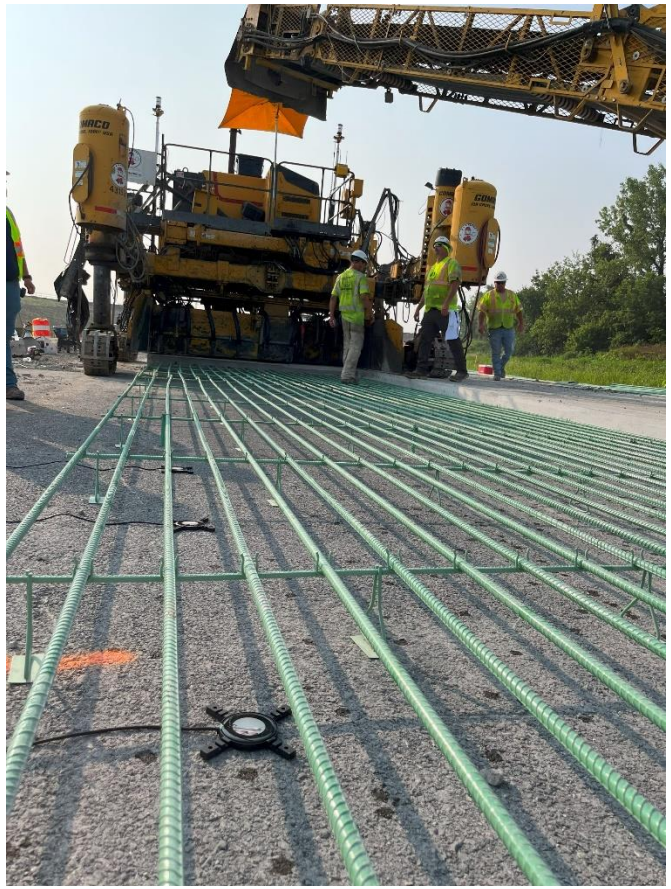
REBEL® Concrete Sensor Test Results Overview for Road & Bridge

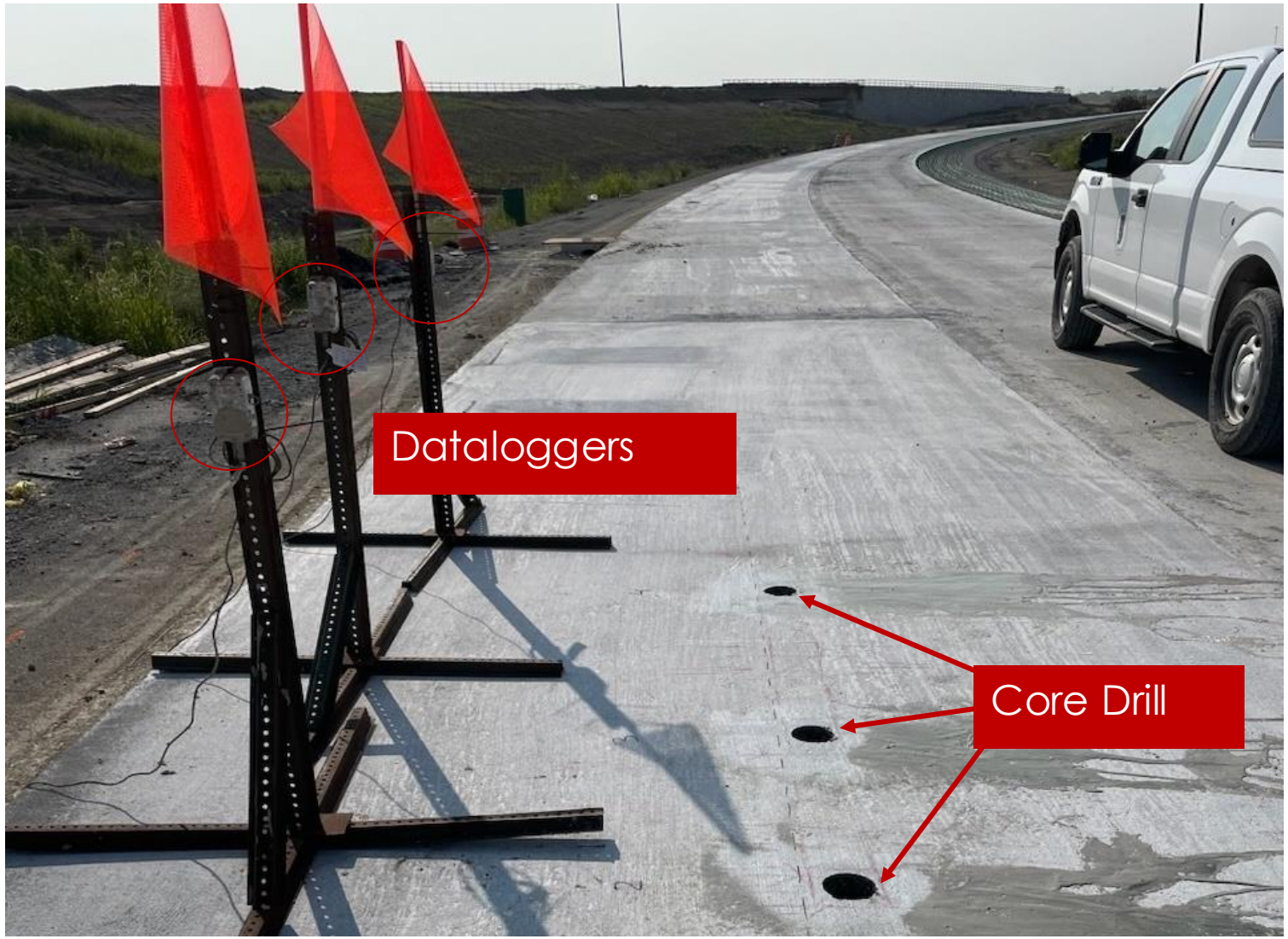
Summer 2023 – Fall 2024

Date	7-25-2023
Location	Indianapolis, IN
Pavement Thickness	11’’
Rebar	#6 (0.75’’)

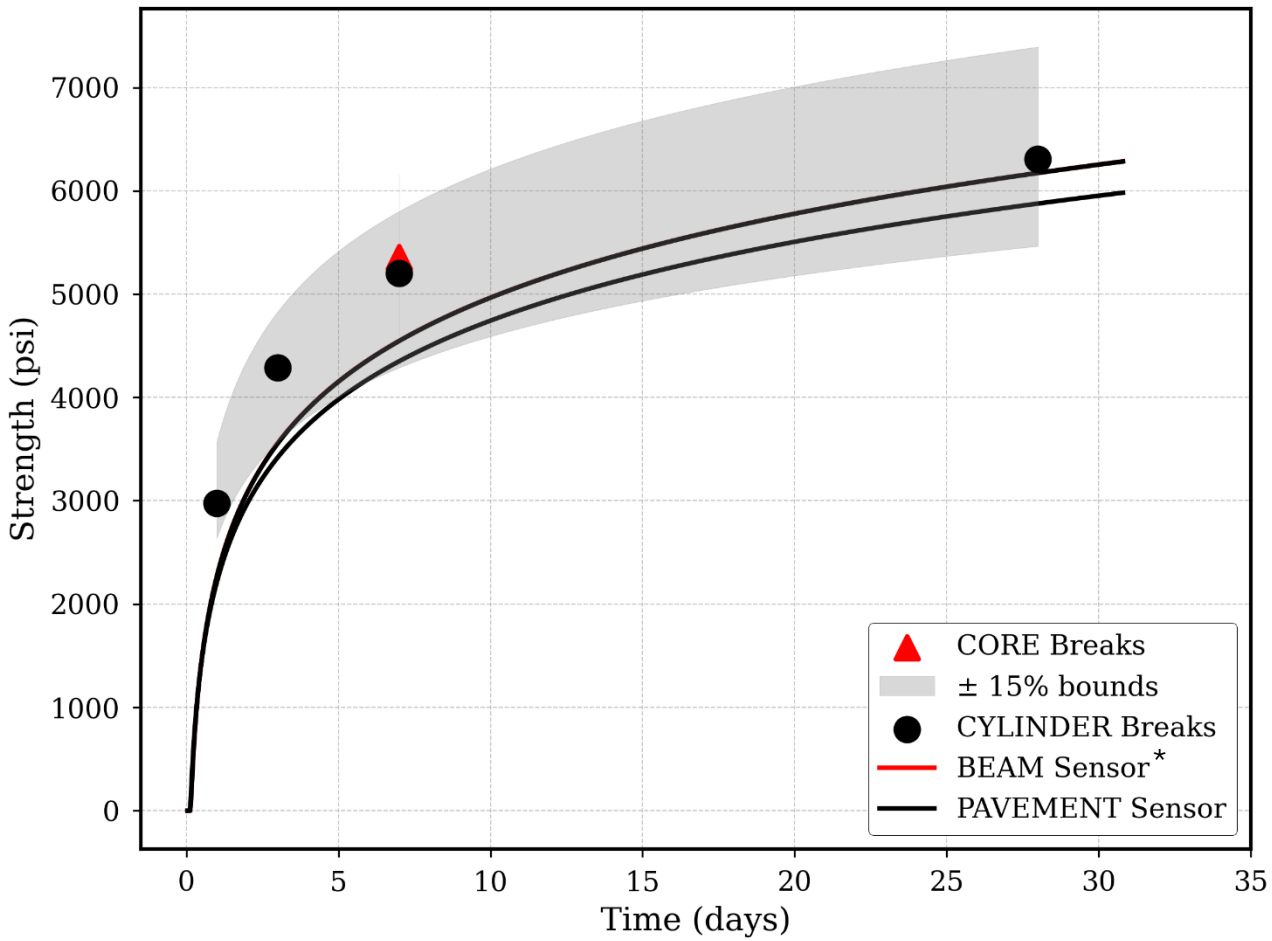
Ingredients	**Amount (/yd^3)**
Fine Agg.	1268 lbs.
Coarse Agg.	1830 lbs.
Cement	425 lbs.
Slag	145 lbs.
Water	233.7 lbs.
W/C Ratio	0.410


Paving Depth = 11”
#6 Rebar




Dataloggers
Core Drill

- 2 sensors placed in the pavement and 1 in a companion beam taken to the lab
- Cylinders were measured at 1, 3, 7, and 28 days
- Core was taken at 7-days
- Pavement sensors were within ACI allowable variability of 15% across all ages beyond 7 days



