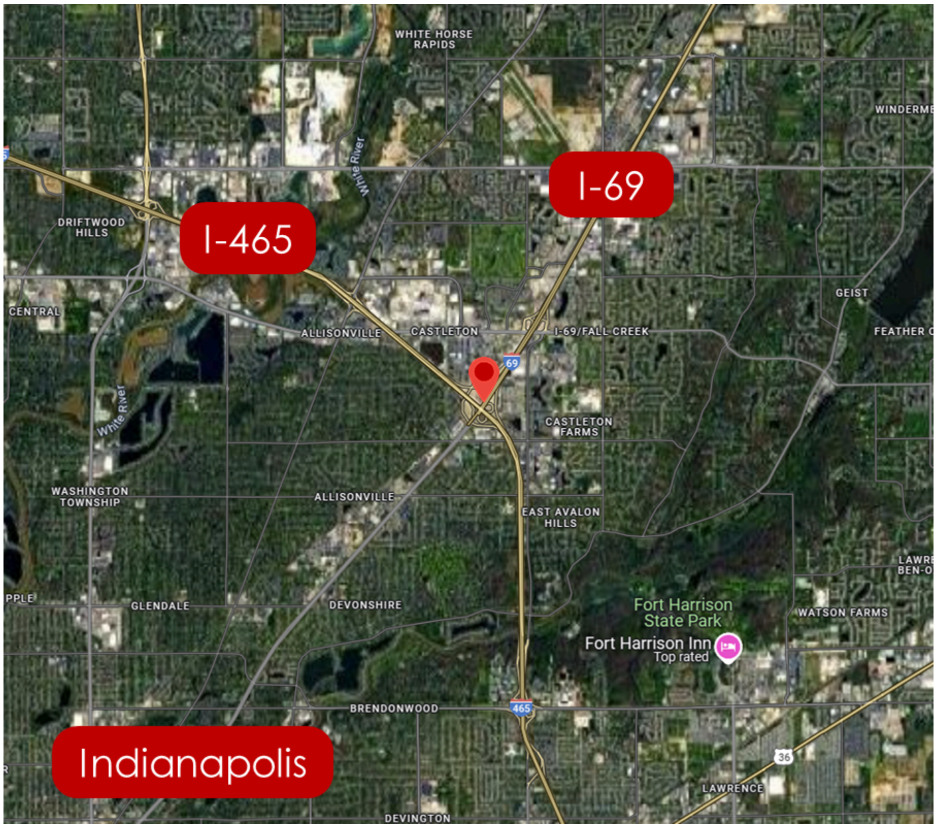
Title
White Paper: Enhancing Concrete Strength and Quality Monitoring with In-Situ REBEL® Sensors: Insights from INDOT's I-465 Pavement Project.

Abstract
This white paper examines the use of Wavelogix® REBEL® sensors to monitor the compressive strength of concrete over time, providing critical data for the construction and infrastructure sectors. Using data from the Indiana Department of Transportation (INDOT), this study evaluates concrete maturity and strength development, demonstrating the value of real-time monitoring for enhancing project timelines, ensuring safety, and optimizing material performance. By leveraging REBEL sensors on a pavement project on I-465, the project highlights the REBEL sensor's ability to provide reliable, in-situ compressive strength at a fraction of the cost of destructive cylinder testing.

Introduction
Concrete is one of the most widely used construction materials, valued for its strength and durability in infrastructure projects worldwide. Understanding and monitoring its compressive strength over time is essential for ensuring structural integrity and project success. Traditional methods of evaluating concrete strength, such as cylinder testing, provide data at specific intervals, often failing to fully capture strength development trends, particularly in fast-paced construction environments. Moreover, these methods are cost intensive. This inefficiency, combined with the high costs associated with preparing, curing, and transporting cylinders, underscores the need for more precise, real-time strength monitoring solutions to ensure quality, reduce waste, and optimize project efficiency.

This paper presents a case study utilizing Wavelogix REBEL sensors, which provide continuous, real-time monitoring of concrete compressive strength. This innovative approach offers a more comprehensive understanding of concrete performance, enabling engineers and project managers to make data-driven decisions, accelerate project timelines, enhance safety, and optimize material use. This paper focuses on the Indiana Department of Transportation's (INDOT) multi-stage pavement project on Interstate 465, where REBEL sensors were deployed to track strength development in three pavement sections.