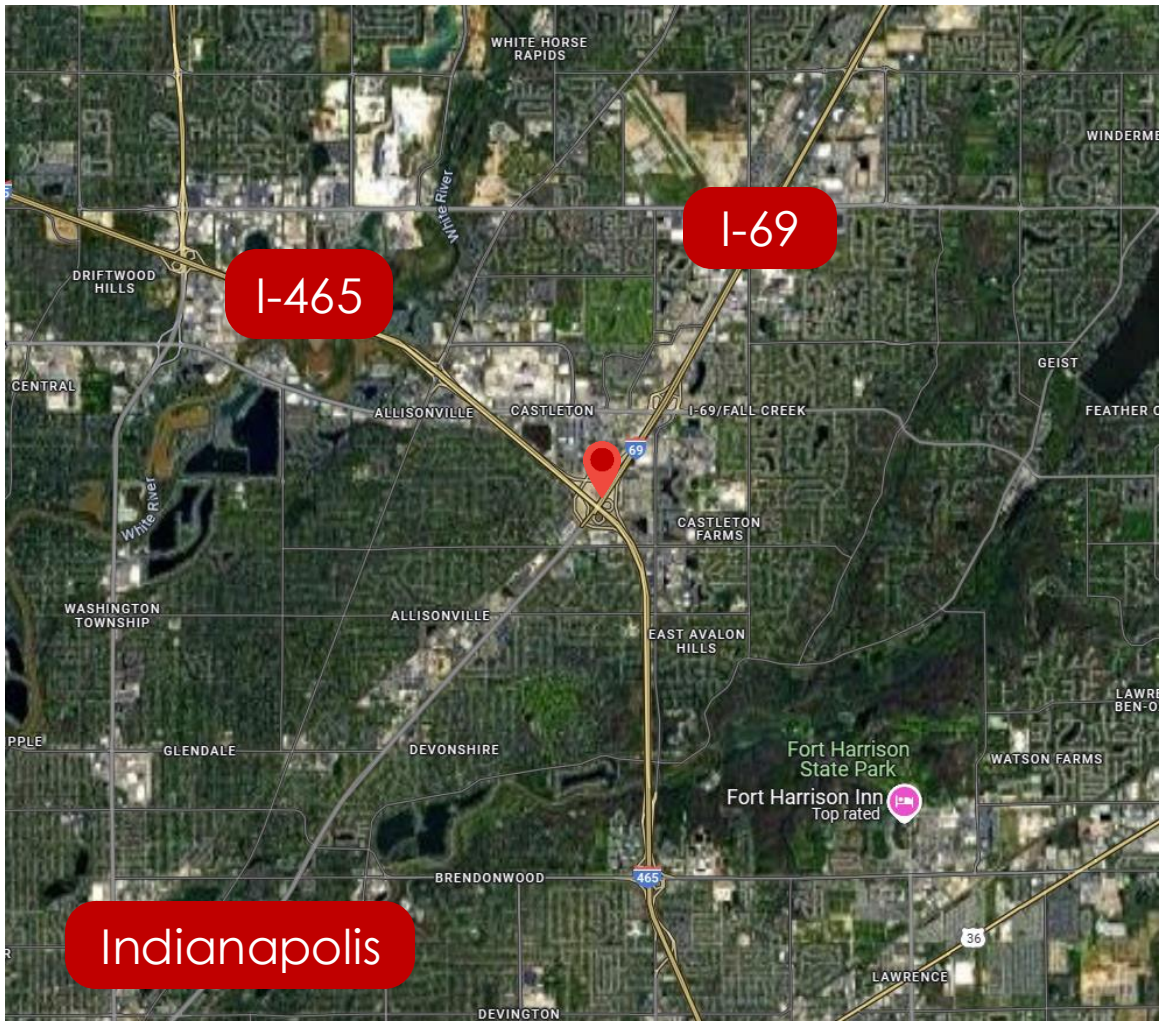
* Red BEAM Sensor Line Overlapped with Top PAVEMENT Sensor Line

- REBEL Sensor measurements were within 15% of cylinders at 7-day and 28-day
- Sensor measurements were within ~16% of cores at 7-days
- Sensor variability was excellent, with <2.5% variation in measurements across sensors at all ages

7-Day Strength	Avg. Strength	Difference from Core (%)
Core	5355	--
Cylinders	5044	5.8
REBEL Sensor	4481	16.3

Age	Avg. Difference Cylinders vs Sensors (psi)	Avg. Difference Cylinders vs Sensors (%)
1-Day	730	24.3
3-Day	778	18.5
7-Day	721	13.8
28-Day	233	3.6

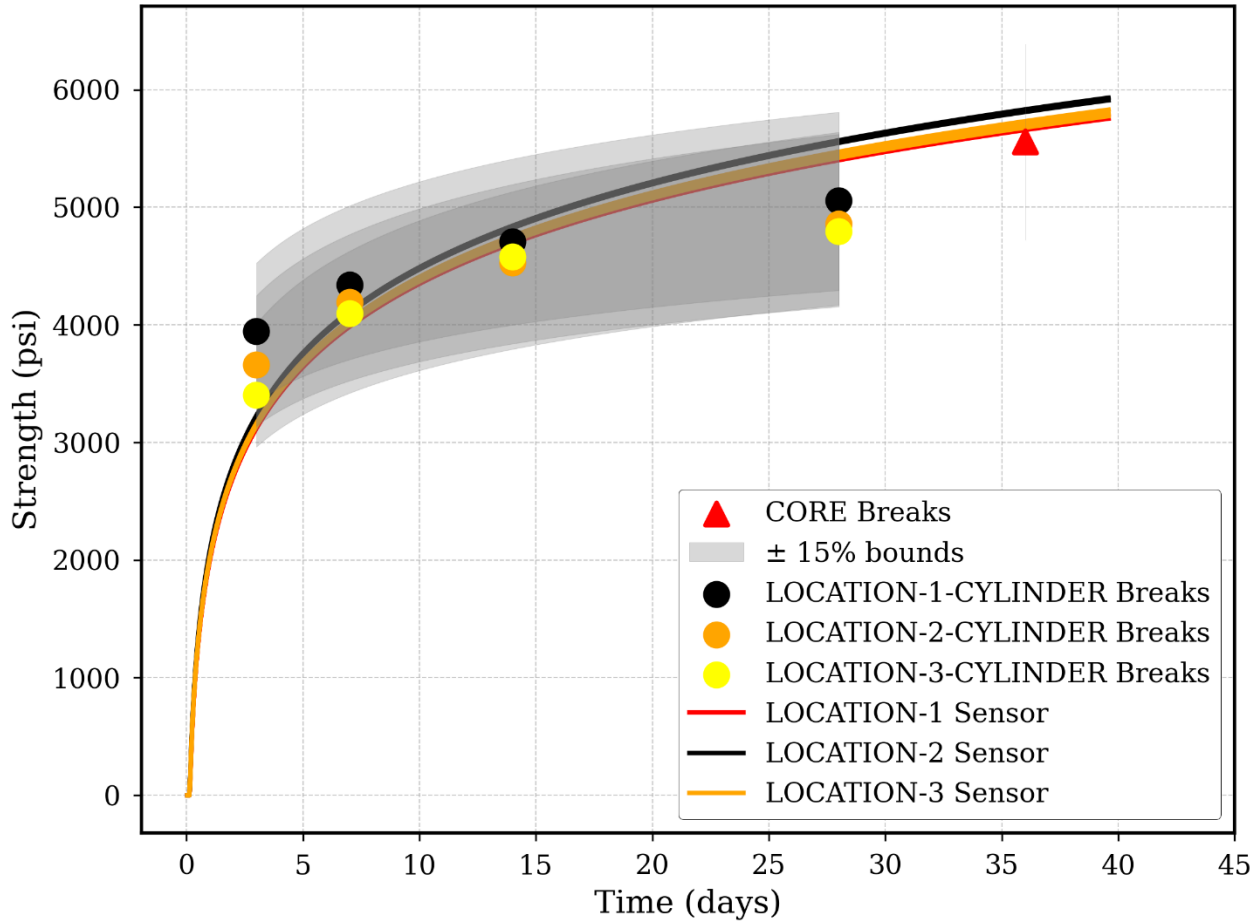
Age	Sensor Variability (%)
1-Day	1.2
3-Day	1.8
7-Day	2.1
28-Day	2.3



Date	9-16-2024
Location	Indianapolis, IN
Project Type	Pavement

Ingredients	**Amount (/yd^3)**
Fine Agg.	1301 lbs.
Coarse Agg.	1780 lbs.
Cement	520 lbs.
Water	230 lbs.
W/C Ratio	0.442

- 3 REBEL sensors were placed at different locations in the pavement
- 3 cylinders were measured for each critical age (3, 7, 14, and 28-days)
- Core was measured at day 36
- Sensors were within the 15% of cylinders across all ages, and were within 15% of the core at 36-days



* Cylinder strength extrapolated from curve fit

- REBEL Sensors were within 15% of cylinders at all ages
- REBEL Sensors were also within 3% of the 36-day core
- Sensor variability was excellent, with <6% variation in measurements across sensors at all ages

36-Day Strength	Avg. Strength	Difference from Core (%)
Core	5557	--
Cylinders*	5087	8.5
REBEL Sensor	5720	2.9

Age	Avg. Difference Cylinders vs Sensors (psi)	Avg. Difference Cylinders vs Sensors (%)
3-Day	513	13.6
7-Day	180	4.2
14-Day	98	2.1
28-Day	552	11.3

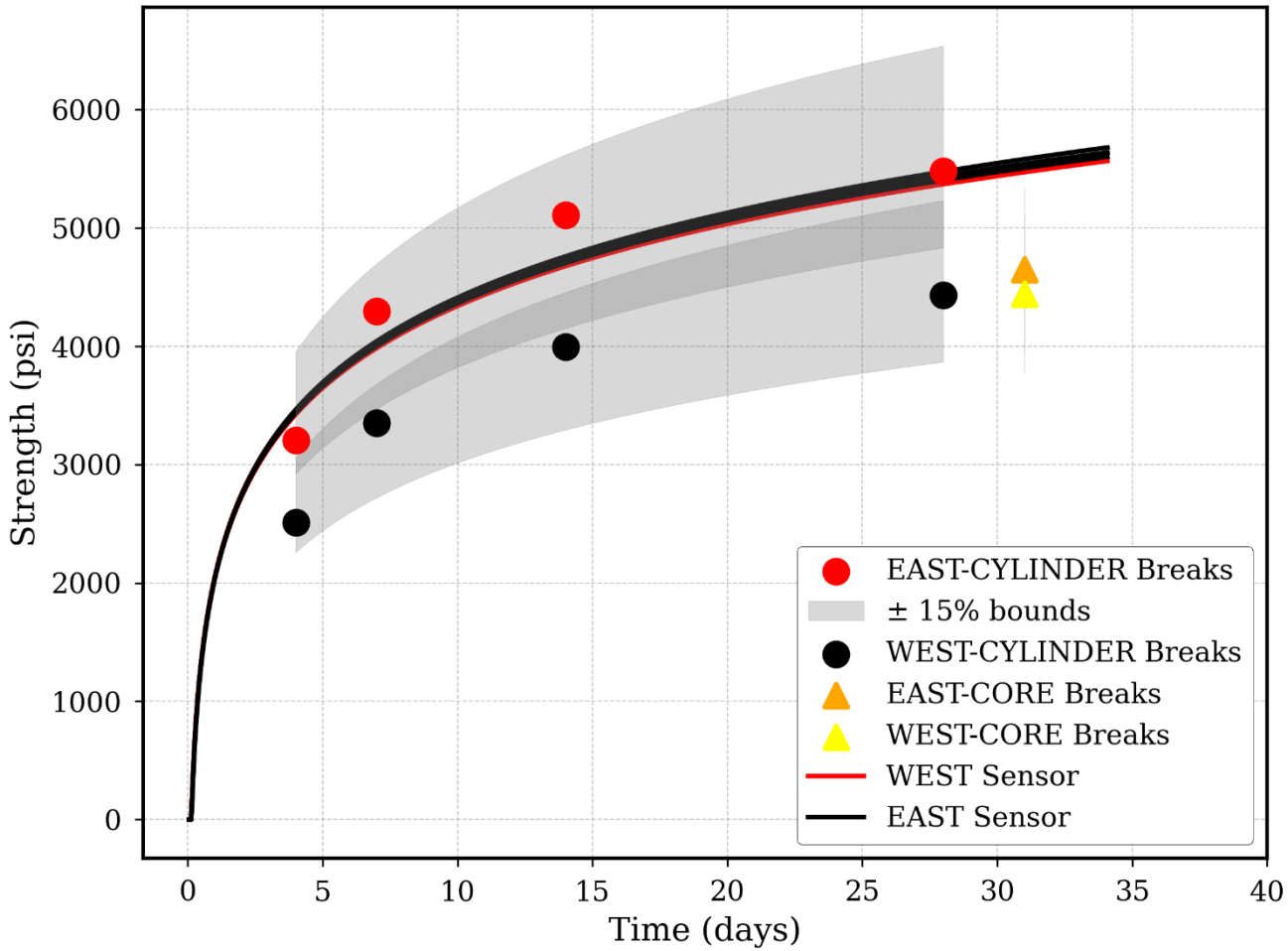
Age	Sensor Variability (%)	Cylinder Variability (%)
3-Day	1.2	6.0
7-Day	1.1	2.4
14-Day	1.1	1.6
28-Day	1.1	2.2

* Cylinder strength extrapolated from curve fit

Date	7-2-2024
Location	Indianapolis, IN
Project Type	Bridge Deck

Ingredients	**Amount (/yd^3)**
Fine Agg.	1115 lbs.
Coarse Agg.	1700 lbs.
Cement	460 lbs.
Slag	198 lbs.
Water	288 lbs.
W/C Ratio	0.438

- REBEL Sensors were placed at the East and West sides of the structure
- Cylinders were measured at 4, 7, 14, and 28-Days for both the East and West sides
- Cores were taken for the East and West sides at 32 days



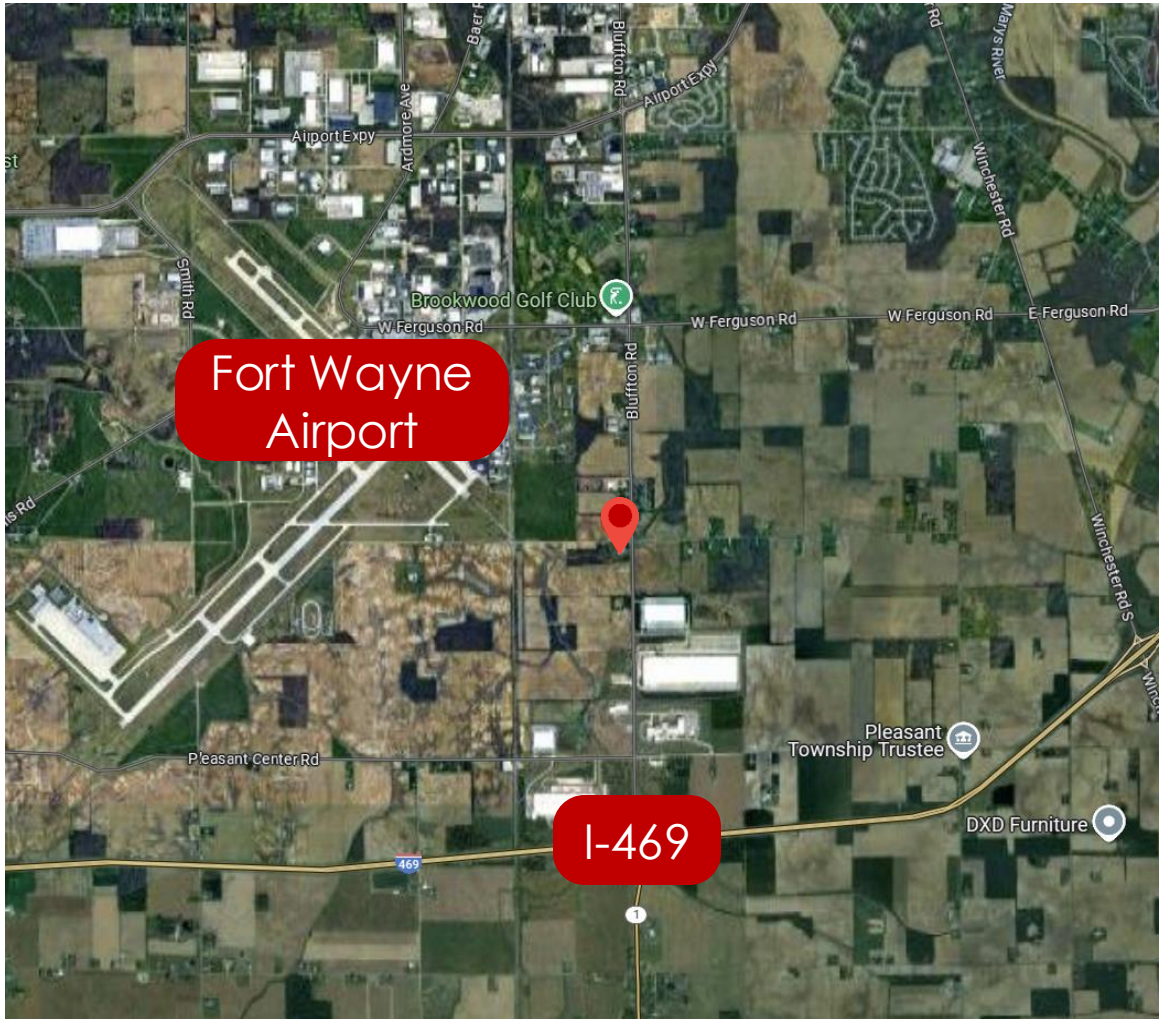
- Cores were significantly lower than both sensor and cylinder measurements
- Average sensor measurements were very consistent with cylinder measurements (within 5% across ages greater than 7 days)
- Sensor measurements were significantly more consistent than cylinders, with less than 1% variability across measurements

32-Day Strength	Avg. Strength	Difference from Core (%)
Core	4543	--
Cylinders*	5225	15.0
REBEL Sensor	5529	21.7

Age	Avg. Difference Cylinders vs Sensors (psi)	Avg. Difference Cylinders vs Sensors (%)
4-Day	370	12.2
7-Day	151	3.5
14-Day	257	5.1
28-Day	115	2.2

Age	Sensor Variability (%)	Cylinder Variability (%)
4-Day	0.4	12.2
7-Day	0.5	12.4
14-Day	0.6	12.2
28-Day	0.6	10.6