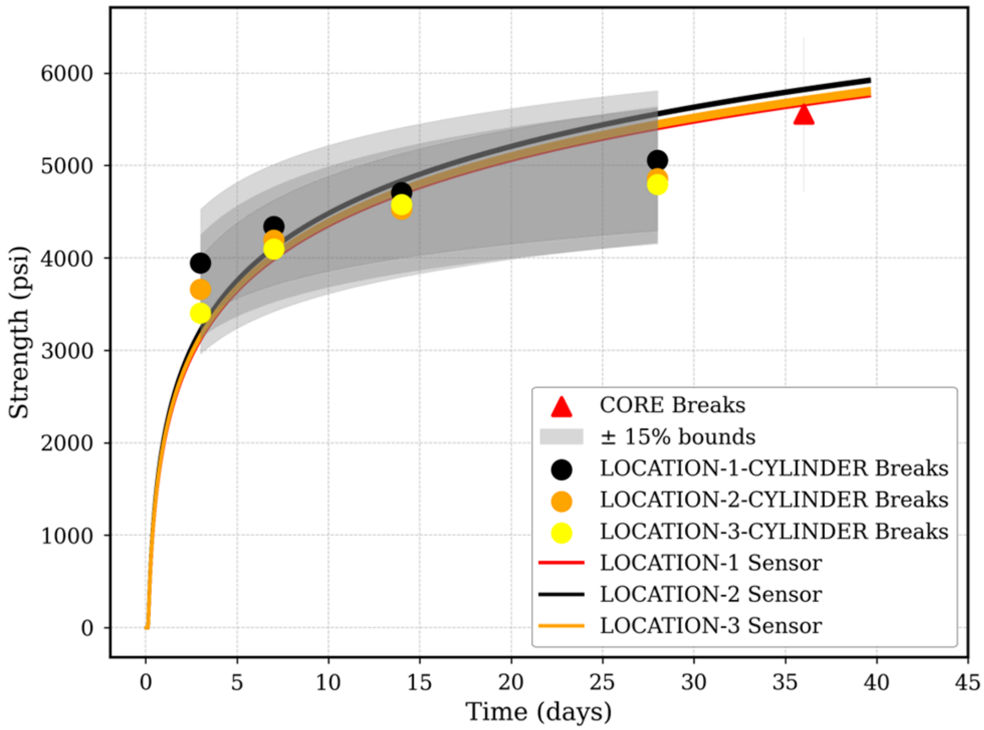


Data Collection Methodology

The INDOT I-465 pavement project consisted of three groups of concrete poured in three different locations monitored by separate groups of 3 REBEL sensors. A group of 4x8 cylinders was made for each location so that the sensors and cylinders were taken from the same truckload of concrete. Each group continuously measured the compressive strength of concrete over time. Cylinder break tests were conducted on days 3, 7, 14, and 28 to provide a basis for comparison with REBEL sensor data. A core of location 2 was taken at 36 days to compare the sensor's measurements of the in-place strength.

The target compressive strength for this concrete mix design was set at 4000 psi. The REBEL sensors provided consistent, real-time measurements, allowing INDOT to track the strength progression in each section closely. This data was then plotted to compare the real-time readings from the REBEL sensors with the results from traditional cylinder tests and core samples.

Results and Graph Analysis



The graph above illustrates the compressive strength development over time for the different groups in the INDOT pavement project. Key insights from the graph include:

1. The Sensor Accurately Measures In-Place Strength: The sensors track well with the cylinder testing, but a few important differences exist. The cylinders overestimate the strength of the structure at an early age but underestimate the strength at a later age. This is due to the difference in curing condition between the cylinders and the pavement. Despite the cylinders being very consistent, the destructive testing method lags the in-place representation of the REBEL sensor, as shown by the core drill**.**

2. Consistency Across Sensor Groups: The REBEL sensors provided consistent readings across all three groups, showing that the concrete in each location followed a similar strength development curve. This consistency indicates the REBEL sensors' reliability in accurately capturing real-time data across different pavement sections.

3. Comparison with Traditional Cylinder and Core Tests: The REBEL sensor data closely aligns with the cylinder and core test results, with the sensor readings generally falling between the values obtained from these traditional methods. This alignment demonstrates that the REBEL sensors provide a realistic and reliable picture of concrete strength over time, comparable to conventional methods but with the advantage of continuous monitoring.