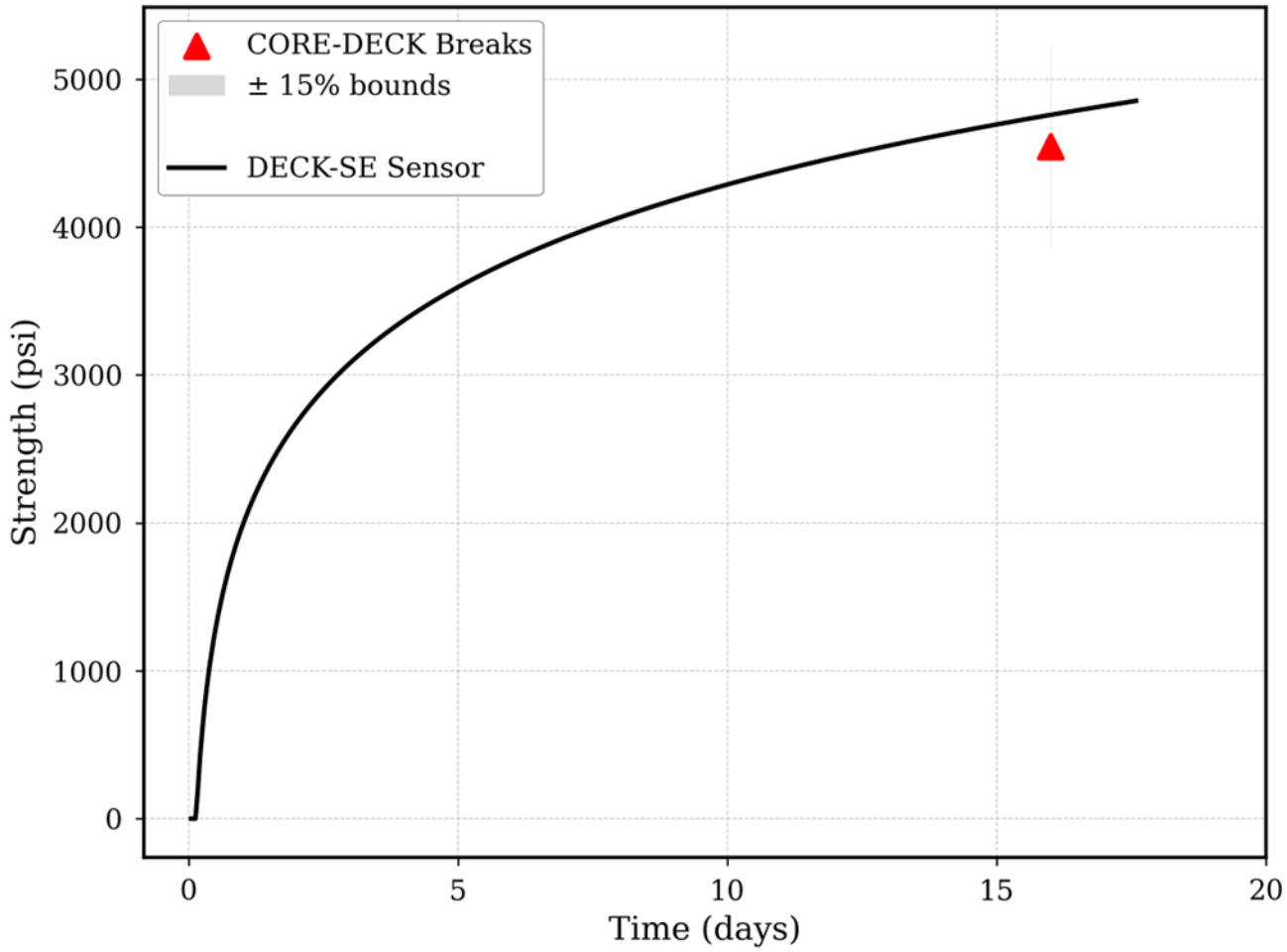
* Cylinder strength extrapolated from curve fit



Date	9-10-2024
Location	Fort Wayne, IN
Project Type	Bridge Deck

Ingredients	**Amount (/yd^3)**
Fine Agg.	1283 lbs.
Coarse Agg.	1720 lbs.
Cement	580 lbs.
Water	261 lbs.
W/C Ratio	0.450

- Sensor was placed in the bridge deck, with one core taken at 16-days
- Sensor was very accurate (within 4.7% of core measurement)



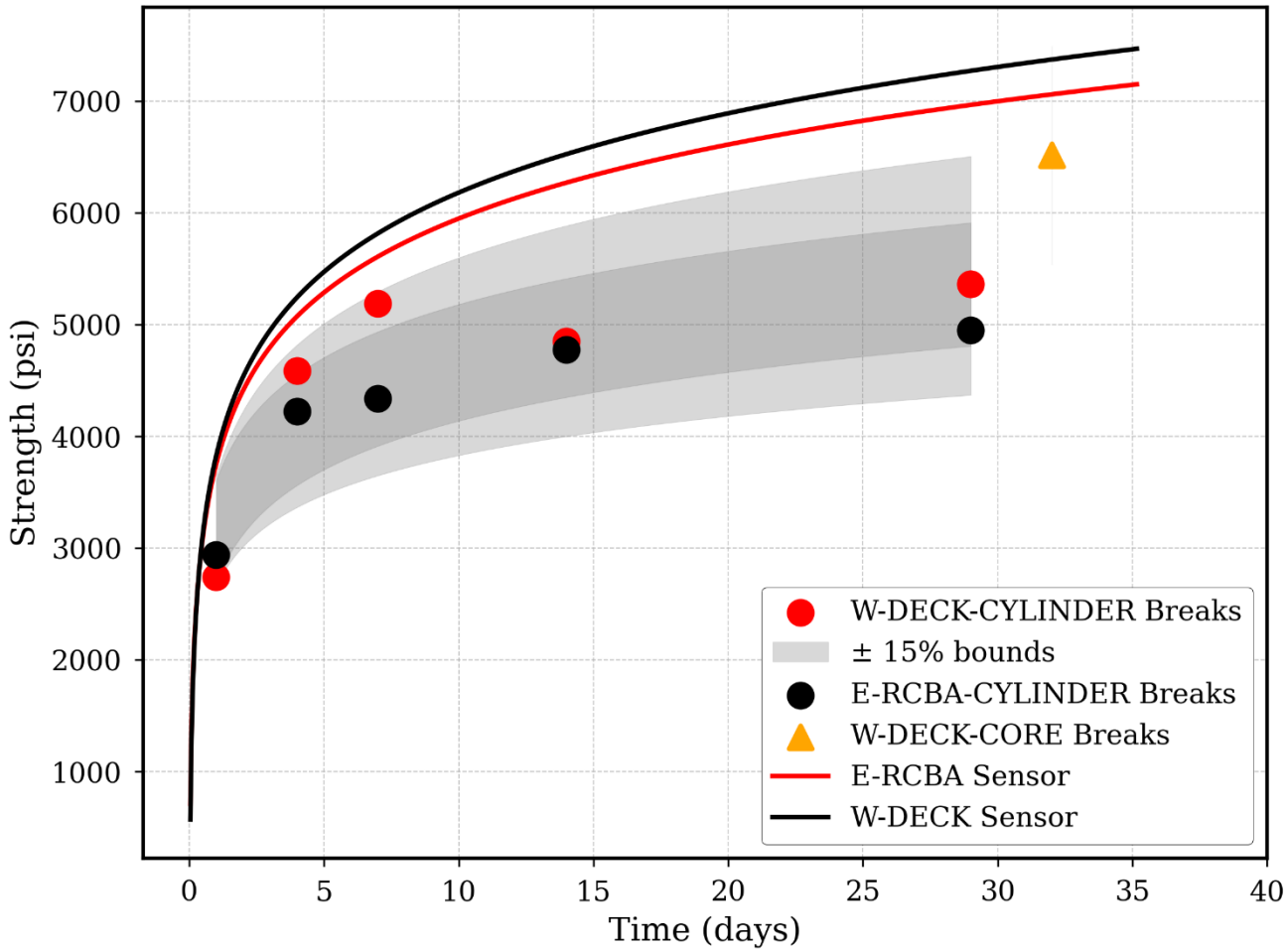
	Avg. Strength	Difference from Core (%)
Core	4545	--
REBEL Sensor	4760	4.7

Age	Avg. Difference (psi)	Avg. Difference (%)
16-Day	214	4.7

Date	6-6-2024
Location	Anderson, IN
Project Type	Bridge Deck

Ingredients	**Amount (/yd^3)**
Fine Agg.	1188 lbs.
Coarse Agg.	1634 lbs.
Cement	650 lbs.
Water	287 lbs.
W/C Ratio	0.441

- 1 sensor was placed in the bridge deck with another in the approach
- Cylinders made for 1, 4, 7, 14, and 28-days
- Both sets of cylinders broke below expectations at 14 and 28 days
- Core break at 32 days confirms that the sensor results fall in line with the in-place strength



- Both sets of cylinders broke below expectations at 14 and 28 days
- The core break at 32 days confirms that the sensor results fall in line with the in-place strength

32-day	Avg. Strength	Difference from Core (%)
Core	6517	--
Cylinders*	5464	16.1
REBEL Sensor	7216	10.7

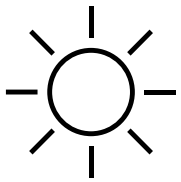
* Cylinder strength extrapolated from curve fit

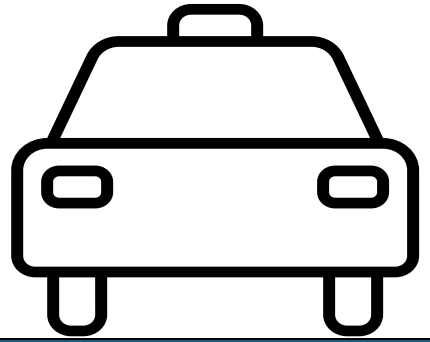
Date	7-16-2024
Location	Palm Desert, CA
Project Type	Pavement

Ingredients	**Amount (/yd^3)**
Fine Agg.	1184 lbs.
Coarse Agg.	1952 lbs.
Cement	423 lbs.
Fly Ash	141 lbs.
Water	243 lbs.
W/C Ratio	0.43

- This paving project consisted of 4 groups of sensors: 2 groups in the pavement and 2 in companion samples
- One pavement group was placed on the base and the other was raised to the middle of the pavement
- The sensors in companion samples were placed in 6” x 6” x 21” beam molds with one group left on site and the other in the lab

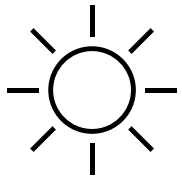
Four groups of sensors were deployed





Sensors at the middle of pavement

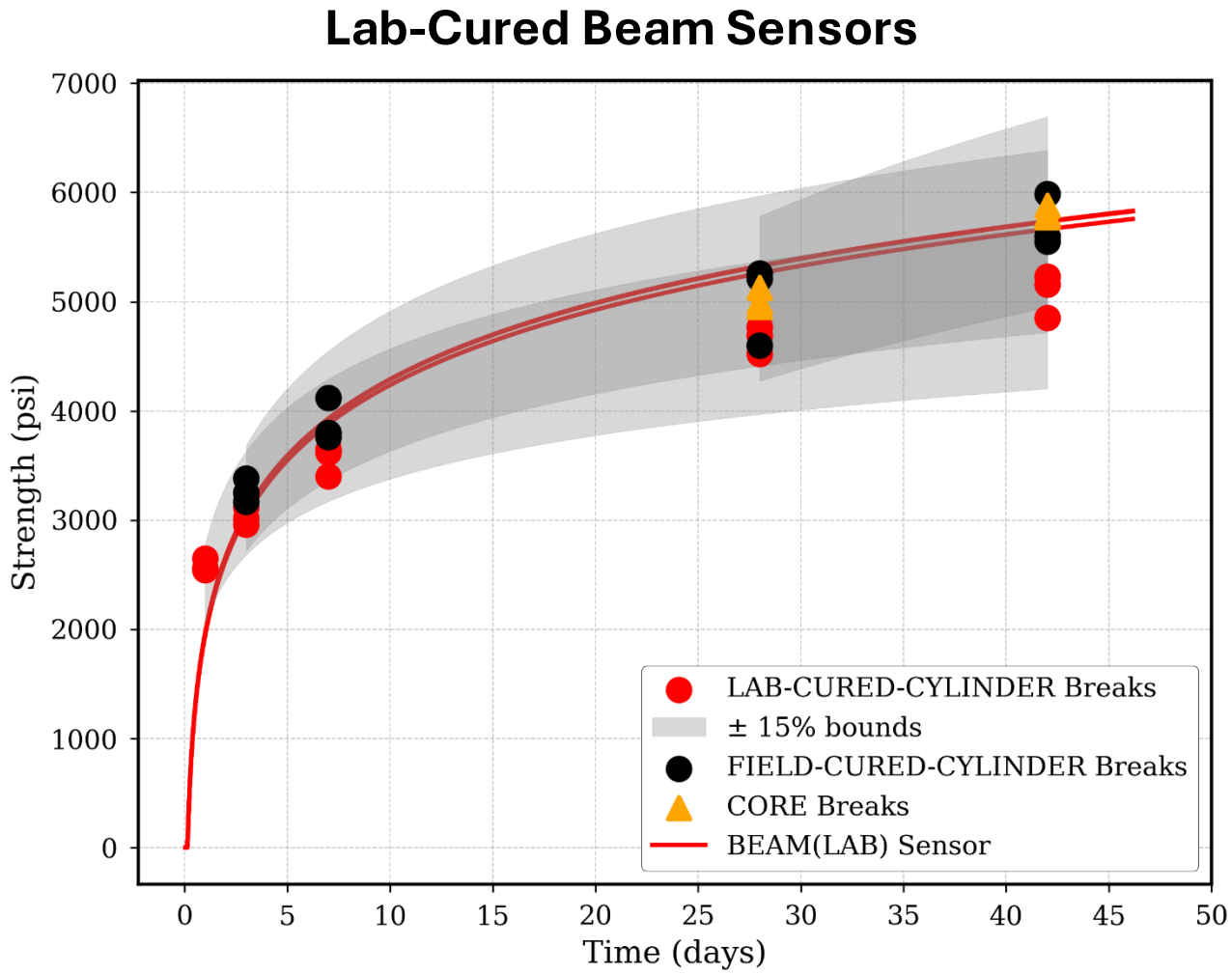
Sensors at the bottom of pavement



Sensors in a beam cured in the field

Sensors in a beam cured in the lab

- The sensors in the lab-cured beam sample reported strength close to the in-field cylinders and sensors
- 4 sets of cylinders were measured at 1, 3, 7, 28, and 42-days
- Cores were taken at 28 and 42 days



- Sensors were within 10% of cylinder measurements taken past day 3
- Variability was low across all sensors at all ages (<1%)
- Lab-cured sensors were within 5% of 28-day cores and within 2% of 42-day cores

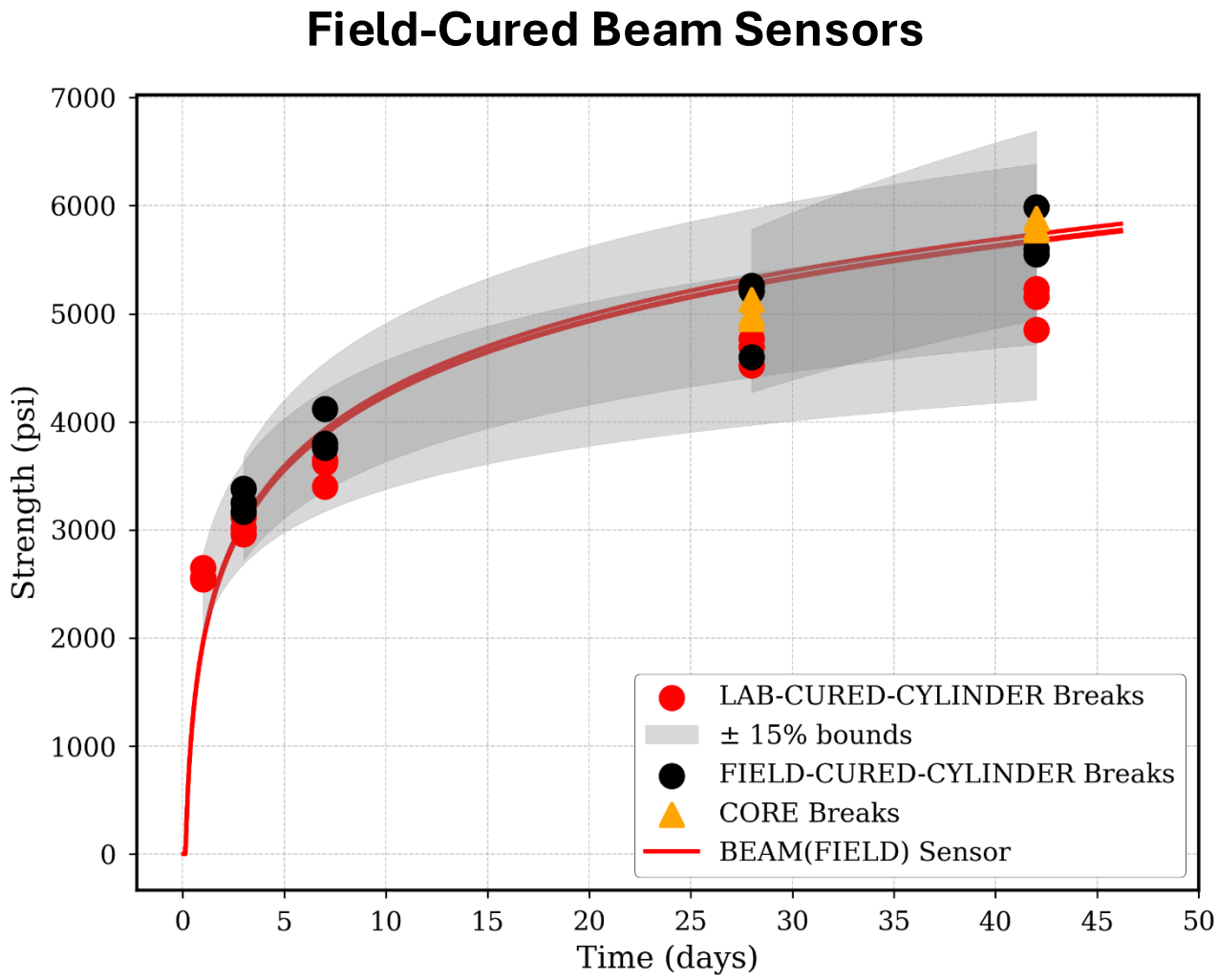
Age	Avg. Difference (psi)	Avg. Difference (%)
1-Day	623	24.1
3-Day	200	6.1
7-Day	23	0.6
28-Day	462	9.5
42-Day	173	3.1

Age	Sensor Variability (%)	Cylinder Variability (%)
1-Day	0.5	1.9
3-Day	0.6	4.4
7-Day	0.6	6.0
28-Day	0.6	5.2
42-Day	0.6	6.5

28-day Comparison	Avg. Strength	Difference from Core (%)
Core	5027	--
Cylinders	4925	2.0
REBEL Sensor	5304	5.5

42-day Comparison	Avg. Strength	Difference from Core (%)
Core	5819	--
Cylinders	5237	10.0
REBEL Sensor	5710	1.9

- The sensors cured in the in-field beam tracked very closely to the field-cured cylinders and core drills
- 4 sets of cylinders were measured at 1, 3, 7, 28, and 42-days
- Cores were taken at 28 and 42 days



- Sensors were within 6% of cylinder measurements taken past day 3
- Variability was low across all sensors at all ages (<1%)
- Lab-cured sensors were within 5% of 28-day cores and within 2% of 42-day cores

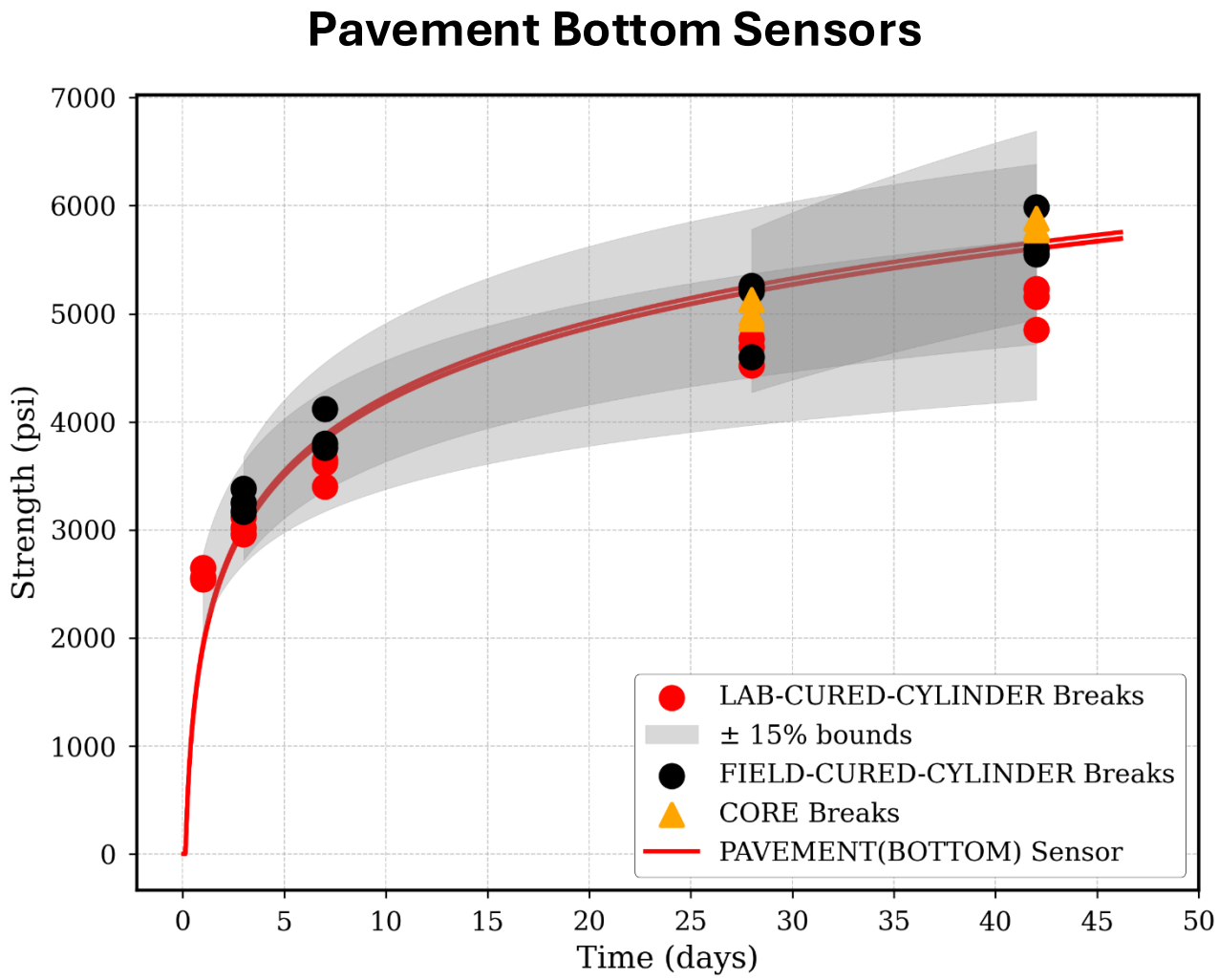
Age	Avg. Difference (psi)	Avg. Difference (%)
1-Day	627	24.3
3-Day	208	6.3
7-Day	13	0.3
28-Day	448	9.3
42-Day	158	2.9