4. Achievement of Target Strength: The data shows that all three sensor groups approached or exceeded the 4,000-psi target within a reasonable timeframe. This information is crucial for determining readiness for the next construction phase, such as form removal or load-bearing capacity.

5. Early Strength Attainment: The REBEL sensors continuously captured the progression of strength attainment, highlighting points where the concrete strength rapidly increased within the first week. This early strength data can help project managers make faster, more informed scheduling and resource allocation decisions, potentially accelerating the construction timeline.

Key Observations

1. **Real-Time Data Accuracy**: The REBEL sensors provided real-time compressive strength measurements that aligned well with traditional methods, offering the added benefit of continuous monitoring without the delays of laboratory testing.

2. **Enhanced Project Timeline**: With REBEL sensors delivering strength data in real-time, INDOT could make informed decisions to proceed with construction phases as soon as the concrete reaches the required strength. This can accelerate construction timelines significantly by reducing idle time and enabling quicker transitions between project stages.

3. **Cost and Labor Savings**: Traditional concrete testing methods require additional labor and time for sample collection, curing, and testing. REBEL sensors reduce these labor requirements by providing automated, continuous data, saving labor costs, and decreasing the reliance on laboratory tests.

wavelogix®

Comparison Cost for Cylinder Break vs. REBEL® Sensors			
Cylinder Set Break Cost		**REBEL® Sensor Cost**	**Savings**
Concrete Use: 15 Cylinders/100CY = 150 lbs. of Concrete	Testing Schedule: 3 cylinders tested at 1,3,7,14,28 days		
Labor: 4 hrs @ $100	$400	$ 0	
Transportation: Round trip to/from the site	$100	$ 0	
Cylinder Cost: 15 cylinders @ $25 each	$375	$ 200	
Lab Equipment: Flat rate	$100	$ 0	
Final reporting, Profit & Overhead	$400	$ 0	
Total Cost / 100CY Concrete Poured	$1,375/100 CY Concrete Poured	$ 200/100 CY Concrete Poured	$1,175/100 CY Concrete Poured Savings
INDOT Project 3 sets of cylinders	**3 * $1375 = $4,125**	**3 * $200 = $600**	**$3,525 Savings**
12 Bridges/year 3 sensors/bridge	**36 * $1375 = $49,500**	**36 * $200 = $7,200**	**$42,300 Savings**
Road Paving12 foot lane/mile 24 sensors/mile/lane	**24 * $1375 = $33,000**	**24 * $200 = $4,800**	**$28,200 Savings**

Discussion

The use of REBEL sensors on the INDOT I-465 project highlighted several advantages for infrastructure construction. The consistency and reliability of the data enabled project managers to monitor concrete strength attainment continuously, reducing the need for conservative delays often built into schedules to ensure safety. With REBEL sensors, strength attainment can be accurately verified in real-time, providing opportunities to expedite critical construction activities, such as form removal and load-bearing readiness.

Additionally, by providing accurate data on strength development, REBEL sensors help reduce the need for excess material. For example, contractors may feel more confident adjusting the concrete mix with real-time feedback, potentially reducing material costs and contributing to more sustainable construction practices.

Implications

The REBEL sensors' ability to provide continuous and precise data on concrete compressive strength offers numerous implications for the construction and infrastructure sectors:

Project Acceleration: Real-time monitoring allows for faster decision-making, reduces project timelines, and enables quicker completion of multi-stage projects.
Improved Resource Allocation: With reliable data, labor and materials can be allocated more efficiently, minimizing waste and reducing operational costs.
Enhanced Safety: Accurate tracking of strength development ensures that critical milestones, such as load-bearing capacity, are met before progressing, improving site safety and reducing the risk of structural issues.

Conclusion

This study demonstrates the substantial benefits of using Wavelogix® REBEL® sensors in infrastructure projects. In the INDOT I-465 pavement project, REBEL sensors provided continuous, reliable, real-time data on concrete compressive strength. By aligning closely with traditional cylinder and core sample results, the sensors proved to be a trustworthy alternative, offering the added benefits of labor and cost savings, faster project timelines, and improved safety.

Adopting REBEL sensor technology could transform how construction schedules are managed and optimized for future projects, especially those with complex staging requirements or stringent timeline constraints. As INDOT and other agencies continue to integrate this technology, the construction industry can expect improved productivity, resource efficiency, and sustainability in project execution.