Age	Sensor Variability (%)	Cylinder Variability (%)
1-Day	0.4	1.9
3-Day	0.5	4.4
7-Day	0.5	6.0
28-Day	0.5	5.2
42-Day	0.5	6.5

28-day Comparison	Avg. Strength	Difference from Core (%)
Core	5027	--
Cylinders	4925	2.0
REBEL Sensor	5289	5.2

42-day Comparison	Avg. Strength	Difference from Core (%)
Core	5819	--
Cylinders	5237	10.0
REBEL Sensor	5696	2.1

- The sensors on this plot were placed in the bottom of the pavement
- 4 sets of cylinders were measured at 1, 3, 7, 28, and 42-days
- Cores were taken at 28 and 42 days



- Sensors were within 8% of cylinder measurements taken past day 3
- Variability was low across all sensors at all ages (<1%)
- Lab-cured sensors were within 5% of 28-day cores and within 2% of 42-day cores

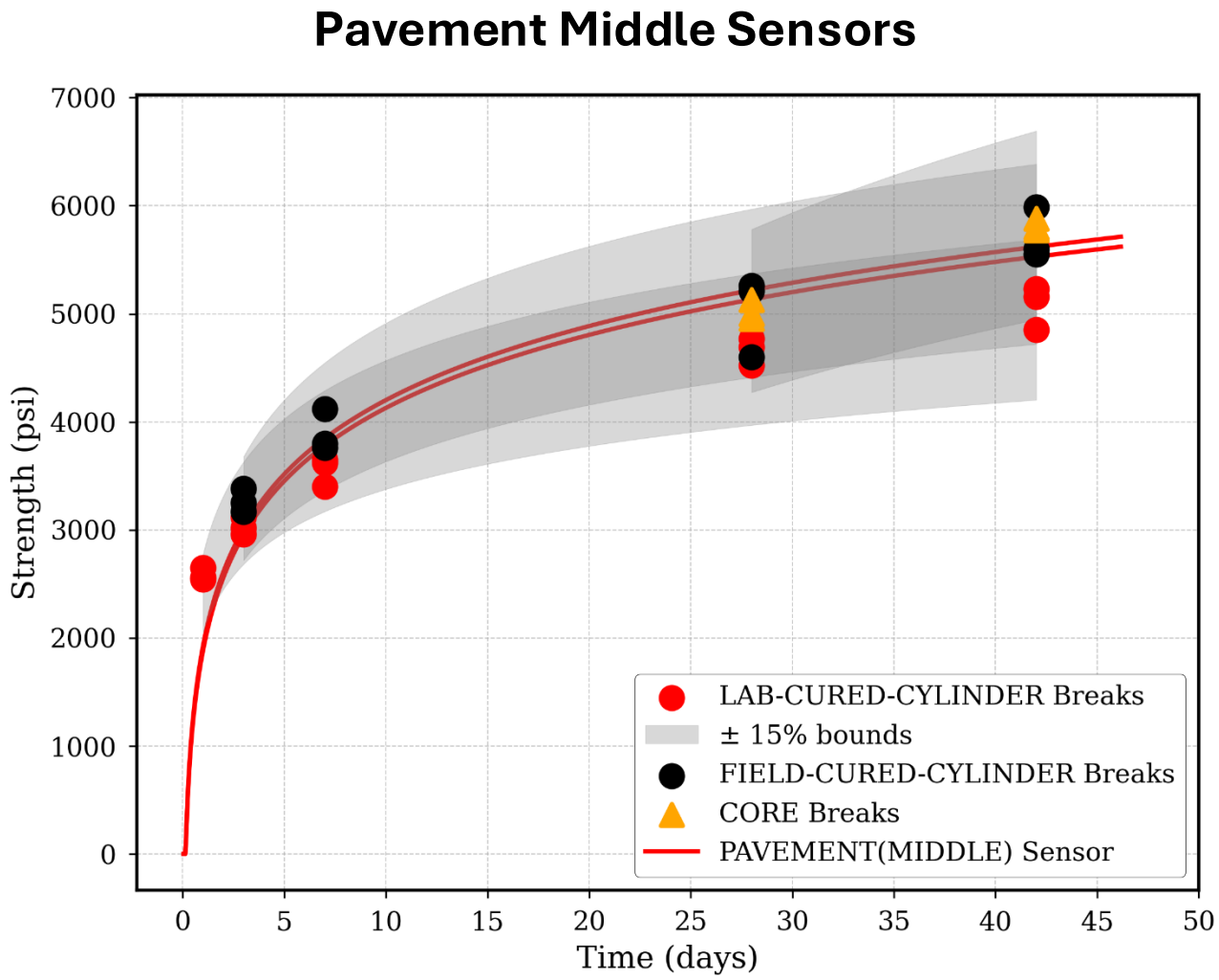
Age	Avg. Difference (psi)	Avg. Difference (%)
1-Day	656	25.4
3-Day	250	7.6
7-Day	36	0.9
28-Day	380	7.8
42-Day	85	1.5

Age	Sensor Variability (%)	Cylinder Variability (%)
1-Day	0.7	1.9
3-Day	0.6	4.4
7-Day	0.5	6.0
28-Day	0.5	5.2
42-Day	0.5	6.5

28-day Comparison	Avg. Strength	Difference from Core (%)
Core	5027	--
Cylinders	4925	2.0
REBEL Sensor	5221	3.9

42-day Comparison	Avg. Strength	Difference from Core (%)
Core	5819	--
Cylinders	5237	10.0
REBEL Sensor	5622	3.4

- The sensors on this plot were placed in the middle of the pavement
- 4 sets of cylinders were measured at 1, 3, 7, 28, and 42-days
- Cores were taken at 28 and 42 days



- Sensors were within 8.5% of cylinder measurements taken past day 3
- Variability was low across all sensors at all ages (<1.1%)
- Lab-cured sensors were within 3% of 28-day cores and within 4% of 42-day cores

Age	Avg. Difference (psi)	Avg. Difference (%)
1-Day	679	26.3
3-Day	280	8.5
7-Day	72	1.8
28-Day	334	6.9
42-Day	45	0.8

Age	Sensor Variability (%)	Cylinder Variability (%)
1-Day	1.1	1.9
3-Day	1.0	4.4
7-Day	0.9	6.0
28-Day	0.8	5.2
42-Day	0.8	6.5

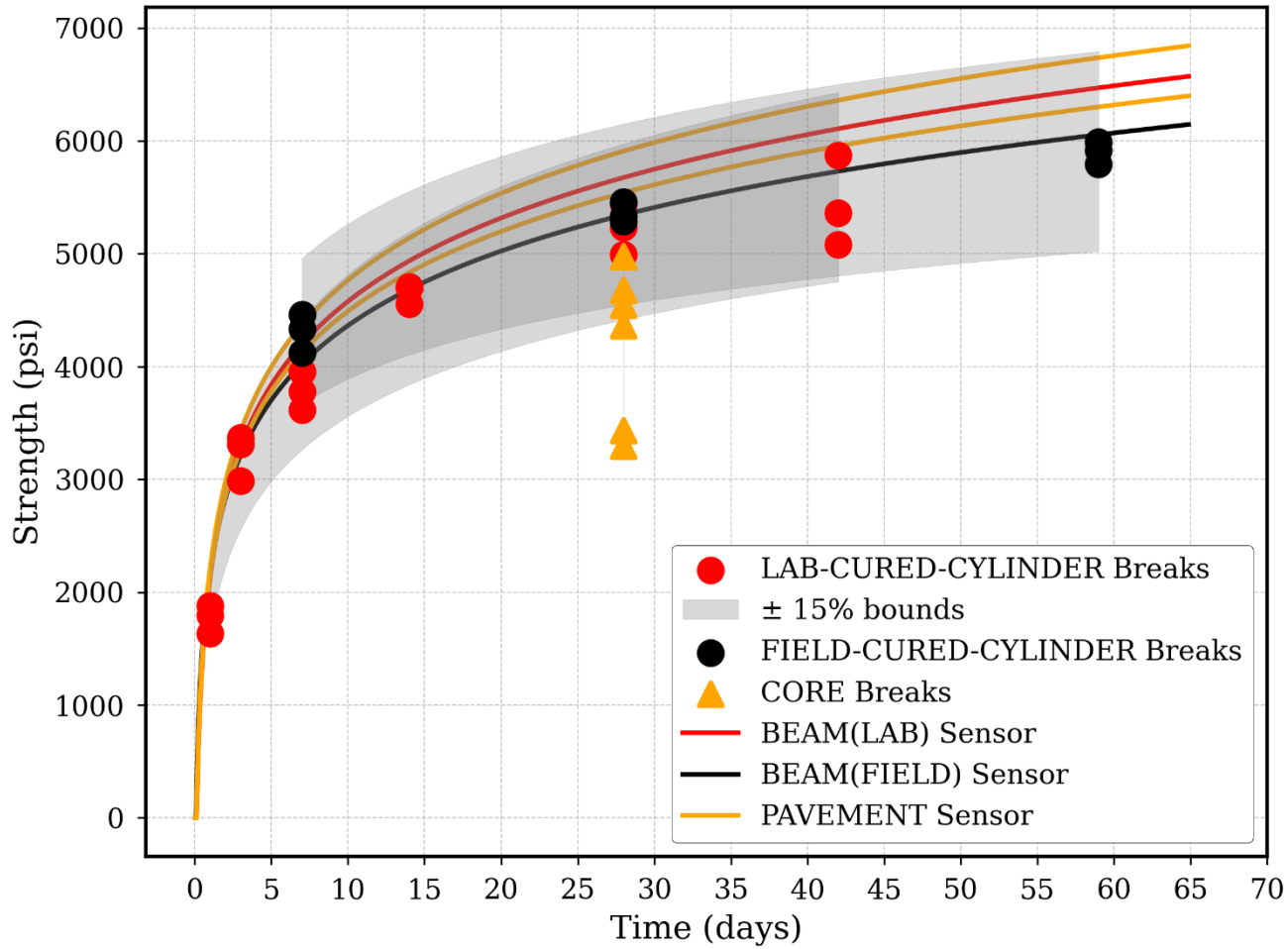
28-day Comparison	Avg. Strength	Difference from Core (%)
Core	5027	--
Cylinders	4925	2.0
REBEL Sensor	5175	3.0

42-day Comparison	Avg. Strength	Difference from Core (%)
Core	5819	--
Cylinders	5237	10.0
REBEL Sensor	5574	4.2

Date	9-15-2023
Location	Sacramento, CA
Pavement Thickness	14’’
Rebar	6’’ interval, 7.5’’ high

Ingredients	**Amount (/yd^3)**
Fine Agg.	1426 lbs.
Coarse Agg.	1796 lbs.
Cement	510 lbs.
Fly Ash	90 lbs.
Water	189 lbs.
W/C Ratio	0.32

- Cylinders were measured at 1, 3, 7, 14, 28, 42, and 59 days
- Cores were measured at 28-days
- Sensors were placed in a beam in the lab, a beam in the field, and in the pavement
- Of the 6 cores taken, 5 broke significantly lower than expected at 28-days

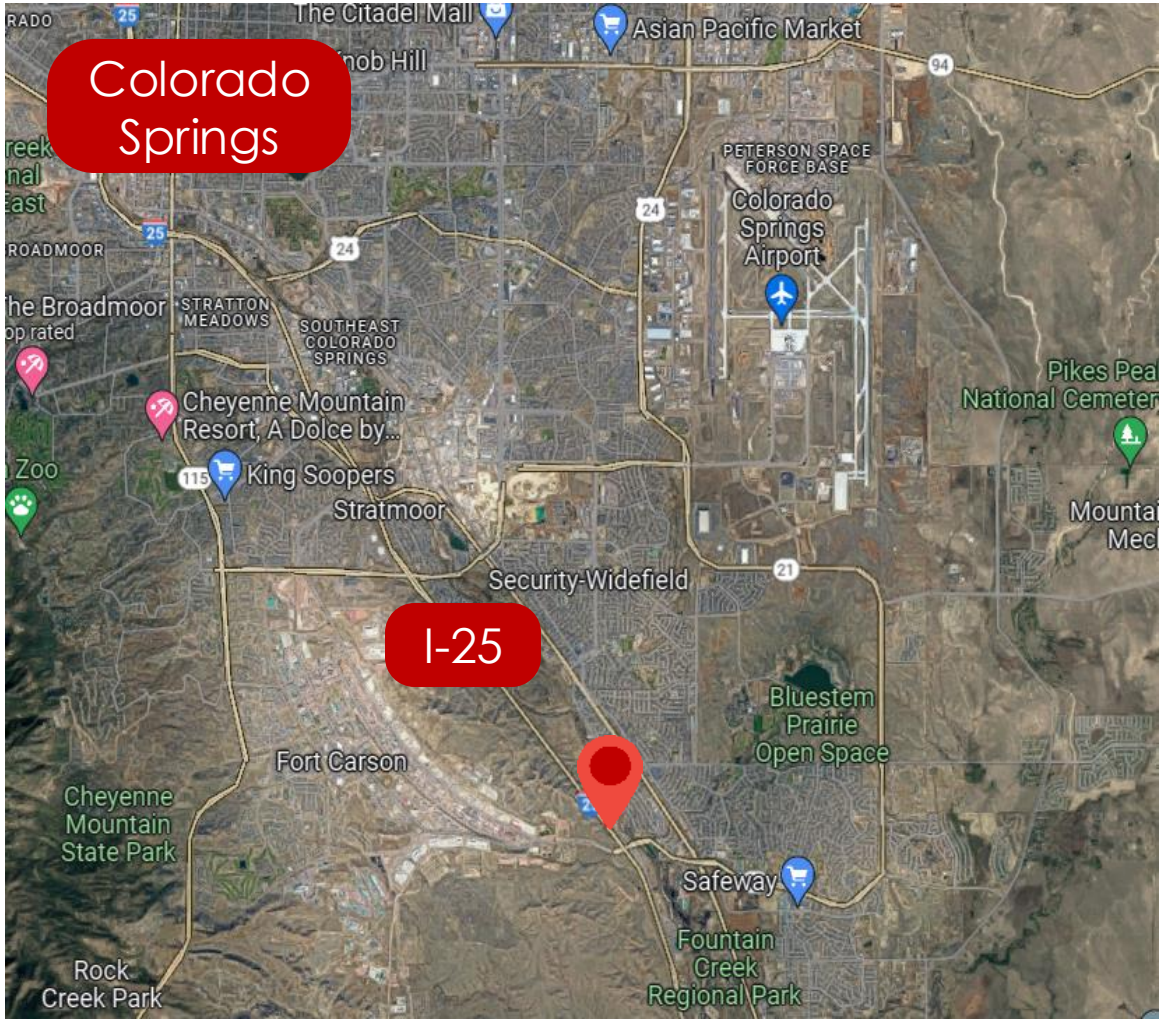


- Given the low core measurements, both sensors and cylinders were much higher than measured by the cores
- Sensors were within 15% of cylinders across ages, except for 1-day, where they were still <400psi different from cylinders
- Sensors had significantly lower variability than cylinders at most ages

Age	Avg. Difference (psi)	Avg. Difference (%)
1-Day	391	22.2
3-Day	56	1.7
7-Day	395	10.5
14-Day	243	5.2
28-Day	182	3.4
42-day	720	13.2
59-day	620	10.5

Age	Sensor Variability (%)	Cylinder Variability (%)
1-Day	1.5	5.8
3-Day	2.4	5.2
7-Day	3.0	7.3
14-Day	3.4	1.5
28-Day	3.7	14.9
42-day	3.3	6.0
59-day	3.3	1.3

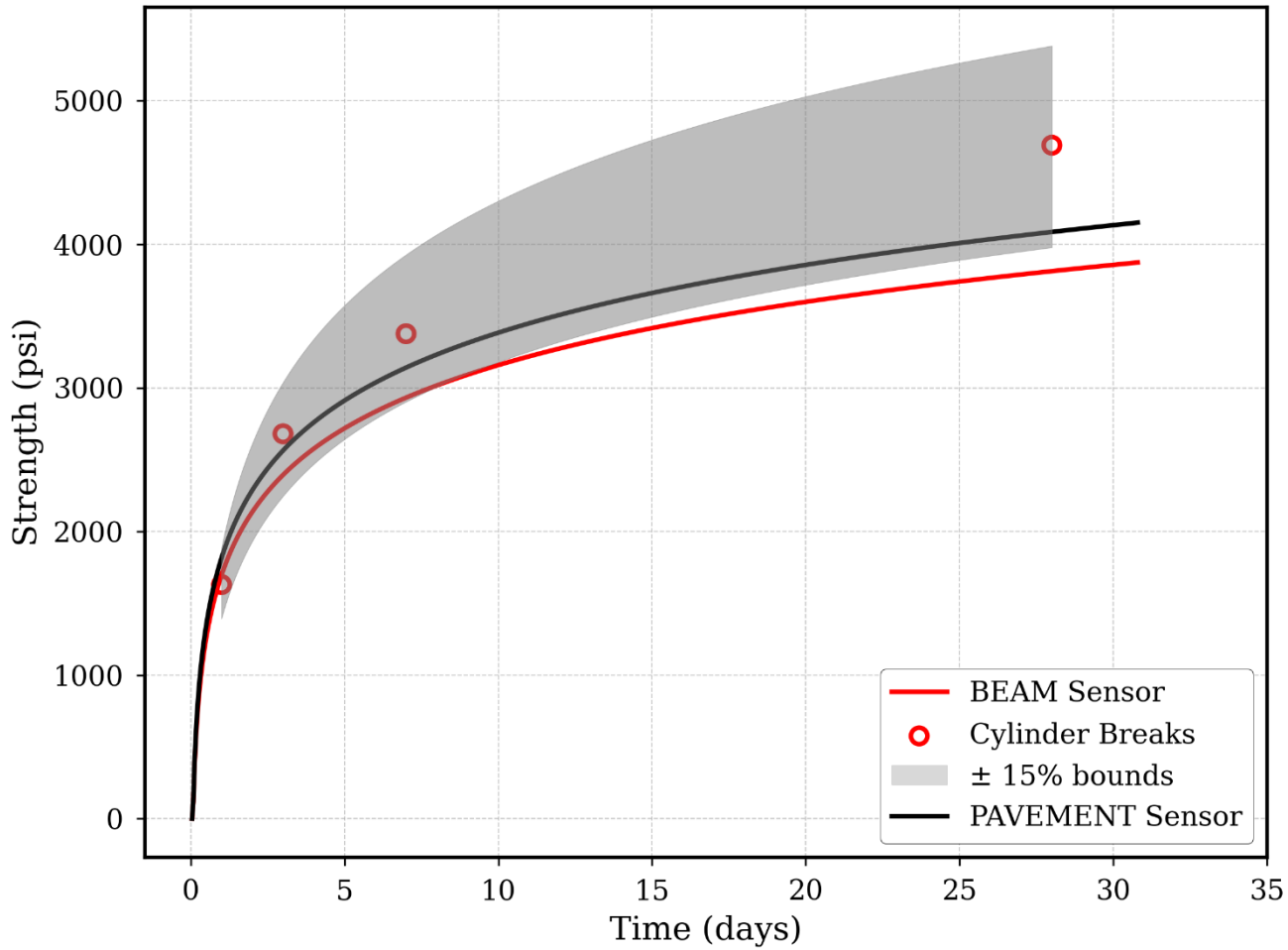
28-day	Avg. Strength	Difference from Core (%)
Core	4215	--
Cylinders	5254	24.6
REBEL Sensor	5877	39.4



Date	8-8-2023
Location	Spring, CO
Pavement Thickness	9.5”

Ingredients	**Amount (/yd^3)**
Agg.	3119 lbs.
Cement	440 lbs.
C R Mineral (natural pozzolan)	109 lbs.
Water	160 lbs.
W/C Ratio	0.40

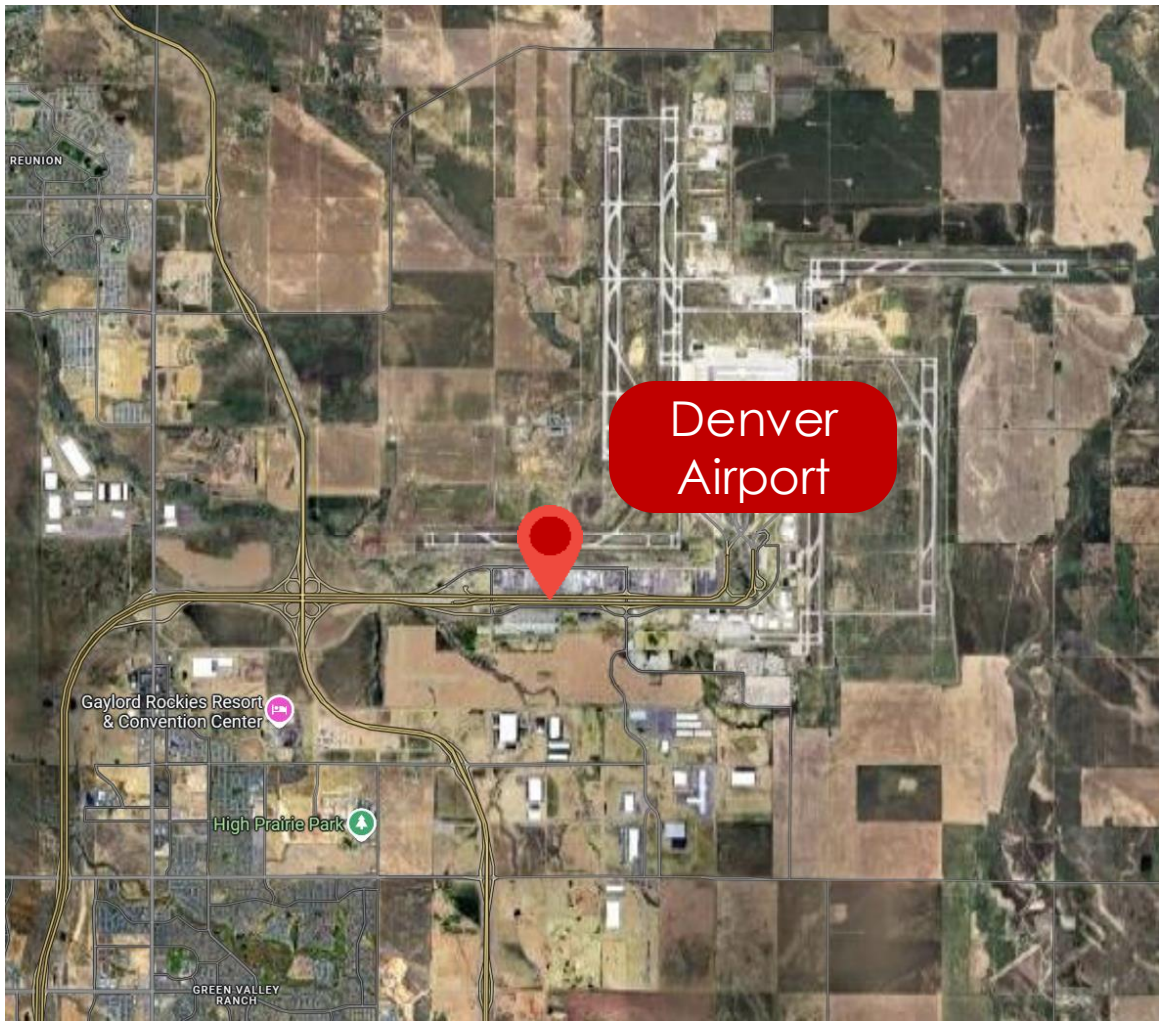
- Sensors in the pavement reported similar strength as the cylinder breaks (within 15%).
- The sensors in a separate beam sample reported lower strengths, which reflects the effect of different curing conditions for in-place structure vs separate sample.



- Sensors were within 15% of cylinders at all ages except for 28-days, where it was within 16%
- Sensors were very consistent, with 3.4% variability in measurements across all ages

Age	Avg. Difference Cylinders vs Sensors (psi)	Avg. Difference Cylinders vs Sensors (%)
1-Day	125	7.6
3-Day	201	7.5
7-Day	340	10.0
28-Day	740	15.7

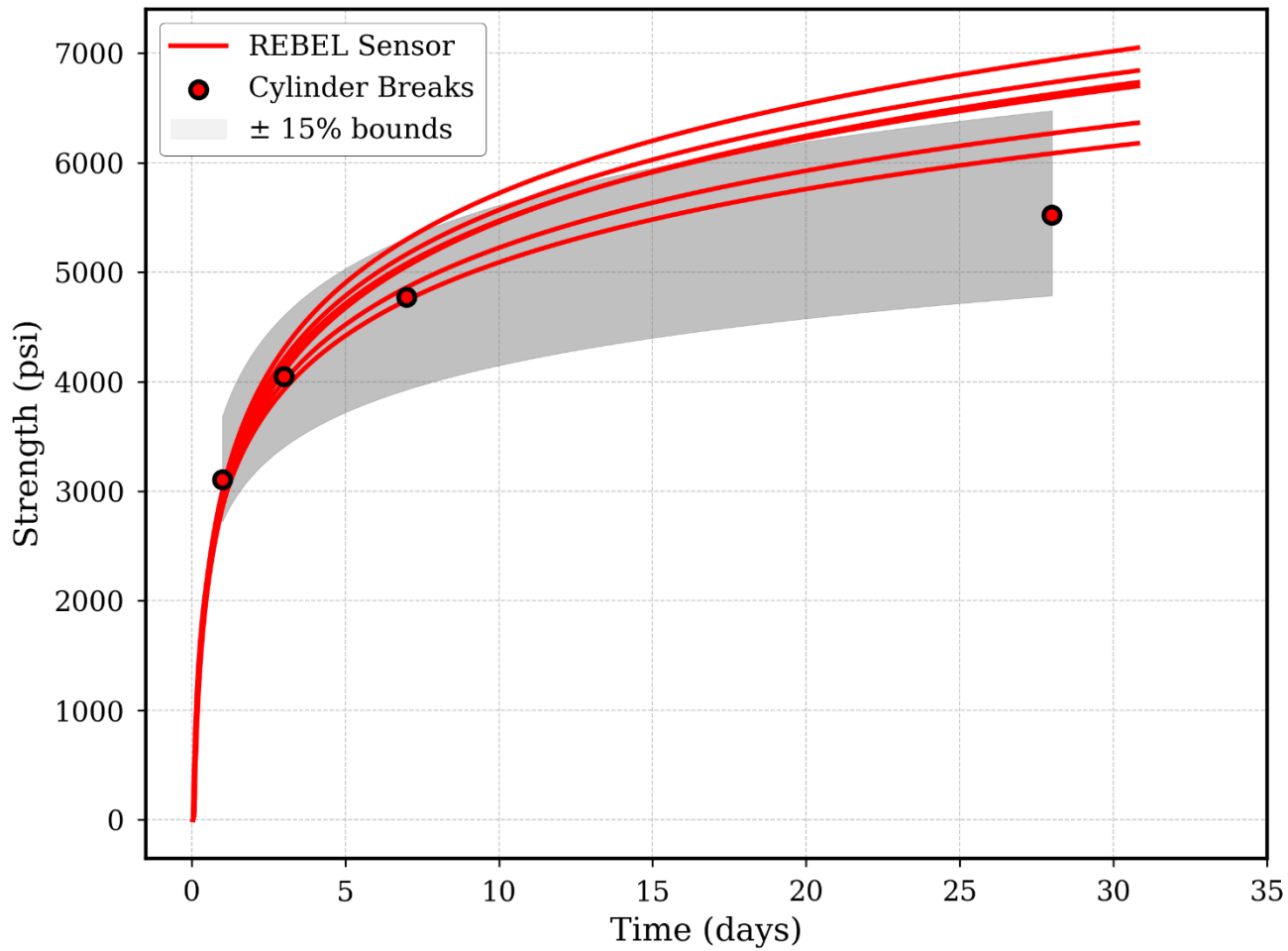
Age	Sensor Variability (%)
1-Day	3.4
3-Day	3.4
7-Day	3.4
28-Day	3.4



Date	8-8-2023
Location	Denver, CO
Project Type	Pavement

Ingredients	**Amount (/yd^3)**
Fine Agg.	1247 lbs.
Coarse Agg.	1871 lbs.
Cement	440 lbs.
C R Mineral	109 lbs.
Water	160 lbs.
W/C Ratio	0.40

- Cylinder measurements were taken at 1-day, 3-day, 7-day, and 28-days
- Expected strength at 28-days was 4500 psi, so the sensor indicates the strength reached 4500 psi at about 5-day, which would have allowed earlier traffic opening.



- Cylinder measurements were taken at 1-day, 3-day, 7-day, and 28-days
- Expected strength at 28-days was 4500 psi, so the sensor indicates the strength reached 4500 psi at about 5-day, which would have allowed earlier traffic opening.

Age	Avg. Difference Cylinders vs Sensors (psi)	Avg. Difference Cylinders vs Sensors (%)
1-Day	188	6.0
3-Day	112	2.7
7-Day	173	3.6
28-Day	1016	18.3

Age	Sensor Variability (%)
1-Day	1.9
3-Day	3.0
7-Day	3.7
28-Day	4.3

Date	10-24-2024
Location	Manchester, MO
Project Type	Pavement Repair

- Only one cylinder break was taken at 7-days
- One sensor was placed in the pavement for comparison
- Sensors were within 6% of cylinder break at 7-days

Age	Difference (psi)	Difference (%)
7-Day	294	5.8